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Title:	Georgia Pacific Lumber Kiln Emissions Data, Supplemental Environmental Project September 24, 1997 to March 31, 2000. Summary Report. National Council for Air and Stream Improvement, April 2000 *Included CD with data files*

Georgia-Pacific Corporation

Lumber Kiln Emissions Data Supplemental Environmental Project

September 24, 1997 – March 31, 2000

Summary Report

April 2000

ncasi

NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT, INC.
SOUTHERN REGIONAL CENTER
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August 7, 2001

Mr. Gary D. McAlister
U.S. Environmental Protection Agency
Emission Inventory Branch, OAQPS
Technical Support Division
79 T. W. Alexander Drive – MD-19
Research Triangle Park, NC 27711

Dear Gary:

As per your request, I have enclosed a copy of the Georgia-Pacific lumber kiln emissions data report. Please contact me via phone at (352) 377-4708, ext. 254 or via e-mail at r_law@src-ncasi.org if you have any questions or comments.

Sincerely,

Richard Law/TLS

Richard W. Law
Project Engineer

cc: Dallas W. Safriet
Paul J. Vasquez

RWL:tls

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GEORGIA-PACIFIC CORPORATION

LUMBER KILN EMISSIONS DATA SUPPLEMENTAL ENVIRONMENTAL PROJECT

EXECUTIVE SUMMARY

Georgia-Pacific Corporation (G-P) retained the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI) to manage and conduct a Supplemental Environmental Project (SEP) designed to evaluate the feasibility of using small-scale lumber kilns as surrogates for full-scale kiln testing. Secondary objectives were to develop testing protocols for small-scale and full-scale kilns and obtain emission data from full-scale kilns. Production-based mass emission rates of volatile organic compounds (VOCs) were the primary criteria by which small-scale kilns were evaluated. A limited assessment was also conducted for emissions of formaldehyde and methanol. A screening analysis was performed for a select group of 'hazardous air pollutants' (HAPs), acetone, alpha-pinene, and beta-pinene.

The typical lumber kiln is a non-steady-state, batch process, air emission source with substantial fugitive emissions and multiple emission points. These kilns must be sampled over an extended period of time to obtain a representative sample. Southern pine lumber kilns typically operate in a batch manner, with each batch or drying cycle lasting 15 to 30 hours. Since the emissions are not steady-state, emission samples are best taken continuously throughout the kiln cycle. Obtaining accurate exhaust flow rate and pollutant concentration data from lumber kilns has historically proven to be both difficult and expensive. Because of this, only small amounts of data have previously been available, and some of these data are of questionable value due to lack of a standardized test protocol(s), inability to assess fugitive losses, difficulties encountered during testing, etc. For these reasons, an alternative approach to measurement of these emissions is desirable.

The project was divided into two phases. The first phase assessed the variability in kiln operations and emission rates from four small-scale kilns. The second phase involved a comparison of air emissions testing results obtained while drying carefully matched batches of lumber at two small-scale and two full-scale lumber kilns. The full-scale kilns were selected based on idealized testing criteria including the existence of no more than two vents, low fugitive emissions, etc.

PHASE I: SMALL-SCALE KILN VARIABILITY STUDY

The first phase of the study, termed the Variability Study, was conducted at four small-scale kilns. The kilns were operated by Mississippi State University (MSU), Oregon State University (OSU), North Carolina State University (NCSU) and a consulting group.

Lumber from a 20 year old slash pine plantation was processed at G-P's Cross City, Florida, Chip-N-Saw mill. Statistically equivalent lumber samples were obtained from the mill and distributed to all of the Variability Study small-scale kilns. Each small-scale kiln received four sample charges.

Even though all four small-scale kiln operators were provided with standard protocols for sampling and kiln operation, there was considerable variability in the mass emission rate results. The VOC mass emission rates ranged from 0.94 pounds of VOC as carbon per thousand board feet (lb VOC as C/MBF) to 3.20 lb VOC as C/MBF. The formaldehyde mass emission rates ranged from 0.009 to 0.026 lb/MBF and the methanol results ranged from 0.024 to 0.221 lb/MBF.

Two of the four small-scale kiln operators were chosen to participate in the second phase of this project. They were chosen based on the consistency of the data collected and their willingness to allocate the resources necessary to complete this project. These two kilns were located at MSU and OSU.

PHASE II: FULL-SCALE TO SMALL-SCALE KILN CORRELATION STUDY

Two G-P owned and operated full-scale kilns were tested for this project. One was direct-fired and the other was steam-heated. The direct-fired kiln, located in Idabel, Oklahoma, was equipped with a Power Vent System that collected and vented the kiln exhaust through two roof stacks. The steam-heated kiln, located in Bay Springs, Mississippi, was originally equipped with a Vent-X-Changer system. The heat exchanger elements had been removed however, so the Vent-X-Changer acted in a similar manner to the Power Vent system with only one exhaust stack. Both kilns, as tested, exhibited low rates of fugitive emissions.

There were six charges tested at each full-scale kiln. Lumber samples for testing at the small-scale kilns were extracted from the lumber that made up each full-scale kiln test charge by a random method. The small-scale kilns received at least one corresponding sample charge for each full-scale kiln charge that was tested. Data were collected from 12 full-scale kiln test charges and 24 small-scale kiln sample charges.

Continuous VOC sampling was conducted over each of the 36 drying cycles. Formaldehyde and methanol data were collected over 12 drying cycles. The burner for the direct-fired kiln was sampled for total VOC, formaldehyde, and methanol. Speciated VOC sampling was conducted at one full-scale and two small-scale kilns

The data obtained from the Phase II portion of this project indicate that small-scale kilns can successfully emulate the operation of full-scale kilns. By matching specific full-scale kiln temperature schedules, the small-scale kilns can also model full-scale kiln VOC mass emission rate curves. The small-scale kilns were somewhat, but not completely, successful in matching the production-based emission rates of the full-scale kilns.

When the entire VOC data set was analyzed, the OSU small-scale kiln emission test results proved to be statistically similar to the full-scale kiln results. The MSU results were shown to be significantly different. When the direct-fired and steam-heated kiln data sets were separated, however, a separate statistical analysis showed that 50% of both the MSU and OSU results were statistically similar to the full-scale kiln results. The average VOC mass emission rates from the full-scale kilns (FSK), MSU, and OSU are shown in Table ES.1.

Table ES.1.

Temperature Schedule	VOC Mass Emission Rate (lb VOC as C/MBF) FSK	MSU	OSU
Direct-fired	3.8	2.4	3.0
Steam-heated	3.5	3.1	4.2

Statistical analysis was not conducted on the formaldehyde and methanol results because of the small data set. A gross overview of the data, however, indicates that methanol emissions were reasonably similar at the full-scale and small-scale kilns but formaldehyde emissions were more variable. This may be due to the low concentrations of formaldehyde detected at the steam-heated full-scale kiln, MSU and OSU. An additional observation from these data sets shows that a significantly greater amount of formaldehyde was detected from the direct-fired full-scale kiln. One possible explanation for this finding is that formaldehyde is formed in the blend box of the direct-fired kiln. The formaldehyde mass emission rates are shown in Table ES.2.

Table ES.2.

Temperature Schedule	Formaldehyde Mass Emission Rate (lb/MBF)		
	FSK	MSU	OSU
Direct-fired	0.103	0.020	0.009
Steam-heated	0.016	0.003	0.021

The small-scale kilns were not able to emulate the formaldehyde mass emission rate profiles from either of the full-scale kilns. A reasonably fair match was made, however, for the methanol mass emission rate profiles. This is indicated by the methanol results shown in Table ES.3 below.

Table ES.3.

Temperature Schedule	Methanol Mass Emission Rate (lb/MBF)		
	FSK	MSU	OSU
Direct-fired	0.161	0.107	0.116
Steam-heated	0.205	0.167	0.225

The direct-fired lumber kiln and burner were tested simultaneously. The data show that VOC, formaldehyde and methanol emissions from the burner were relatively insignificant.

A limited assessment of speciated VOCs was conducted over three kiln charges. The results indicated that alpha-pinene, beta-pinene, and methanol were the predominant compounds. Acetaldehyde and acetone were the only other compounds present at levels above 0.01 lb/MBF. The relationship of these compounds is in agreement with the majority of southern pine sources tested in the Wood Products MACT Study recently completed by NCASI.

The results from this project indicate that if operating consistency is achieved, standard procedures are followed, and small-scale kiln conditions are fully matched to those of the full-scale kiln, then small-scale kilns can successfully model air emissions from full-scale kilns. This suggests that small-scale kiln process conditions should be carefully monitored, and the results of this monitoring should be provided along with the mass emission rate results.

The future use of small-scale kilns as surrogates for testing full-scale kilns should be evaluated with due respect to the inherently high variability in normal full-scale kiln test results. The full-scale kilns tested in this report are idealized and among a very few in the country that have exhaust stacks. If typical difficult-to-test kilns, without stacks, had been tested, the full-scale kiln emission results would likely have been more variable and the statistical comparisons more favorable for both MSU and OSU. As expertise in operating and sampling small-scale kilns increases, data quality and consistency should improve.

GEORGIA-PACIFIC CORPORATION

LUMBER KILN EMISSIONS DATA SUPPLEMENTAL ENVIRONMENTAL PROJECT

SUMMARY REPORT

1.0 INTRODUCTION

The National Council for Air and Stream Improvement, Inc. (NCASI) entered into a Service Agreement with Georgia-Pacific Corporation (G-P) on September 24, 1997 to conduct a Supplemental Environmental Project (SEP). The SEP was designed to assess the feasibility of using small-scale-scale kilns as emission testing surrogates for full-scale kilns. A secondary purpose was to identify and quantify air emissions that result from the drying of southern pine lumber and to develop test protocols for lumber kilns.

The typical lumber kiln is a non-steady-state, batch process, air emission source with substantial fugitive emissions and multiple emission points. As a consequence, obtaining accurate exhaust flow rate and pollutant concentration data from lumber kilns has proven to be both difficult and expensive. The small amount of data available shows a wide range of volatile organic compound (VOC) emission results for similar kilns drying the same wood species under similar conditions. Furthermore, some of these data are of questionable value due to the lack of standardized test protocol(s), inability to assess fugitive losses, difficulties encountered during testing, etc. For these reasons, an alternative emission test method using laboratory sized dry kilns (small-scale kilns) is desirable.

A considerable amount of detail was involved in this project and is reflected in the size of this report. An overview of the report is provided below to assist the reader in sifting through the details and finding the desired information.

Section 2.0 provides a literature review of previous methodologies developed to estimate emissions from lumber kilns. In Section 3.0 the difficulties encountered in full-scale kiln testing are discussed. Sections 4.0 and 5.0 provide detailed descriptions of the kilns tested and methodologies used. The results are provided in table format in Section 6.0. Graphs and discussion of the results follow in Section 7.0. Conclusions are drawn in the final section of this report (Section 8.0).

2.0 LITERATURE REVIEW OF LUMBER KILN TEST METHODOLOGY

A relatively small body of published information exists concerning VOC test methodologies for lumber kilns. The available information can be segregated into three areas: (1) laboratory methods, (2) small-scale kilns, and (3) innovative approaches to full-scale kiln testing.

2.1 Laboratory Methods for Estimating Lumber Kiln Emissions

Rice and Zibilske (1999) estimated VOC losses from northeastern wood species with an extraction technique and measurement of the dissolved organic chemical (DOC) content of the extract. Differences in DOC levels between green and dry samples were used to estimate the worst case VOC loss from lumber during the drying process. Estimates of 1.1, 1.3, 1.2, 0.9 and 0.7 lb of carbon per thousand board feet (lb/MBF) were obtained for balsam fir, white spruce, red spruce, black spruce, and red pine, respectively. Within each species the measurements were highly variable. Some of the variability appeared to be due to differences between heartwood and sapwood, as well as differences in the wood moisture contents of the various wood samples.

Dallons, Lamb, and Peterson (1994) used EPA Method 25D and modified EPA Method 24 to estimate VOC releases from lumber. In these laboratory methods, the concentrations of organic compounds extracted from wood were evaluated prior to and following drying. The difference in the extracted material from the green and dry wood samples was assumed to equal VOC losses from the kiln. For this study, southern pine lumber from four different kiln charges was evaluated with ten pairs of samples obtained from each charge. The results from this study showed relatively high variability among the samples. The authors attributed much of the variability to natural variation within the lumber. The average estimated VOC release, expressed as methane, was approximately 2 lb/MBF.

2.2 The Use of Small-Scale Kilns to Estimate Lumber Kiln Emissions

A small-scale kiln was designed and constructed at Mississippi State University (Punsuvon 1994). This work, in part, established small-scale kiln operational procedures. In this initial work at Mississippi State University (MSU), monoterpenes were measured before and after drying in the southern pine lumber and in the kiln condensate. It was determined that alpha- and beta-pinene were the major compounds emitted from the wood during the drying process. As part of this work, the breakdown, or reaction, products of terpenes in both air and water were studied. The major compounds found were alpha-terpineol, alpha-pinene oxide, alpha-campholene aldehyde, vebenol, pinocamphone, myrtenol and verbenone. These studies and the following studies conducted at MSU all utilized southern pine lumber.

Ingram, Taylor, and Templeton (1995) discuss the difficulties involved in emissions testing of large-scale kilns and reasons for construction of the small-scale kiln at MSU. In this paper, small-scale kiln design objectives are also discussed. Preliminary test results indicate average emission values of 5.84 and 4.67 lb VOC/MBF for high (245°F) and conventional (180°F) temperature drying schedules, respectively. The VOC units were not specified. Typical VOC concentration curves for the high temperature schedules were described as highest after 1 to 2 hours, then decreasing to hour 6, increasing slightly to hour 9, and then decreasing continually until drying stopped. For conventional schedules the concentration peaked during the first two hours, subsided quickly, and decreased throughout the remainder of the drying cycle.

Thompson (1996) quantified VOC and speciated compound emissions at the MSU small-scale kiln. Thompson determined that alpha-pinene, camphene, beta-pinene, myrcene, limonene and 4-allylanisole were the most abundant compounds emitted. Of these, alpha- and beta-pinene represented over 75% of the total emissions. Thompson conducted a number of drying experiments and determined that (1) relatively high (239°F) and low temperatures (176°F) did not significantly affect VOC emissions, (2) knotty wood lumber samples yielded higher levels of VOC emissions compared to lumber samples from clear wood, and (3) emissions from heartwood were greater than emissions from sapwood. The VOC emission profiles obtained from this study followed the same profile described earlier with the maximum values reached approximately 1 to 2 hours into the cycle and then again at approximately 10 hours into the cycle. Thompson determined an average emission rate of 4.0 lb VOC as C/MBF for clear lumber.

Shmulsky's research (1998) at the MSU small-scale kiln was conducted to assess the effects of certain lumber parameters on VOC emissions and to evaluate potential pre-treatments to reduce VOC emissions. This study determined that end grain and the wood's surface area to volume ratio were not statistically significant factors with respect to VOC emissions. Steaming and radio-frequency pre-treatment of lumber were also found to not have statistically significant effects on VOC emissions. Shmulsky's study showed that high humidity kiln operation schedules significantly increased VOC emissions. This paper also discussed the difficulties involved in testing large-scale kilns and suggested that experiments should be conducted to correlate emissions from large- and small-scale kilns. Shmulsky obtained an average VOC emission rate of 3.75 lb VOC as C/MBF.

Su et al. (1998) conducted experiments involving radio-frequency treatment of lumber at the Institute of Paper Science and Technology (IPST) with subsequent drying at the small-scale kiln at MSU. They determined that the size of the lumber sample did not affect the quantity or rate of VOC release from the small-scale kiln. Additionally, experiments were conducted to evaluate the effect of delayed venting. In these experiments, kiln venting was initiated after 2, 3, and 5 hours into the kiln cycles. The corresponding VOC emission rates were 3.05, 2.47 and 1.89 lb VOC/dry ton of wood. The VOC units were not specified. Seasonal variability was assessed, although at this time only preliminary results are available. The authors also made a preliminary determination that the VOC content of loblolly pine trees did not vary significantly with season.

Wu and Milota (1999) presented results from a small-scale kiln drying Douglas-fir lumber. The effects of dry bulb temperature, wood moisture content, and relative humidity inside the kiln were evaluated for their effects on VOC emissions from drying. It was determined that higher initial wood moisture contents and higher dry bulb temperatures both resulted in higher VOC emission rates. They also determined that there was no significant effect of kiln relative humidity on VOC emissions. They determined a typical emission rate of approximately 1.47 lb VOC as propane/MBF for Douglas-fir. The VOC concentration of the dryer emissions was observed to increase steadily during the first 2 to 4 hours and decrease rapidly when the wet-bulb set point was reached. Approximately 70 percent of the emissions were released in the first half of the kiln schedule. The authors provided detailed information on lumber sample collection, kiln operation, and calculations.

NCASI (1996), in conjunction with staff from the University of Idaho, conducted measurements of VOC emissions from a small-scale kiln. Ten different species of softwood lumber were dried according to drying schedules used for these species in full-scale kilns. In this report, detailed information was provided on the University of Idaho small-scale kiln, as well as on the VOC sampling system. The study determined that there was no significant correlation between VOC emissions and corresponding turpentine samples from the dried lumber. VOC emissions varied highly among the wood species, ranging from 0.12 to 3.32 lb VOC as C/MBF. The average emissions from southern pine duplicate samples from lumber cut in Arkansas and Texas averaged 2.36 and 3.32 lb VOC as C/MBF, respectively.

2.3 Innovative Methodologies for Full-Scale Kiln Testing

Glass and Elam (1995) developed procedures for measuring gas flow rates from large-scale kilns using water mass balance and combustion stoichiometry, respectively, for steam-heated and direct-fired lumber kilns. The direct-fired kiln for which the combustion stoichiometry approach was used would have been very difficult to test by conventional methods because it had 42 exhaust vents and a drying cycle of approximately 72 hours. Natural gas consumption, along with oxygen, carbon dioxide, and moisture measurements, provided the information needed to calculate exhaust flow rates for the direct-fired kiln. The steam-heated kiln was a typical high temperature southern pine kiln with 14 vents and a drying cycle of approximately 18 hours. For the tests at both kilns, representative lumber bundles were weighed prior to and after kiln drying on the mill truck scale. Emission rates of 1.4 and 1.7 lb VOC as C/MBF were obtained for the direct-fired and steam-heated kilns, respectively.

McLaurine, Ferguson, and Slocum (1999) presented the results from using the water mass balance and carbon mass balance approaches to estimate emissions from full-scale kilns. One steam-heated and one direct-fired southern pine kiln, located within 100 miles of each other, were tested for VOC emissions. The steam-heated kiln was also tested for methanol and formaldehyde emissions. The authors determined that the greatest source of variability with the water balance method was measurement of lumber moisture loss during the drying cycle. For the steam-heated kiln, the lumber moisture loss was approximately 2.1 lb/board foot. The VOC, formaldehyde, and methanol emission rates were 1.88, 0.025, and 0.26 lb/MBF, respectively. For the direct-fired kiln, the moisture loss was 1.67 lb/board foot. The measured VOC emissions for the direct-fired kiln were 2.49 lb/MBF and 1.37 lb/MBF for the water mass balance and carbon mass balance approaches, respectively.

3.0 FULL-SCALE KILN TESTING – DIFFICULTIES AND APPROACHES

3.1 Difficulties

Several of the papers reviewed in the prior section mentioned difficulties involved in testing full-scale kilns. The difficulties are, in part, the driving force behind their work. This section will review some of the problems associated with testing full scale kilns and the approaches that have been taken to solve those difficulties.

Perhaps it is worthwhile to stop and consider a typical VOC stack test. Simplified, a typical test involves measurement of gas velocity and associated parameters to enable calculation of an air flow rate. Typically flow measurements are made prior to and following VOC concentration measurements. Flow rates and VOC concentrations are used to calculate mass emission rates.

In a typical test, the velocity is measured from an exhaust stack through two sample ports that are 90 degrees apart. A relatively simple VOC continuous monitoring system would provide VOC concentrations over the sampling run, generally for one hour. Three one-hour sample runs would characterize a source.

This typical test procedure is acceptable for the majority of sources because (1) most sources have exhaust stacks and (2) most processes are continuous. For continuous sources, an assumption is made that the emission concentration and exhaust flow rate are relatively steady-state. Using this assumption, three one-hour "snapshots" are considered representative of typical operations.

Keeping these ideal stack testing conditions in mind, now consider the typical steam-heated southern pine lumber kiln. Most steam kilns have from 8 to 20 vents segregated into two rows on top of the kilns. The vents are little more than openings in the roof with covers that are modulated open and closed. The vent covers in one row are connected so that they open, close, or partially open or close in unison. Vents are closed or partially closed to conserve energy and/or maintain a specific humidity level. Vents are opened or partially opened to allow water vapor to escape the kiln and to maintain a specific humidity level. The amount of venting is generally controlled by wet and dry bulb temperature measurements or, indirectly, by the humidity inside the kiln. One vent row serves as an inlet for fresh (dry) air while the other vent row serves as an exhaust. In order to evenly dry the lumber inside the kiln, internal kiln fans are reversed approximately every three hours. At this time, the vent rows change duties with the inlet air row becoming the exhaust and vice versa.

The typical southern pine kiln operates in a batch manner. A green lumber "charge" or batch is placed in the kiln at ambient temperatures. Doors are closed and hot air is introduced to the kiln. For the next two or three hours hot air is simply circulated within the kiln allowing the temperatures of the kiln and lumber to increase to the point where drying can begin. After this initial heating period, the vents begin to open and modulate to maintain the humidity specified by the kiln operator. Exhaust flow rate, moisture levels, and pollutant concentrations vary considerably throughout the remainder of the drying cycle. A typical southern pine drying cycle is complete in 15 to 30 hours.

A typical stack test simply cannot be conducted because (1) there are no stacks with sample ports and (2) an assumption cannot be made that conditions are steady-state. Stack sampling contractors are, therefore, forced to deviate from typical procedures by developing alternative approaches to measuring or estimating flow from typical dry kilns. They must also be able to sample continuously over the entire drying cycle, which generally means they must have two or three test crews to cover the extended sampling period.

Two additional difficulties are particularly troublesome. They are: (1) measurement or estimation of fugitive emissions and (2) difficulties involved in sampling very high moisture gas streams. Both of these are related, directly or indirectly, to the enormous amounts of water that must be evaporated. With the exception of the first two or three hours of operation, when there is a need to conserve heat, there is little reason for kilns to be "tight" or leak proof. Water vapor must exit the kiln, and it seems to be of little concern if it exits through a poor door seal or through other openings or cracks, rather than through a roof vent. Quantifying the fugitive emission rate is extremely difficult.

Because the green wood charged to the kiln is approximately one-half water by weight, a very large amount of water vapor must exit the kiln during the drying cycle. Moisture levels in the exhaust are highly variable (over time) and may reach levels of 60 to 70% by volume. By definition, air sampling equipment is designed to sample air - not water vapor. Although most air pollution sampling methods can in some way handle moisture levels up to 30%, many begin to have problems above this level. At moisture levels of 60 to 70%, most VOC analyzers will cease to function due to "flame-out." This condition is caused by large amounts of water vapor entering the flame ionization chamber and quenching the flame. Prior to this point high moisture conditions cause low bias in the VOC readings. Sampling contractors "solve" this problem in a number of innovative ways, some of which provide inaccurate results.

Although this discussion has focused on southern pine steam-heated kilns, most of these same problems exist for southern pine direct-fired kilns. Western softwood kilns also have many of these same problems and are very labor intensive to test due to drying cycles that can exceed three days in length.

It should be noted that during the initial planning stages of this project a decision was made to avoid testing typical full-scale kilns. Instead two, relatively rare kilns with exhaust stacks were tested. Because of this, many of the major difficulties and uncertainties involved in testing full-scale kilns were avoided.

3.2 Approaches

The wood products industry and sampling contractors are approaching the problems inherent in testing full-scale kilns in a number of different ways. As discussed in the literature review section, some contractors have used mass balance approaches to measure flow rate. For direct-fired kilns this is accomplished by carefully measuring the fuel input over the entire kiln cycle and measuring either oxygen or carbon dioxide concentrations at a point in the system that represents combustion plus dilution air. An F factor is then used to calculate the total exhaust flow rate. For steam-heated kilns, the mass balance is based on the amount of water entering and leaving the system. Samples of the lumber charge are weighed prior to and after drying, and frequent moisture measurements are made at representative kiln exhausts. Kiln condensate must also be measured. In this approach, water is theoretically converted to water vapor at standard temperature and pressure. The ratio of water vapor to dry air in the exhaust can then be used to determine the total flow rate from the kiln. Mass balance theory and calculations are explained in detail by McLaurine et. al. (1999).

Those attempting to use more conventional means of measuring kiln emissions have also tried several approaches. Some contractors have sampled a "representative vent" on each side of the kiln. This is typically done by building a stack over the vent and cover. The results obtained from the representative vent are then multiplied by the total number of vents in a row. Some mills or contractors have built temporary ducting systems and stacks that collect the entire kiln's emissions into one or two emission points. Then the emissions are measured in a conventional manner. One, somewhat complicated but theoretically sound, approach has been to sample all of the vents simultaneously. In this case, boxes with relatively small stacks are constructed surrounding each kiln vent and cover. The boxes are large enough to allow the vent covers to operate in a normal manner. Exhaust gases from the kiln vents are forced through the stacks. Propeller anemometers measure the flow rate through each stack. A slip steam of kiln exhaust from each vent in a vent row is sent to a common VOC analyzer for quantification.

For all of the full-scale non-mass balance approaches, fugitive emissions must be considered. An estimate of fugitive emissions has been obtained by injecting a tracer gas into the kiln and quantifying the amount recovered through the kiln's vents. This technique has, thus far, had limited success.

Although substantial progress has been made, there is still a lot of uncertainty involved in full-scale kiln testing. Innovative approaches push the industry toward better solutions to this problem. Meanwhile, full-scale kiln test results are perhaps better viewed as reasonable estimates than as accurate characterizations.

4.0 FULL-SCALE KILNS AND SMALL-SCALE KILNS USED IN THE PROJECT

4.1. Kiln Descriptions

4.1.1 *Direct-Fired Full-Scale Kiln*

The direct-fired full-scale kiln chosen for this project was Kiln #2 at the G-P, Idabel, Oklahoma, saw mill facility. Dry Kiln #2 is a two-track kiln with a capacity of 120 thousand board feet (MBF) of lumber. The mill was chosen for this project because Kiln #2 is outfitted with a Power Vent system developed by Irvington-Moore.

The Power Vent system is designed to control air into and out of the kiln through two roof stacks (Figure 4.1). The roof stacks are positioned on each side of the kiln fan assembly that re-circulates the air inside the kiln. The kiln fans reverse the direction of air flow through the lumber charge every three hours. Depending on the direction of the air flow, one side of the Power Vent system will vent the kiln by activating the variable speed fan located at the base of the stack. The stack fan on the other side of the Power Vent system will remain dormant and allow air into the kiln.

A portion of the kiln air is constantly reheated in a blend box connected to the side of the kiln (Figure 4.2). This gas enters the blend box at approximately 200°F and mixes with the burner air at approximately 1600°F. After mixing in the blend box, the return air is drawn out of the blend box by a fan and blown back into the kiln. The temperature of the air returning to the kiln is at approximately 450°F. During kiln fan reversals, the flow of kiln air entering the blend box is reduced. Therefore ambient air is allowed to enter the blend box through a set of louvers to cool the burner air in the blend box.

The heat source for Kiln #2 is a sloped pile burner or gasifier. The fuel for the gasifier is the green sawdust produced from sawing operations at the front end of the mill. The sawdust is collected and conveyed to a silo. The silo continuously feeds a fuel hopper that provides fuel for multiple burners. A feed screw pulls the sawdust from the fuel hopper and supplies fresh fuel to the gasifier. A fuel level indicator in the burner activates and stops the feed screw as needed.

Air is introduced over and under the burner grate at a flow rate below that required for complete combustion. The smoldering fuel on the burner grate is designed to create hot gases that rise to the top of the burner chamber. Near the point of exit from the burner, excess oxygen is mixed with the hot gas to complete the combustion process. The hot air generated from this process is transported a short distance to the blend box where it is mixed with the re-circulated kiln air. Flames from the combustion of the hot gas were observed entering the blend box.

Tests conducted by NCASI determined that the average burner fuel feed rate was approximately 80 lb of green sawdust per minute. The sawdust had an average wood moisture content of approximately 50% (wet basis).

On the week prior to testing, mill personnel conducted routine cleaning of the burner grate.

4.1.2 *Indirect-Fired Full-Scale Kiln*

NCASI could not locate a steam-heated southern pine lumber kiln a Power Vent system similar to the direct-fired kiln. Almost all of the commercial steam-heated lumber kilns operated with multiple roof vents and did not meet the criteria of this project. The best option available for this project was the steam-heated kilns at the G-P facility in Bay Springs, Mississippi. The three lumber kilns at this facility each utilize the Carter-Sprague Vent-X-Changer™ system. Two of the three kilns at this site

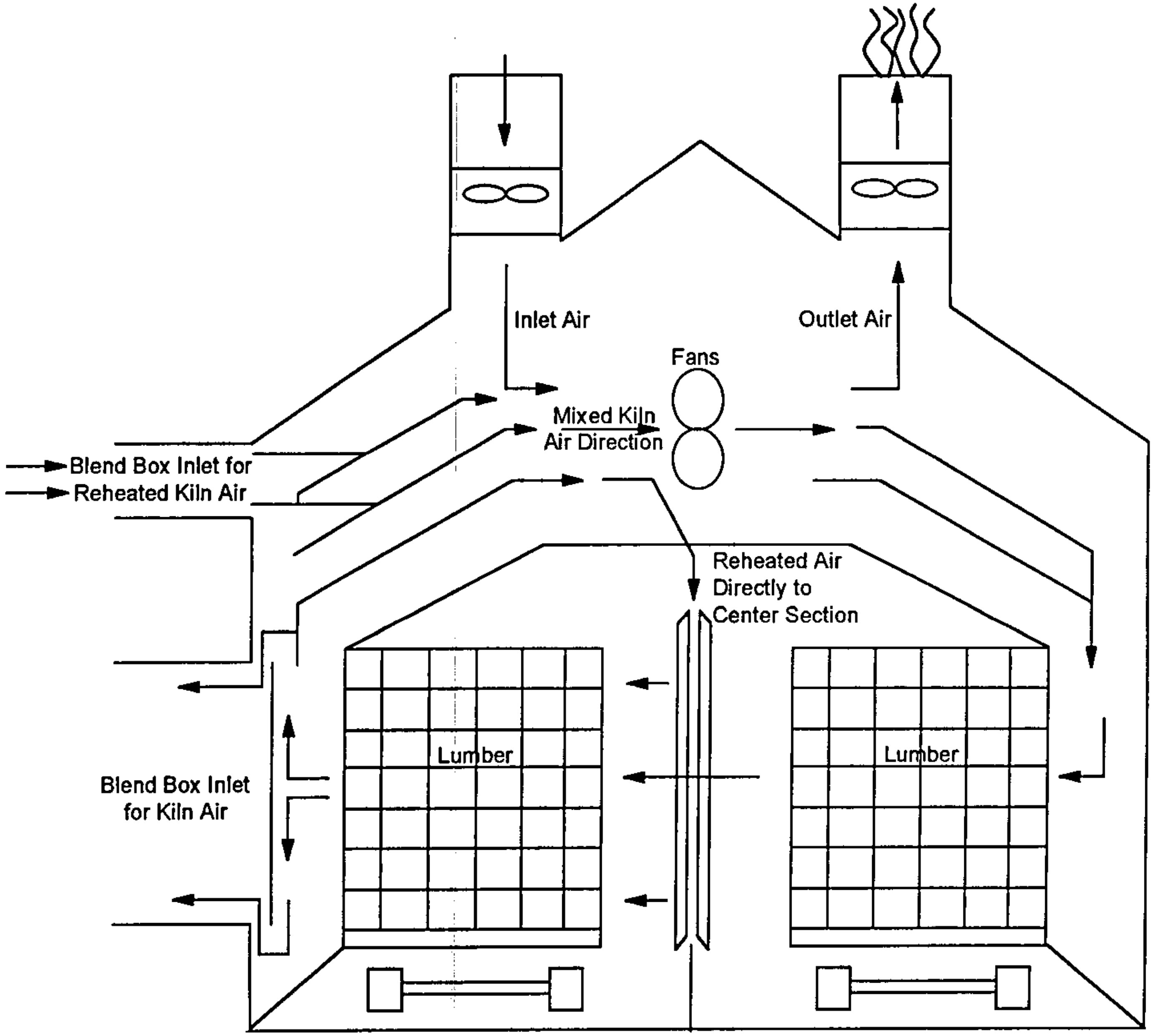


Figure 4.1. Direct-Fired Full-Scale Kiln with Power Vent System under Normal Operations Conditions

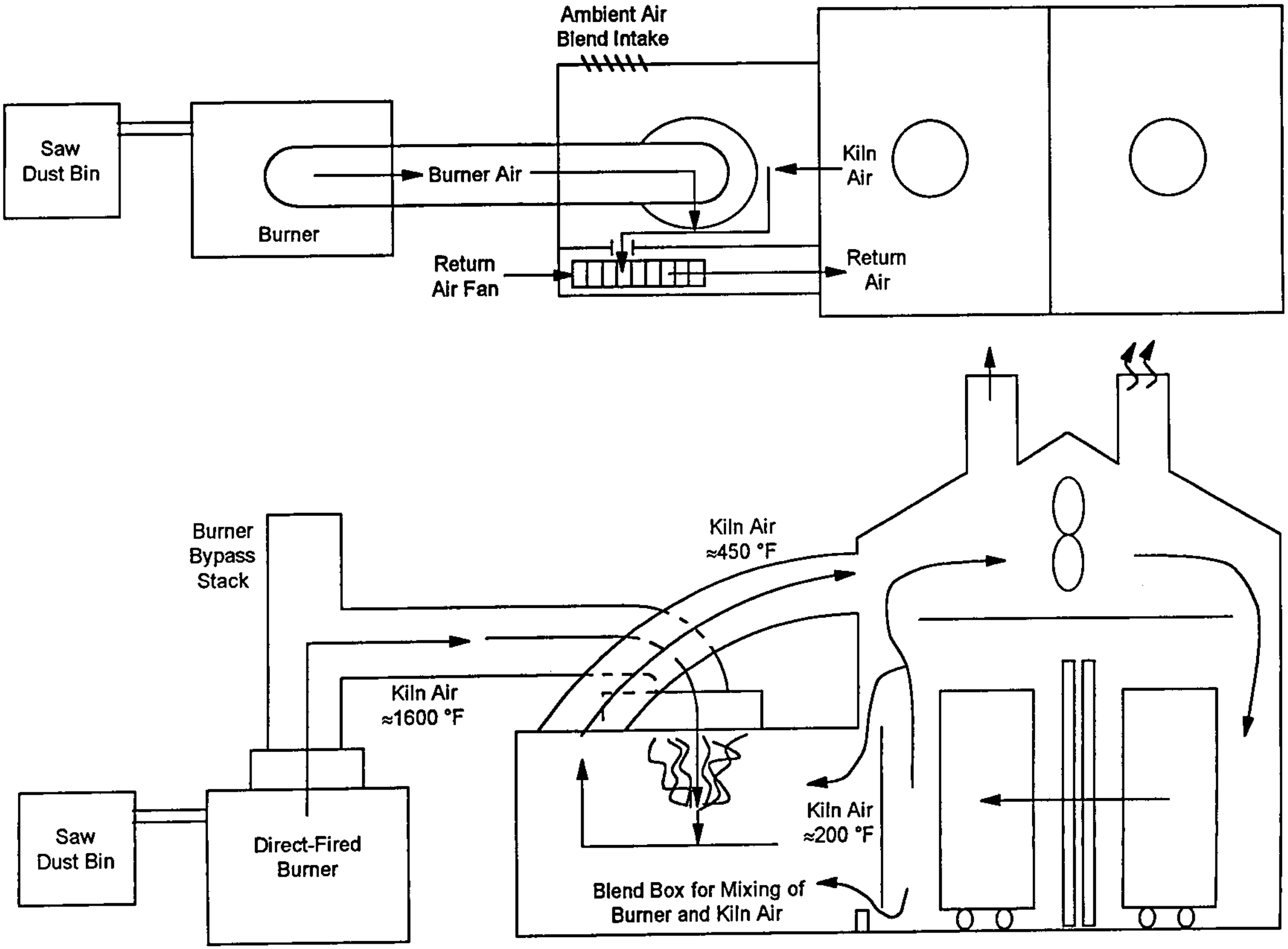


Figure 4.2. Air Flow Path for Direct-Fired Full Scale Lumber Kiln

were dropped from consideration, however, due to complications in reaching the emission sources. The remaining kiln, Kiln #3, was tested.

The components of the Vent-X-Changer™ system are shown in Figure 4.3. Normally, this unit operates as a heat exchanger that uses the heat from the exhaust air to pre-heat the inlet air to the kiln thereby reducing overall boiler demand.

Kiln #3, at Bay Springs, is outfitted with a Vent-X-Changer at one end of the kiln (Figure 4.4), but the air-to-air heat exchanger elements (shown in Figure 4.3 as item #8) had been removed. In essence, this unit now functioned similar to a Power Vent system with one emission stack. As shown in Figure 4.3, the Vent-X-Changer has one motor that drives a common shaft for the inlet (item #19) and outlet (item #11) fans. The outlet fan is situated directly below the exhaust stack.

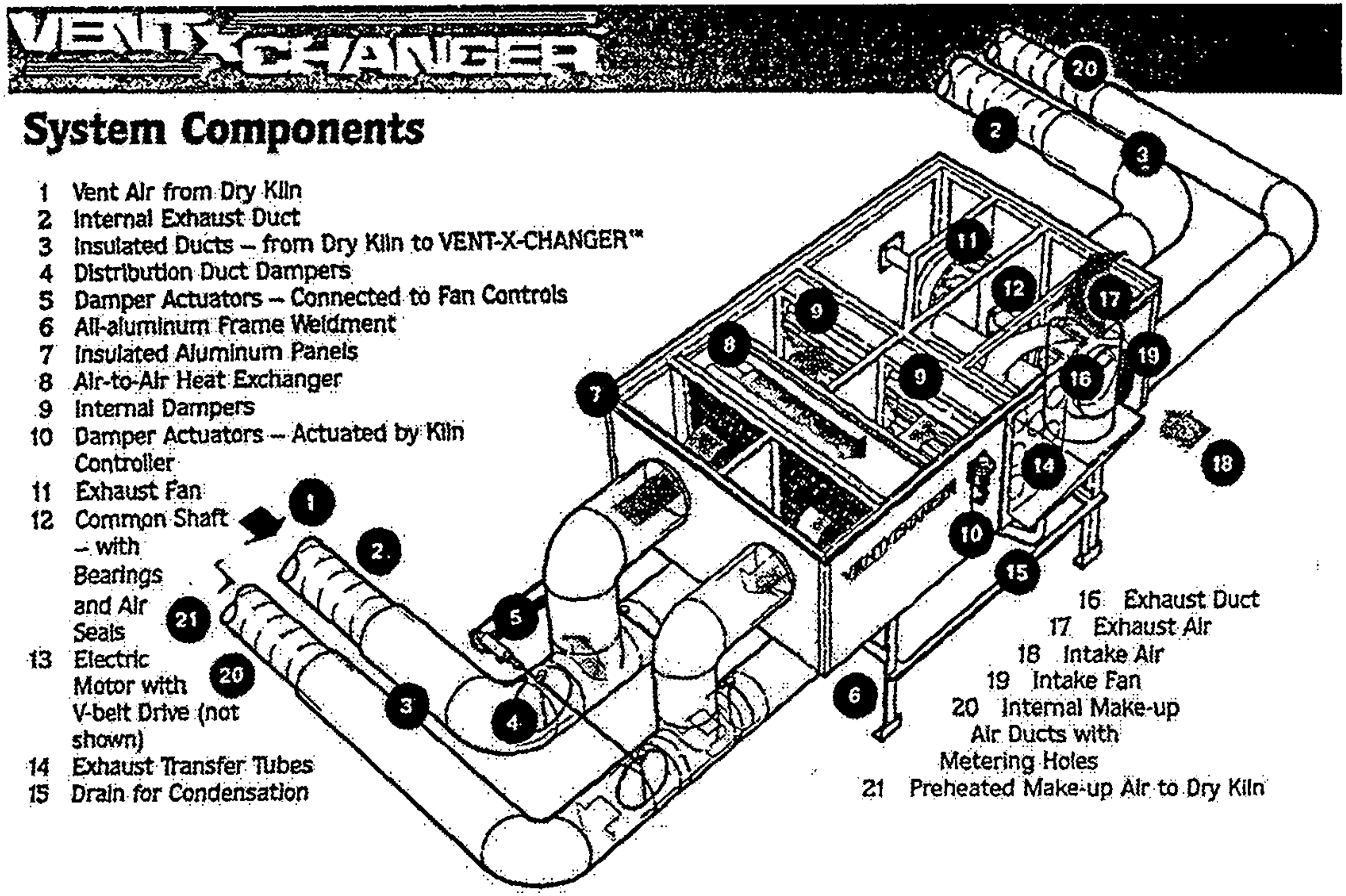
Kiln #3 is a two-track kiln with a capacity of 156 MBF of lumber. The lumber is stacked on kiln cars and rolled into the kiln. The kiln operates much like a traditional steam-heated kiln except there are no roof vents. A series of reversible kiln fans are located above the charge to move air through the lumber. Steam is not injected into the kiln during the drying cycle.

Ductwork extends under the roof along both sides of the kiln. For each side there are two conduits. One conduit conveys air into the kiln and another conduit conveys the exhaust out of the kiln. Louvers are located at the point where the ductwork emerges from the end of the kiln. Under normal operating conditions, one side of the kiln exhausts while the other side provides inlet air. The louvers open and close depending on the air flow in each conduit.

4.1.3 *Small-Scale Kilns*

The Phase I Variability Study was initiated by conducting a survey of the universities, Forest Products Laboratories, and other facilities that operated small-scale dry kilns to ascertain which facilities had VOC sampling capabilities. Table 4.1 shows a list of the facilities that responded to this survey. When the surveys were evaluated, it was determined that only three out of the thirteen respondents had small-scale kilns in operation that were configured to measure VOC emission rates: MSU, OSU, and Horizon Engineering. The small-scale kiln at NCSU was also included in the Variability Study because the kiln was significantly larger than the other three kilns, and it was equipped with conventional roof vents. Sampling of the NCSU kiln was conducted by DEECO.

Lumber was also sent to the Forest Products Laboratory (FPL) in Madison, Wisconsin, to be dried in their small-scale kiln (1500 BF) when they had assembled a VOC measurement system.



System Components

1 Vent Air from Dry Kiln
2 Internal Exhaust Duct
3 Insulated Ducts – from Dry Kiln to VENT-X-CHANGER™
4 Distribution Duct Dampers
5 Damper Actuators – Connected to Fan Controls
6 All-aluminum Frame Weldment
7 Insulated Aluminum Panels
8 Air-to-Air Heat Exchanger
9 Internal Dampers
10 Damper Actuators – Actuated by Kiln Controller
11 Exhaust Fan
12 Common Shaft – with Bearings and Air Seals
13 Electric Motor with V-belt Drive (not shown)
14 Exhaust Transfer Tubes
15 Drain for Condensation
16 Exhaust Duct
17 Exhaust Air
18 Intake Air
19 Intake Fan
20 Internal Make-up Air Ducts with Metering Holes
21 Preheated Make-up Air to Dry Kiln

Figure 4.3. Carter-Sprague Vent-X-Changer System

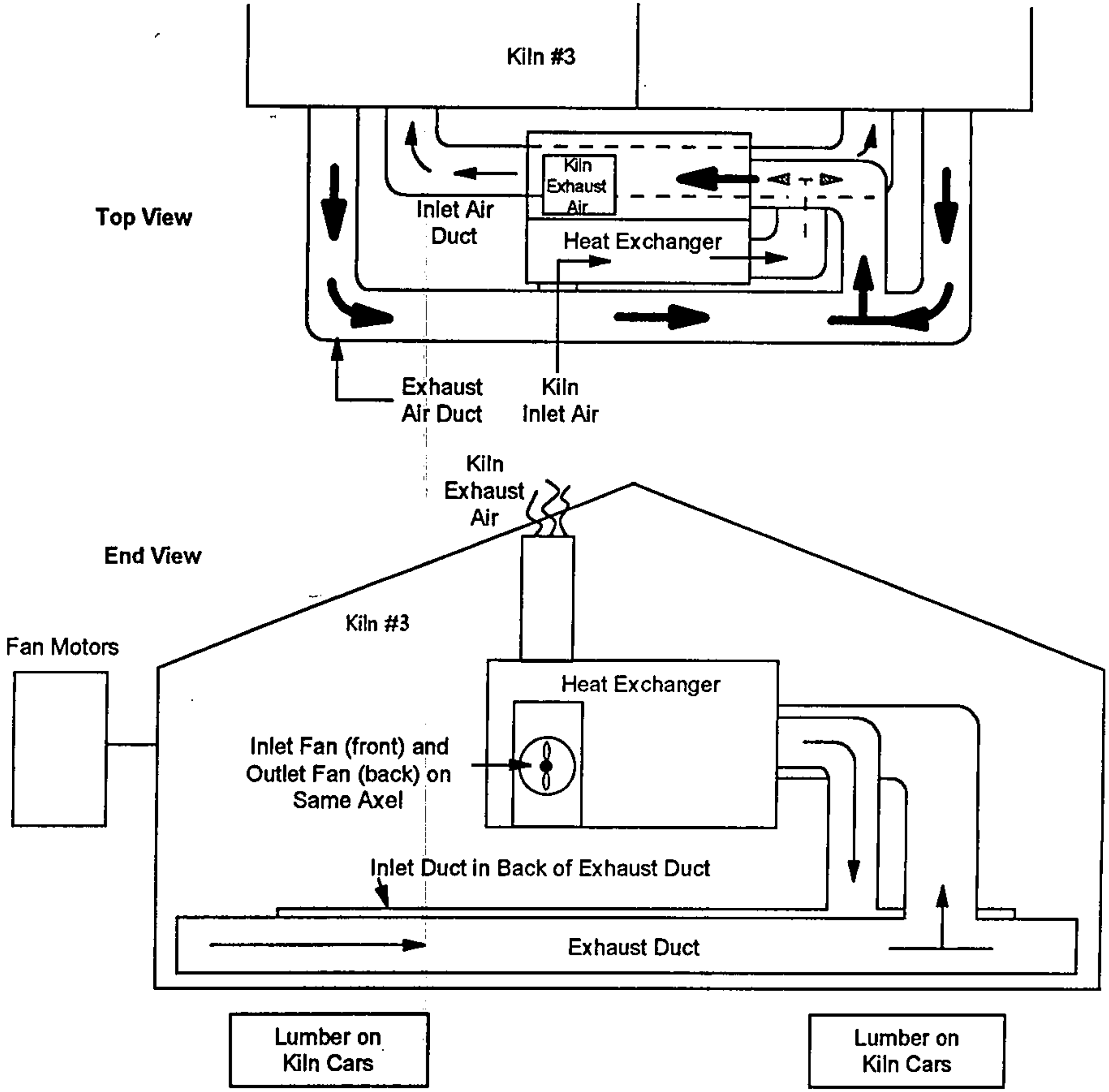


Figure 4.4. Steam-Heated Full-Scale Kiln with Vent-X-Changer System Under Normal Operating Conditions

Table 4.1. Survey Recipients

1. Forest Products Laboratory, Baton Rouge, LA
2. Forest Products Laboratory, Madison, WI
3. Forest Products Laboratory, Mississippi State, MS
4. H. D. Project Management/Horizon Engineering, Portland, OR
5. Michigan Technological University, Houghton, MI
6. North Carolina State University, Raleigh, NC
7. Robert C. Byrd Research Center, Princeton, WV
8. University of British Columbia, Vancouver, BC
9. University of Georgia, Athens, GA
10. University of Idaho, Moscow, ID
11. University of Maine, Orono, ME
12. Oregon State University, Corvallis, OR
13. Virginia Technological Wood Institute, Blacksburg, VA

4.1.3.1 Mississippi State University

The small-scale kiln at Mississippi State University (MSU) is constructed from stainless steel and has a maximum capacity of 31.94 BF. The sample board length for this kiln is restricted to 23 inches. For this project, the 2-by-4 inch lumber samples were stacked, with ¾ inch stickers, 5 boards wide by 5 boards high. For the 2-by-6 lumber, the charge consisted of 15 boards (28.75 BF), or 3 boards wide by 5 boards high.

Figure 4.5 shows a schematic of the MSU kiln. The kiln is configured with the lumber charge stacked under a baffle used to separate the charge from the heating element and internal kiln fan components. The kiln fan is driven by an external motor that moves the air in one direction passing over four 1-kilowatt (kW) electric fin heaters. The electric heaters are controlled by a temperature controller that accepts feedback from a wet bulb and a dry bulb thermocouple located in the upper right side of the kiln.

A compressor supplies inlet air to the kiln. The flow rate into the kiln is controlled by a single mass flow controller rated from 0 to 100 standard (32°F and 1 atmosphere) liters per minute (slpm). The air supplied to the kiln is assumed to be dry and was used to regulate the relative humidity inside the kiln. The mass flow controller also obtains feedback from the wet bulb and dry bulb thermocouples inside the kiln.

The inlet air is introduced into the kiln near the inlet side of the kiln fan housing. The dry inlet air immediately mixes with the re-circulated kiln air, passes through the fan, and over the heating elements in the upper section of the kiln. Some of the air leaves the kiln out the 1.5 inch diameter vent on the left side of the kiln. The rest of the kiln air is diverted under the baffle to pass through the lumber charge in a counterclockwise direction.

4.1.3.2 Oregon State University

The small-scale kiln at Oregon State University (OSU) is constructed of steel and has a maximum capacity of 75 BF. Steam is supplied to heat the kiln through finned pipes located under the lumber charge (Figure 4.6). Two internal kiln fans push air across the steam fin pipe assembly in a

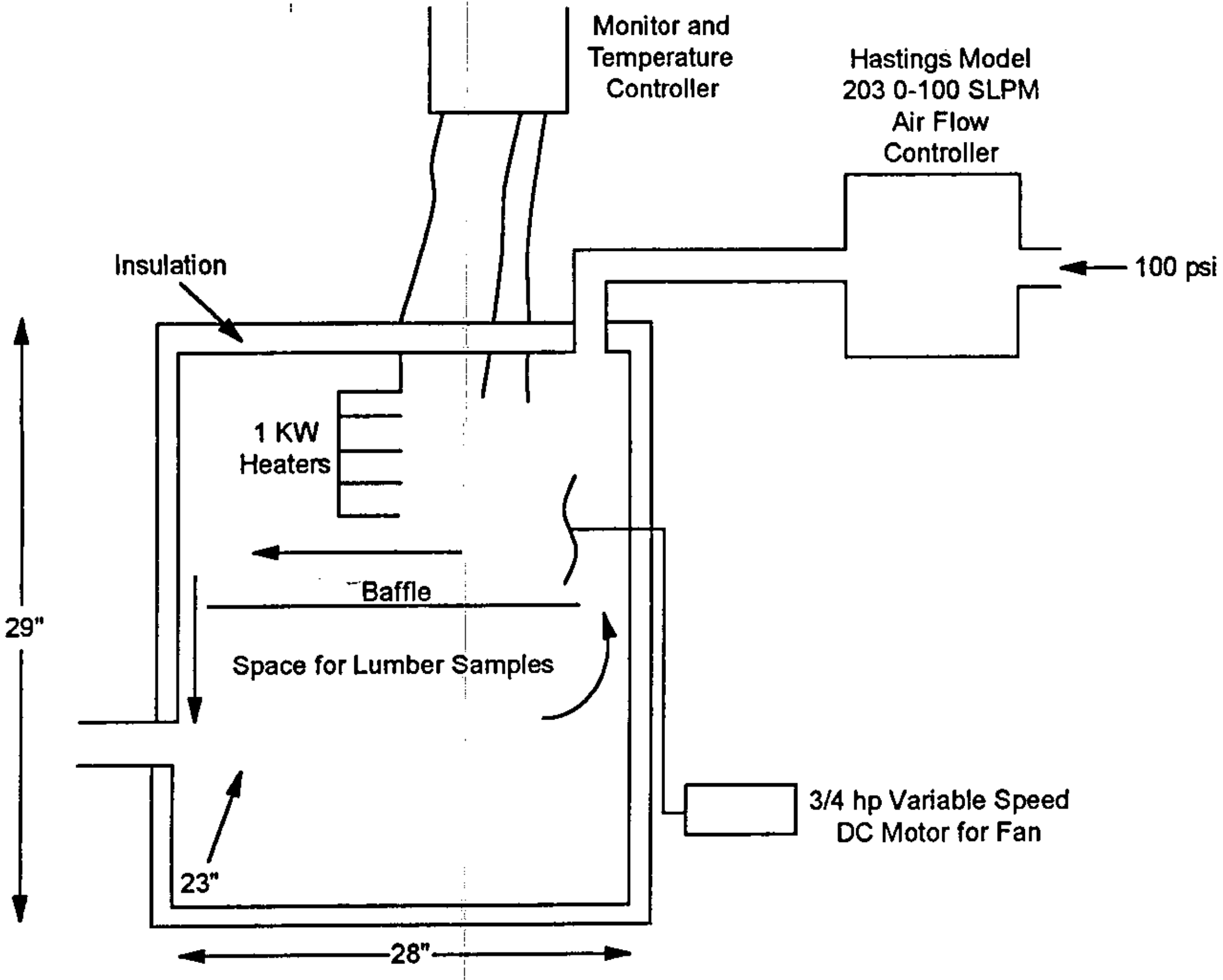


Figure 4.5. Small-Scale Kiln at MSU

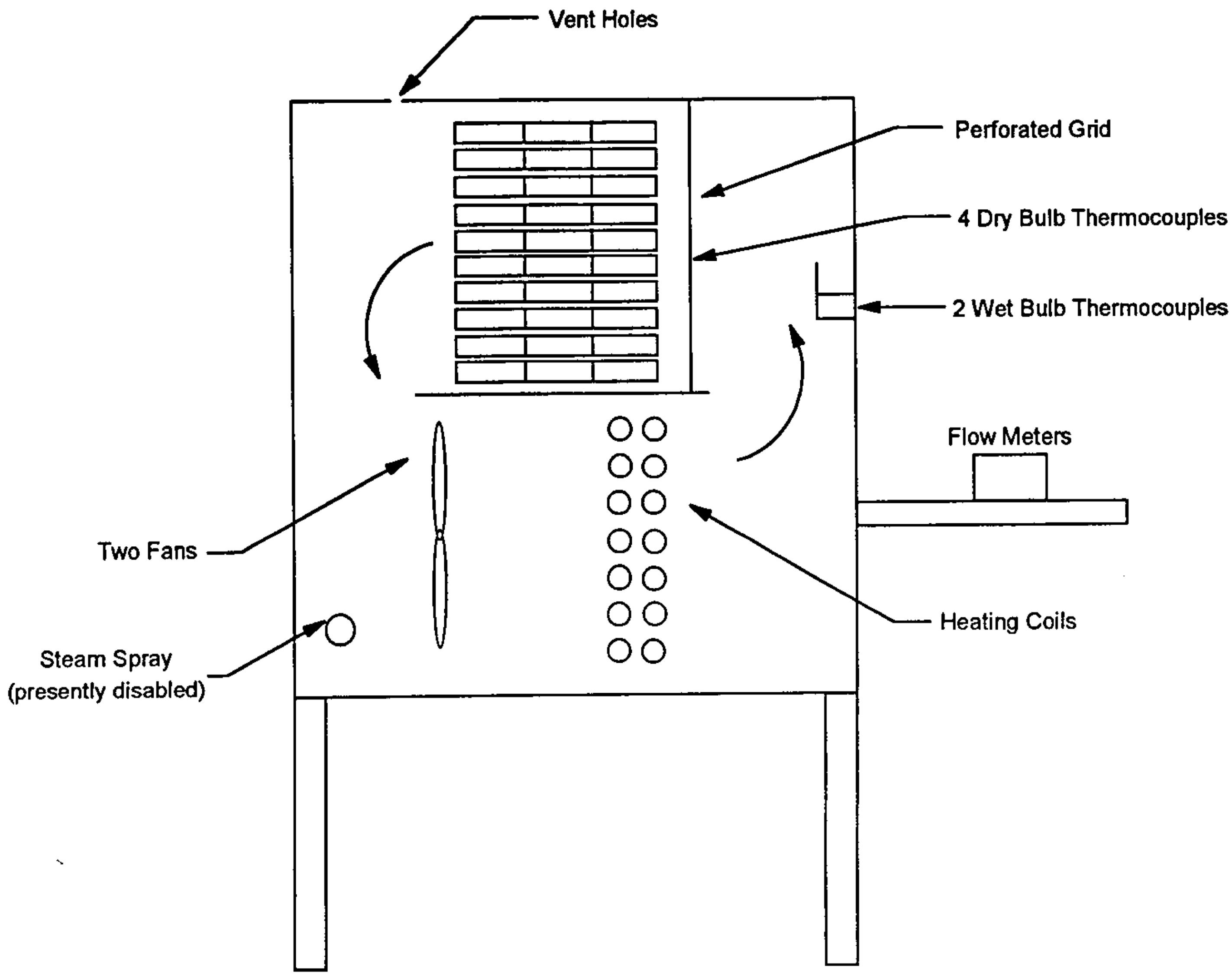


Figure 4.6. Small-Scale Kiln at OSU

counterclockwise direction. The reheated kiln air is then mixed with incoming dry air that is introduced at the lower right side of the kiln.

The mixture of dry inlet air and reheated kiln air then passes by two wet bulb thermocouples attached to the kiln wall and four dry bulb thermocouples attached to the metal grid on the inlet side of the lumber charge. The kiln air then passes through the lumber charge and a portion is exhausted through a roof vent on the exit side of the charge.

At the start of this project, OSU used one primary and two secondary mass flow controllers to control the inlet air flow rate. Each flow controller had the capacity to deliver 1.77 dscfm (at 32°F, 1 atm.). This mass flow controller configuration limited the size of the charge to 49 BF because of the high temperature drying schedule and relatively short drying times demanded for this project. OSU and NCASI decided to exchange the primary mass flow controller for one with a higher flow capability (7 dscfm, at 32° F, 1 atm.). The new mass flow controller allowed the size of the lumber charge to be increased from 49 BF to 73.3 BF for 2-by-4s (30 boards per charge) and 70.3 BF for 2-by-6s (20 boards per charge).

4.1.3.3 Horizon Engineering

Horizon Engineering, Inc. (HE) modified a 31 ft^3 industrial oven into a 50 BF small-scale lumber kiln (Figure 4.7). The charge was placed on a suspended platform that was connected to four load cells by wires at each corner. HE was the only small-scale kiln that used load cells to record the change in weight of the charge, due to water loss, during the drying cycle.

The kiln air was circulated through the lumber charge in a clockwise direction by two squirrel-cage fans. As the kiln air exits the lumber charge it passes by a wet bulb thermocouple, is deflected under a baffle and then mixed with inlet air.

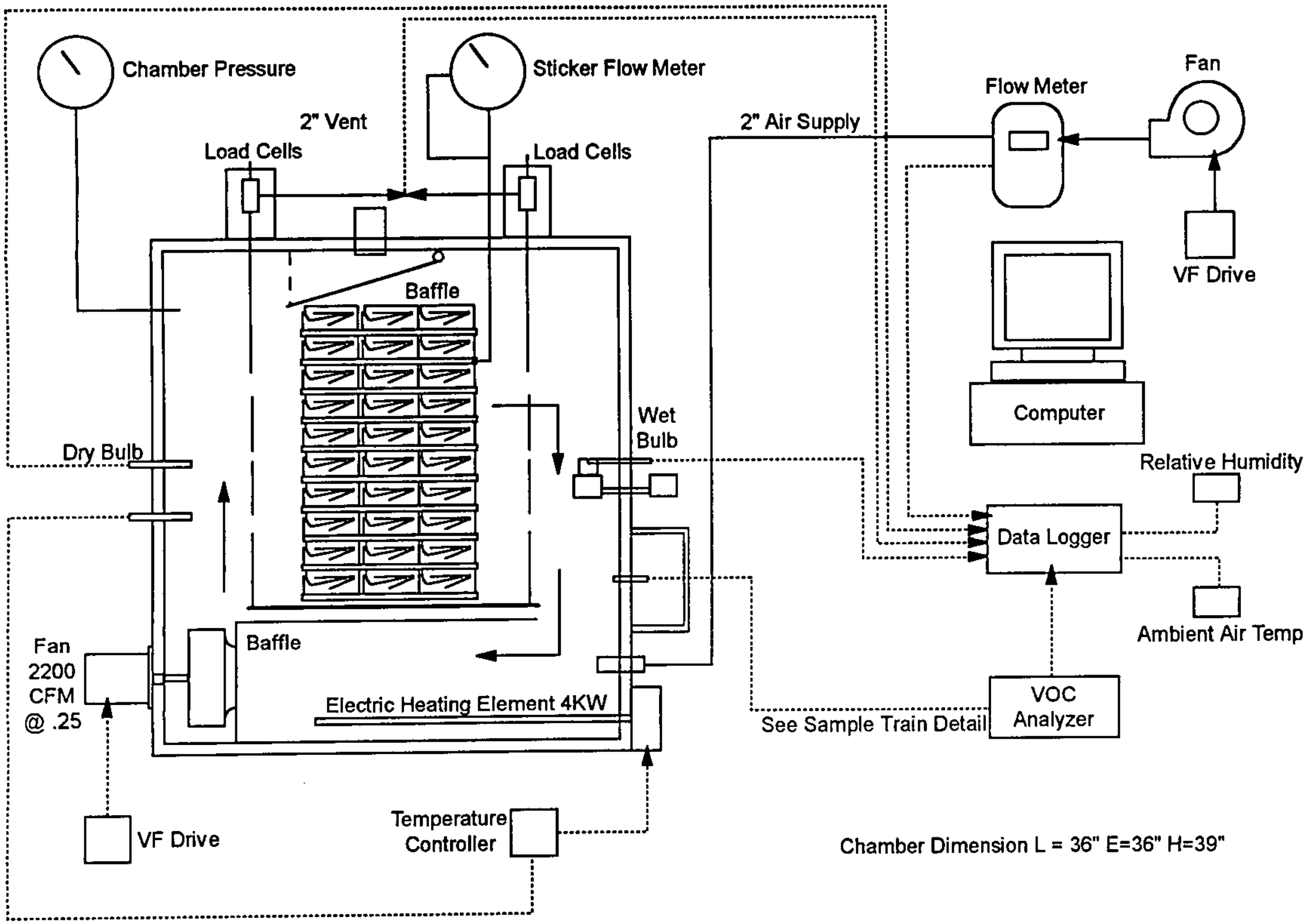
There were two inlet air sources for this kiln, a primary and a secondary source. The primary source is introduced on the lower right side of the kiln at a constant rate of 0.2 dscfm. The inlet for the secondary air source is located in the center of the kiln floor. The secondary air is introduced at a variable rate depending on the relative humidity of the kiln.

The mixture of kiln air and inlet air is heated by a 4 kW electric element. The air then enters the squirrel-cage fan, passes by two dry bulb thermocouples and is forced up to the lumber charge. The exhaust vent is located at the top of the kiln.

4.1.3.4 North Carolina State University

The 1500 BF kiln operated by North Carolina State University (NCSU) has four modulating roof vents. During a typical drying cycle, two of the vents allow air into the kiln while the other two exhaust kiln air. After conducting the trial test charge at NCSU, it was determined that the exhaust flow rate from the two vents was too low to obtain reliable measurements. Therefore, the roof vents on one side of the kiln were sealed to force the kiln to exhaust through one vent and intake through the other.

An 8-foot charge is loaded lengthwise on a kiln cart and rolled into the kiln as shown in Figure 4.8. A baffle above the charge creates a partition between the two kiln fans and the area where the charge is positioned. The kiln fans are capable of moving air in both a clockwise and a counterclockwise direction through the charge similar to full-scale lumber kiln operation. The circulated air inside the kiln is reheated by four steam fin pipes oriented parallel to the fans above the baffle. Three fin pipes are located on the kiln door side of the fan assembly, and the one fin pipe is located towards the back of



Chamber Dimension L = 36" E=36" H=39"

Figure 4.7. Small-Scale Kiln at Horizon Engineering Inc.

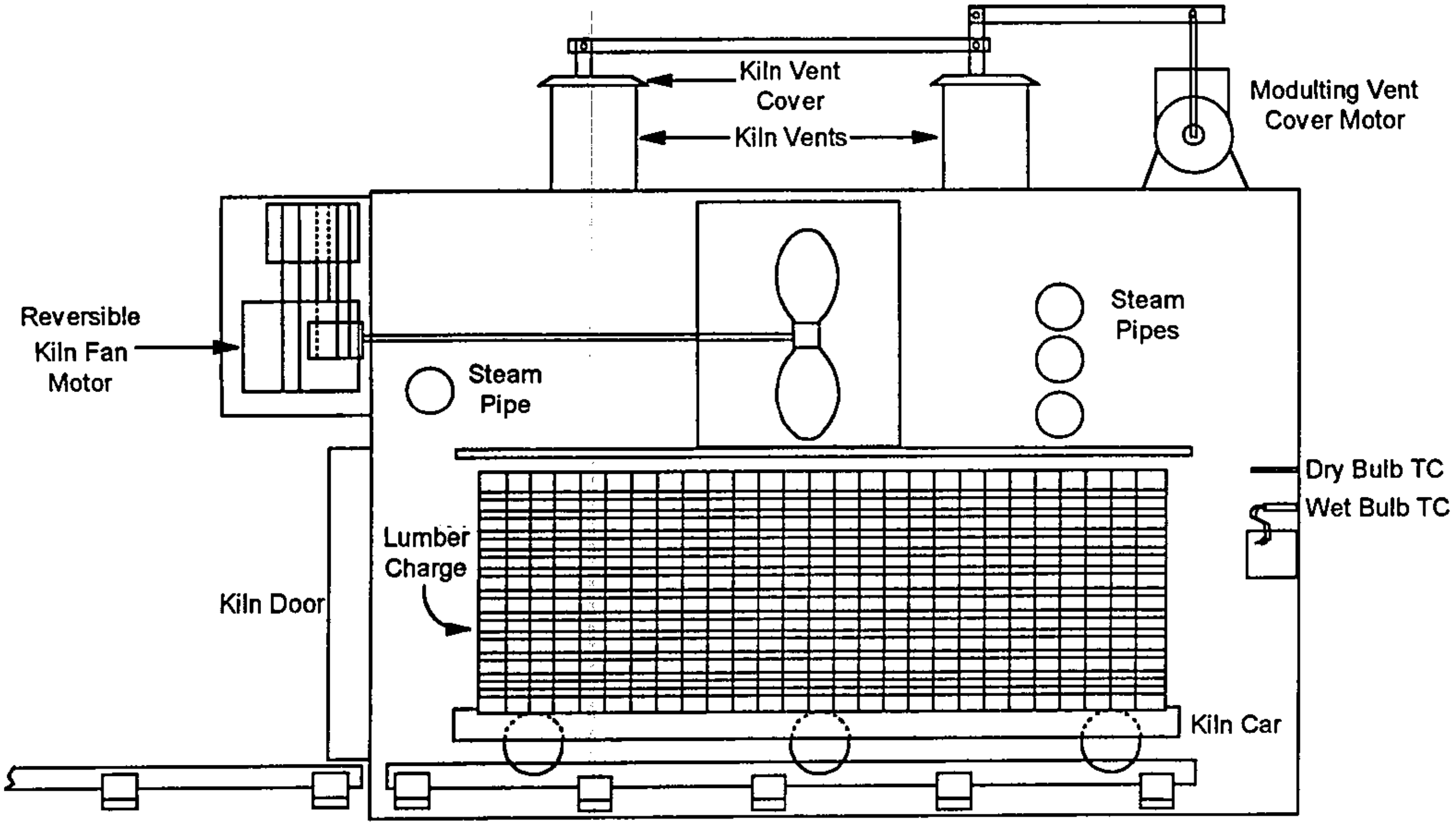


Figure 4.8. Small-Scale Kiln at North Carolina State University

the kiln on the other side of the fans. Both the wet bulb and dry bulb thermocouples are located on the rear wall of the kiln.

4.2 Kiln Operations

The operators of the small-scale kilns participating in this study were required to meet kiln operational criteria that were modeled after commercial high temperature southern pine lumber kilns. The original intent was to develop a list of standard kiln operational parameters for the Variability Study that were based on a typical southern pine kiln schedule and to use those parameters throughout the entire project. During the testing of the full-scale kilns in Phase II, however, some of the kiln operating parameters defined for the Variability Study were modified to replicate the operating schedules used at the direct-fired and steam-heated kilns. In either case, the controlling parameters were determined to be the air velocity through the lumber charge, the kiln wet bulb/dry bulb temperature schedule, and the ending lumber moisture content. The duration of the drying cycle was not considered a controlling parameter because the dimension of the charge in each kiln participating in this study was different and the effect of charge size on drying time was not clearly understood.

4.2.1 *Air Velocity Through the Lumber Charge*

The air velocity through the charge was established specifically for the small-scale kiln operators and was based on an approximation of the air velocity typical of full-scale kilns. After consulting with commercial southern pine lumber kiln operators, an air velocity of 1000 feet per minute (fpm) through the kiln charge was established. The 1000 fpm value was the maximum reasonable value attainable by the small-scale kilns that participated in this project. Therefore, this parameter was not modified for Phase II.

4.2.2 *Kiln Wet Bulb/Dry Bulb Temperature Schedules*

Three different temperature profiles were used at the small-scale kilns, one for the Variability Study test charges, one for the test charges associated with the direct-fired kiln and one for the test charges associated with the steam-heated kiln.

The Variability Study test charges were dried by following a typical southern pine wet/dry bulb temperature set point profile of 175°F/235°F, respectively. The kilns were required to ramp up to these set point temperatures within the first three hours of drying. The scope of work for the Variability Study required that data acquisition start after the kiln had achieved the set point temperatures. Figures 4.9 through 4.12 show an example of the temperature profiles for the first charge at each of these four participating small-scale kilns. A complete set of temperature profiles for the Variability Study test charges has been included in Appendix A of this report.

MSU was able to consistently control the dry bulb temperature during all four kiln charges. After the first three hours of operation, where no forced venting occurred, the dry bulb temperature reached 235°F, but the wet bulb temperature appeared to be higher than the set point (Figure 4.9). However, after the fan began to vent, the wet bulb temperature stabilized at 175°F for the next six hours. At that point the wet bulb temperature decreased as the lumber dried.

OSU had calibration problems with their wet/dry bulb thermocouples necessitating two adjustments to their temperature data. The first correction involved lowering both the measured wet bulb and dry bulb temperatures by 3.8°F. The second correction subtracted 2.83°F, 4.81°F and 4.7°F from wet bulb measurements in test charges 3 through 5, respectively. These two corrections caused the wet/dry bulb temperature profiles to be slightly below the required set point temperatures (Figure 4.10). Despite

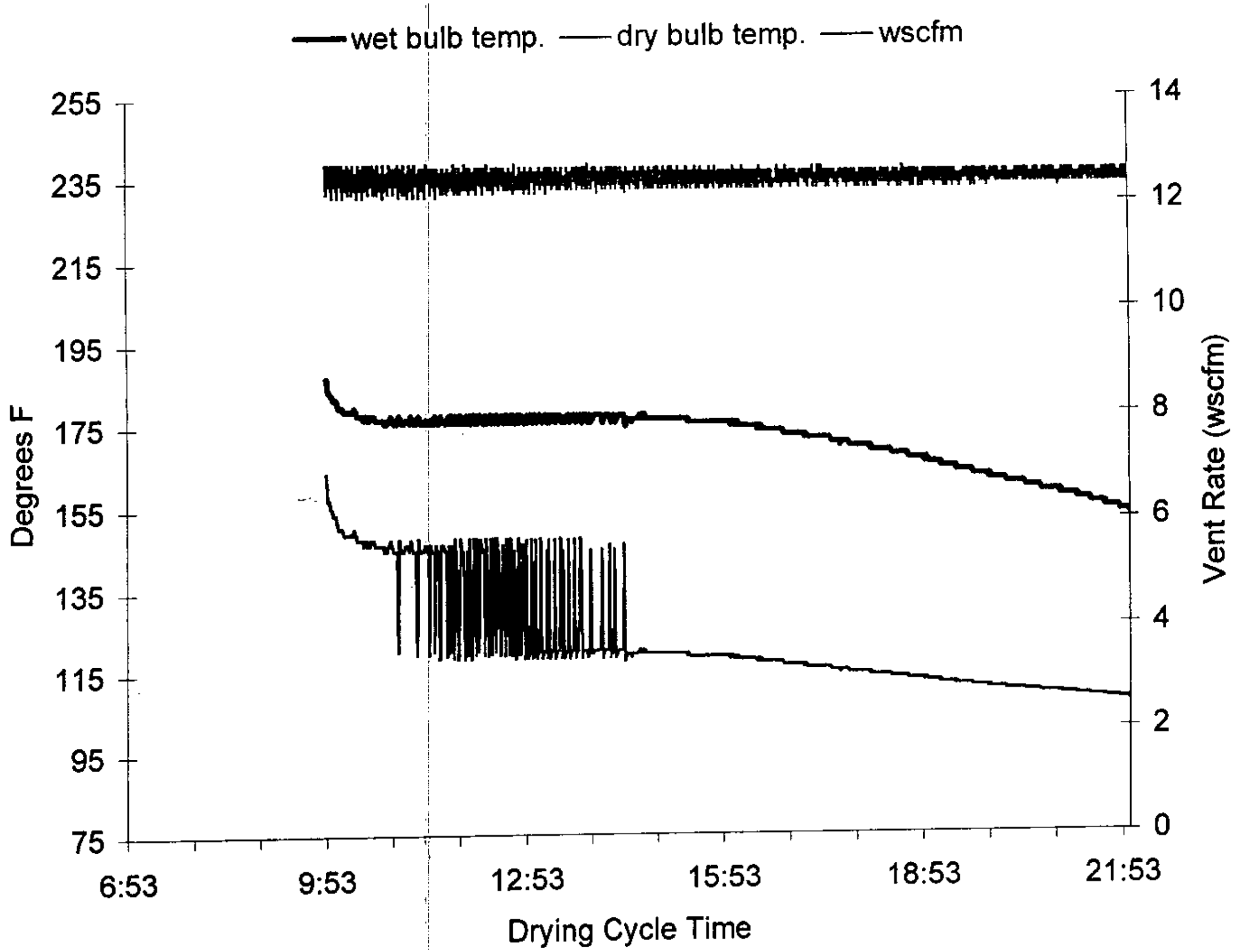


Figure 4.9. Comparison of WB/DB Temperatures to Venting Rate (Variability Study Kiln Charge MSU 2)

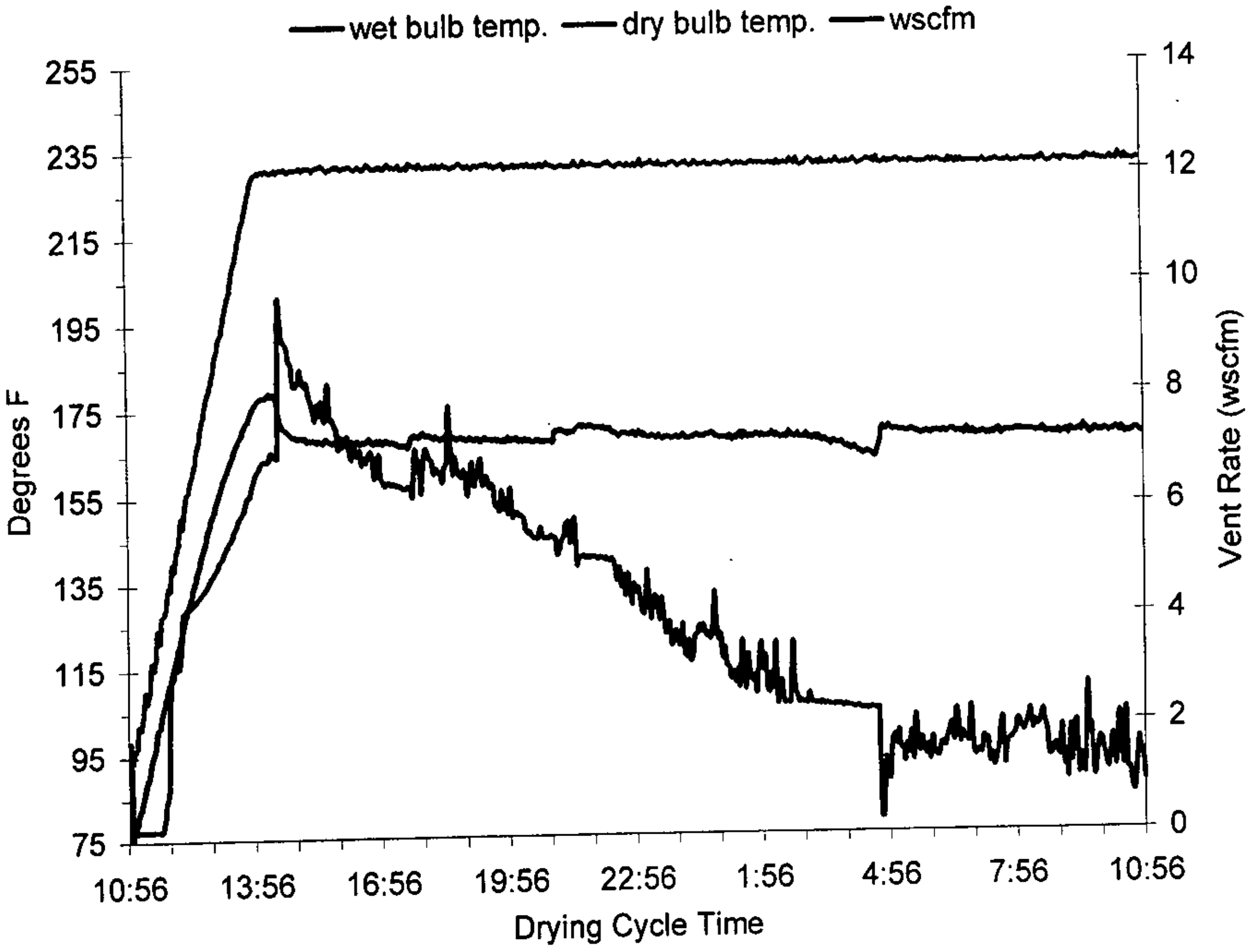


Figure 4.10. Comparison of WB/DB Temperatures to Venting Rate (Variability Study Kiln Charge OSU 3)

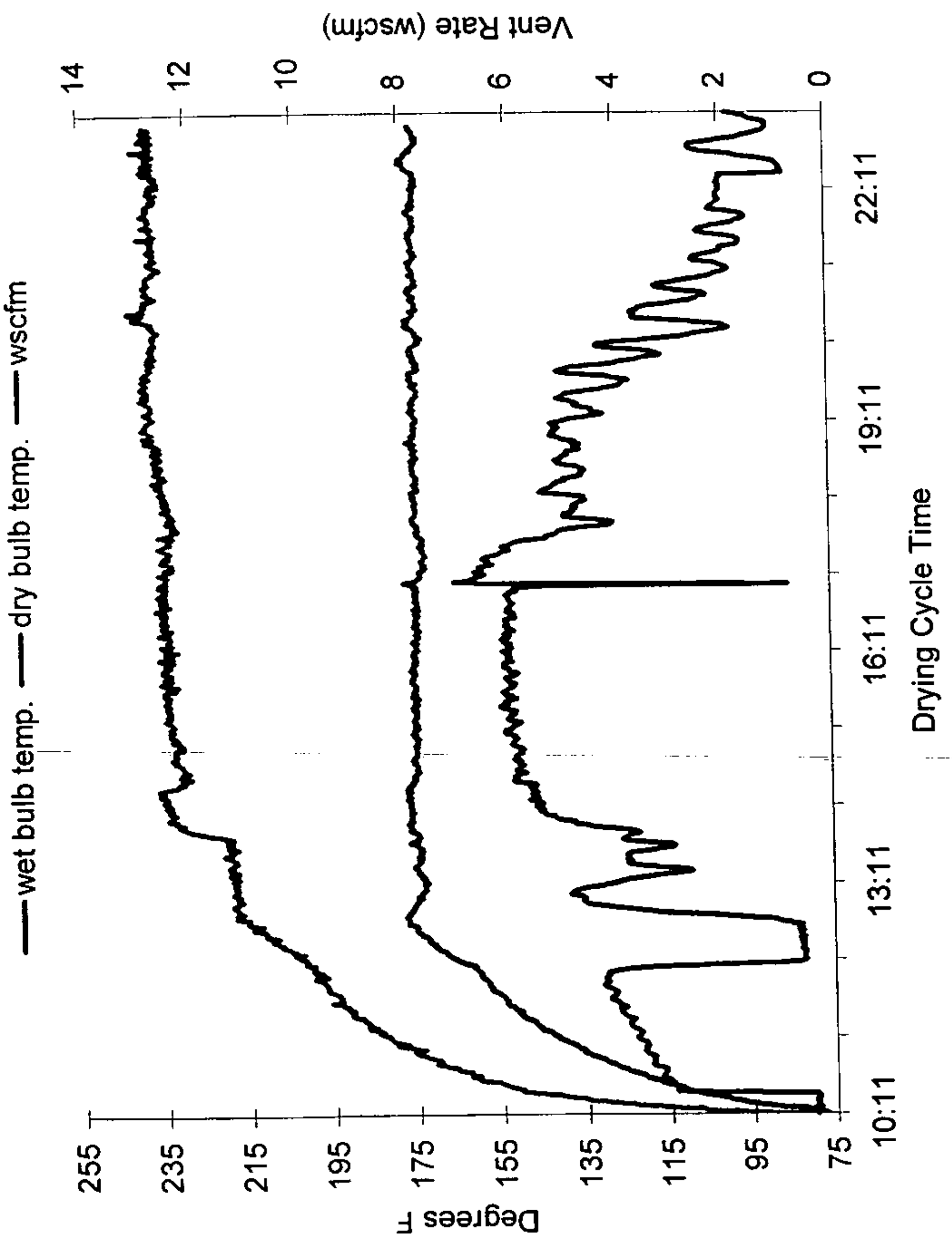
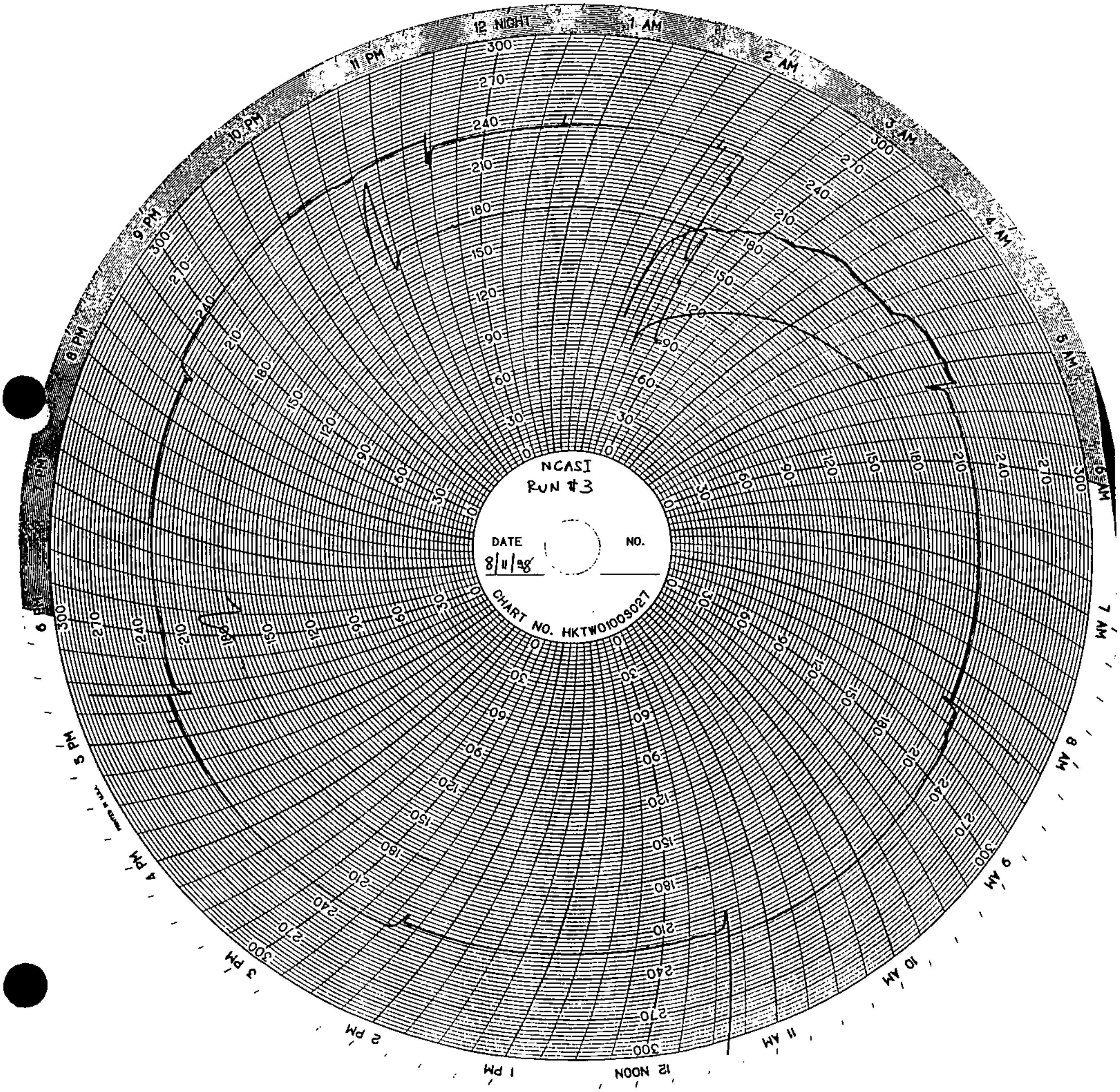


Figure 4.11. Comparison of WB/DB Temperatures to Venting Rate (Variability Study Kiln Charge HE 2)

Figure 4.12. Variability Study Kiln Charge NCSU 3
Wet/Dry Bulb Temperature Schedule



these minor problems, OSU was able to maintain consistent control of the kiln temperatures over all three charges.

The wet bulb temperature profile for each of the three Horizon Engineering (HE) kiln charges stabilized at the correct set point within the first three hours of the cycle, but the dry bulb temperature profile was somewhat variable (Figure 4.11). After the first three hours of drying, the dry bulb temperature for each kiln charge averaged approximately 220°F. The dry bulb temperature did not stabilize at the set point until seven hours into the cycle for the first charge, five hours for the second charge and ten hours for the third charge.

The temperature profiles for the NCSU kiln were recorded on a circular chart. The sketches of the charts show the characteristic shifts in temperature associated with kiln fan reversals. The slight decrease in the dry bulb temperature for one fan direction (Figure 4.12) is discussed in the Kiln Description section of this report. NCSU attached a dry bulb thermocouple to the door side of the charge to verify that the kiln air was reaching the dry bulb temperature of 235°F before passing through the lumber charge in that particular direction. The wet bulb set point was reached within the three-hour criteria during the first and third kiln charges. The wet bulb temperature for the second kiln charge was reported to be at 168°F at the end of the three-hour warm-up period. Steam was introduced to raise the temperature to 175°F. After the initial three-hour warm-up period, all charges were consistently maintained at the designated wet bulb set point temperature without the addition of steam.

The wet/dry bulb temperature profile for the direct-fired kiln followed a different trend than the 175°F/235°F profile used for the Variability Study. Printouts for each of the direct-fired kiln schedules have been included in Appendix B. Although the actual wet bulb/dry bulb temperature profile during the majority of the drying cycle was 170°F/235°F, Figure 4.13 shows how the kiln's wet bulb set point was programmed differently in order to vent the kiln at 100% operating capacity. Note that the wet bulb set point was programmed at 75°F for the first six hours of the cycle, but the actual wet bulb temperature of the kiln air increased to 170°F. Then at the sixth hour, the wet bulb set point was changed to 165°F while the actual wet bulb temperature remained around 170°F.

The temperature profile used at the small-scale kilns to model the direct-fired kiln is described below:

(1) For drying cycle hours 1 through 3, raise the wet bulb/dry bulb temperatures from ambient to 170°F/180°F, respectively.

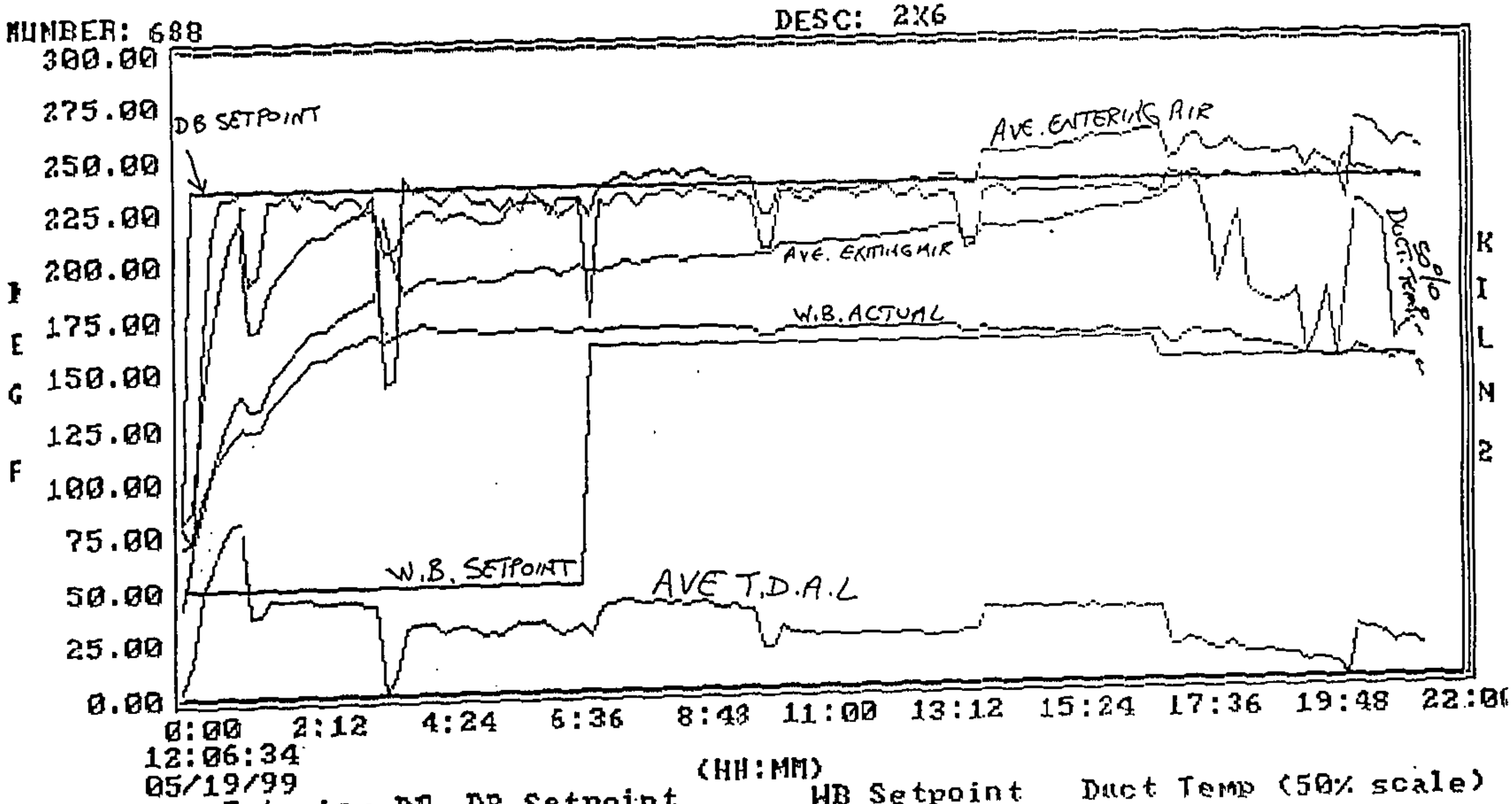
(2) For hours 3 through 15 maintain the wet bulb at 170°F and increase the dry bulb 4.5°F per hour.

(3) For the remainder of the drying cycle, maintain the dry bulb temperature at 235°F until the end of the cycle.

The wet bulb temperature within the small-scale kilns was allowed to drift between 165°F and 170°F during the drying cycle. Furthermore, the operators were given the option of permitting the wet bulb temperature to decrease after 15 hours of drying. As a result, MSU and OSU were successful in controlling the temperatures within their kilns to replicate the direct-fired temperature profile. The complete set of temperature profiles for all of the small-scale kiln direct-fired sample charges is included in Appendix C.

The temperature profile developed for the steam-heated kiln was also different from the profile used for the Variability Study. The printouts of the actual temperature schedule for each steam drying cycle could not be obtained because the printer in the kiln's control room was not functioning. To determine

Figure 4.13. Kiln Charge FSK DF1



```
Average Entering DB   DB Setpoint          WB Setpoint   Duct Temp (50% scale)
Average Exiting DB    Average T.D.A.L.     WB Actual

TIME:          VALUES:   81.207       50.005
05/19/99                 78.307        2.900
12:06:34                 81.207       42.304
                         70.606
```

an average temperature profile for the steam schedule, temperatures were manually recorded at hourly increments. A representative temperature schedule for the steam kiln is shown in Figure 4.14. The small-scale kiln temperature profile developed to model the steam kiln is described below:

(1) For drying cycle hours 1 through 3, raise the wet bulb/dry bulb temperatures from ambient to 170°F/215°F, respectively.

(2) For hours 3 through 5 increase the wet bulb temperature to 195°F and the dry bulb temperature to 230°F.

(3) For hours 5 to 6 maintain the wet bulb temperature at 195°F and increase the dry bulb temperature to 235°F.

(4) For the remainder of the drying cycle maintain the temperatures at 195°F/235°F.

This schedule was considerably more demanding than the proposed schedule for the Variability Study and was difficult for the small-scale kiln operators to implement. The steam kiln temperature profiles for the full-scale and small-scale kilns have been included as Appendix D.

MSU was able to approximate, but not match, the steam kiln temperature profile described above. Figure 4.15 shows the MSU temperature profile during the first test charge attempted, which happened to be MSU INDF5. It was decided after this charge that the set point profile should be simplified to the temperature schedule shown for MSU INDF1 (Figure 4.15). Since the wet bulb profile for MSU INDF5 was not significantly different than the rest of the profiles obtained with the modified temperature schedule, MSU INDF5 was not re-run.

4.2.3 *Determination of Lumber Moisture Content*

One of the objectives of this project was to develop a standard procedure for determining the termination point of the data collected from the drying cycles at both the full-scale and small-scale kilns. The two parameters that were considered to affect the end point of the data were the lumber moisture content and duration of the drying cycle. After consulting with the kiln operators involved with this study, it was established that lumber moisture content was the better choice because it is one of the parameters used in the grading of softwood lumber at all of the commercial full-scale kilns. Most southern pine lumber manufacturers are required to produce finished lumber that has a moisture content of less than 19% dry basis (dry) (U. S. Dept. of Agriculture 1991). To ensure that any given full-scale kiln lumber charge will be at or below the 19%-dry criteria, the commercial kiln operators normally dry lumber charges to an average moisture content of 15%-dry.

Following standard industry practice, all moisture contents expressed for lumber will be on a percent dry basis. This parameter was computed by the expression below:

$$\%Moisture\ Content\ (dry) = \frac{Weight\ of\ water\ in\ wood}{Weight\ of\ totally\ dry\ wood} \times 100$$

The termination point for the Variability Study drying cycles at the small-scale kilns was established to be when the moisture content of the sample charge reached 15%-dry. The method for determining this stopping point was not specified and, as a consequence, all four kilns used different methods to determine this termination point.

As a result of the Variability Study, a standard method, referred to as "Calculated %Wood-MC," was developed to truncate the emissions data when the lumber charge reached 15%-dry moisture content.

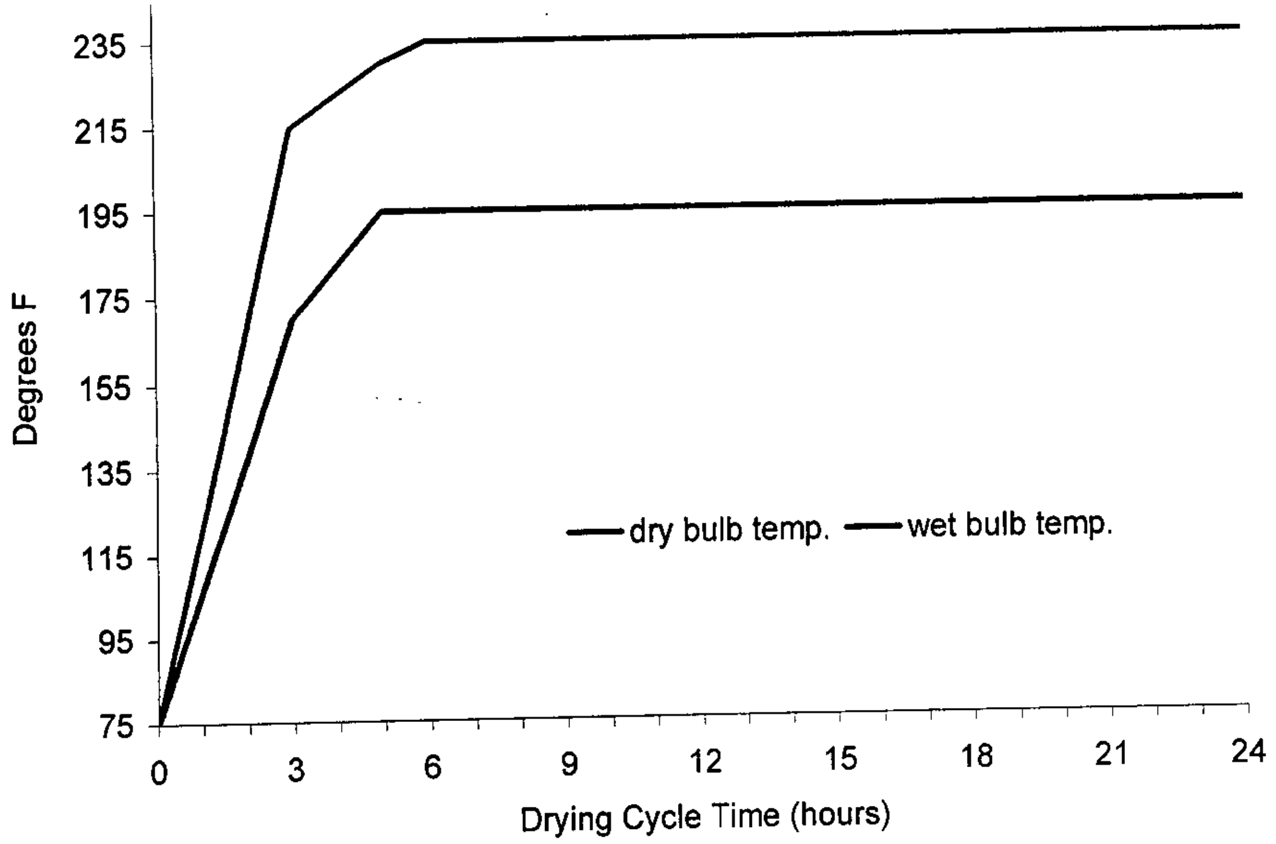
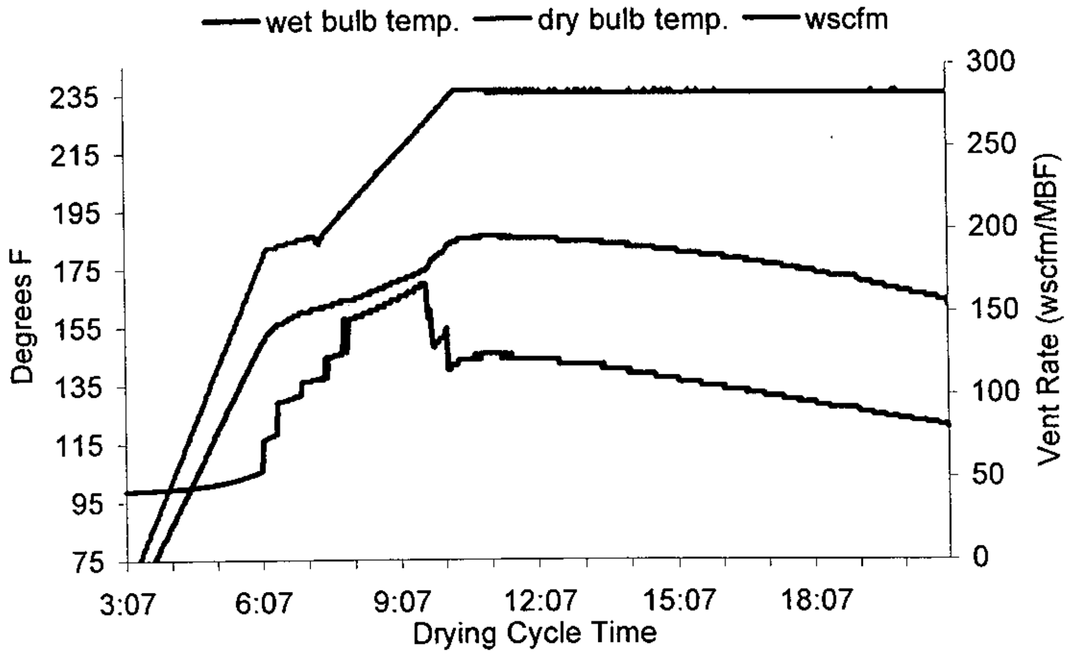


Figure 4.14. WB/DB Temperature Profile for the Steam-Heated Full-Scale Kiln

Kiln Charge MSU-INDF5



Kiln Charge MSU-INDF1

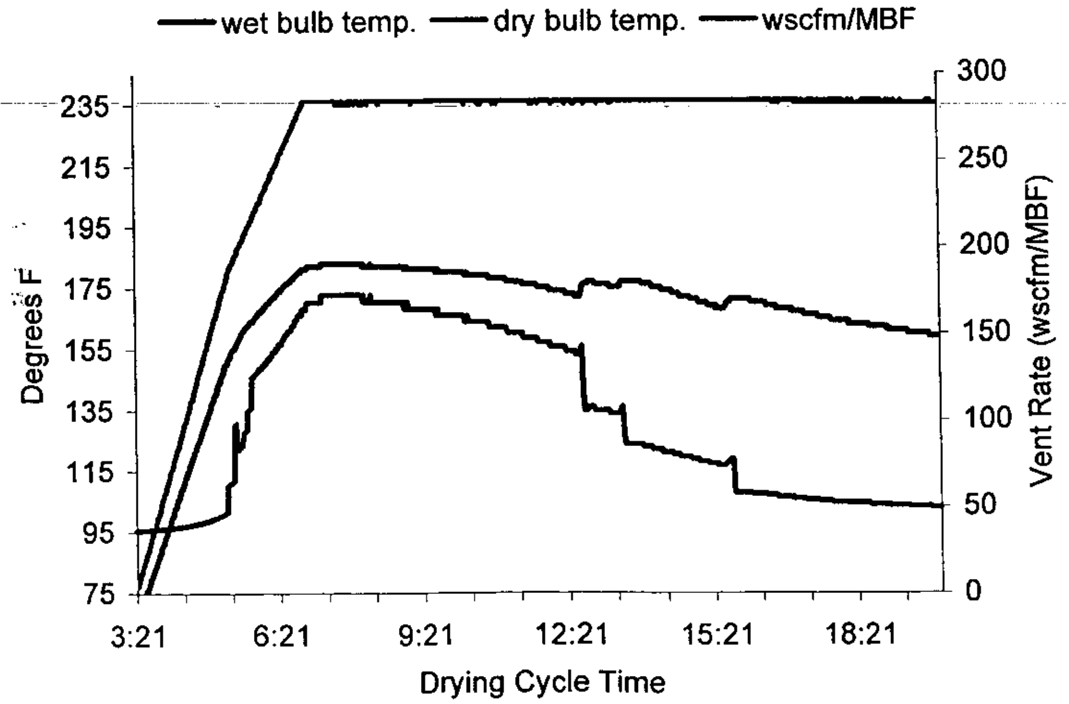


Figure 4.15. Comparison of WB/DB Temperature Profiles to Venting Rate (MSU)

The Calculated %Wood-MC method was based on the concept used by OSU. The modifications to the OSU method were required to insure that the Calculated %Wood-MC method met the following three criteria:

(1) the methodology is based on standard dry kiln operating procedures,

(2) the parameters are defined in the protocols of this project, and

(3) the method is applicable to all small-scale kiln data sets.

The results yielded from the Calculated %Wood-MC method were compared to the load cell data collected for the three kiln cycles reported by Horizontal Engineering, Inc. (HE). Figure 4.16 shows that for cycles 1 and 2 the results from the Calculated %Wood-MC method compare favorably with measured load cell data. Figure 4.16, however, also shows that the trends for two methods diverge at the end of the Kiln Charge HE 3 drying cycle. The reason may be explained by comparing the kiln venting trends shown in Figure 4.17. The kiln exhaust flow rates shown for the first two kiln cycles follow the same general pattern of high flow rates halfway through the drying cycle. The flow rates recorded for HE 3 (Figure 4.17), however, are much lower throughout the entire cycle.

The accuracy of the Calculated %Wood-MC method appears to depend on the exhaust flow rate and the dry bulb and wet bulb temperature schedule. Given a typical drying cycle, the procedure generally compared favorably to load cell data. Therefore, the decision was made to use the Calculated %Wood-MC for all remaining small-scale kiln charges. The percent moisture content profiles determined by the Calculated %Wood-MC method for all of the Phase II kiln charges have been included in Appendix E.

The direct-fired and steam kiln operators combined two methods, the temperature drop across the load (TDAL) and electric moisture meter readings, to assist in determining the ending moisture content of each full-scale kiln lumber charge. At the end of each drying cycle the operators would first make a preliminary assessment of the temperature difference between the air entering the lumber charge and the air exiting the lumber charge, or TDAL. If the TDAL was low enough, the operator would open the kiln doors and randomly test boards along the length of the charge with an electric moisture meter.

Electric moisture meters are generally calibrated to operate in the high heat conditions found within kilns and have an operating range between 6% and 30%-dry wood moisture content. The meters measure the conductivity of the wood. The meters approximate the moisture content of board in the immediate area where the meter is measuring. Therefore, multiple readings up and down the kiln charge are required to obtain an idea of the moisture content for the entire charge. The meter readings were observed to range from 10% to 30%-dry wood moisture content. Due to the variance in readings, the moisture meter readings were not recorded and were not used to determine the kiln-dry moisture content of the full-scale kiln charges.

The mill personnel at the direct-fired kiln did provide an opportunity, however, to weigh about 25% of the first three kiln charges before and after drying. This was done by weighing the packs and a (tared) forklift on a mill scale. The oven-dry weights of the corresponding samples sent to small-scale kilns provided the average dry wood density. The sample density and pack weights that were used to estimate the kiln-dry moisture contents for FSK DF1, DF2 and DF3 are shown in Table F.1, Appendix F. The calculated results indicated that these charges were dried to between 12% and 15%-dry wood-MC.

One of the shortcomings of this study may have been a failure to obtain an accurate final moisture content of the full-scale kiln charges. This is a difficult task, however, due to the variability of the lumber moisture contents within the different drying sections inside the kiln, the layers of the lumber in

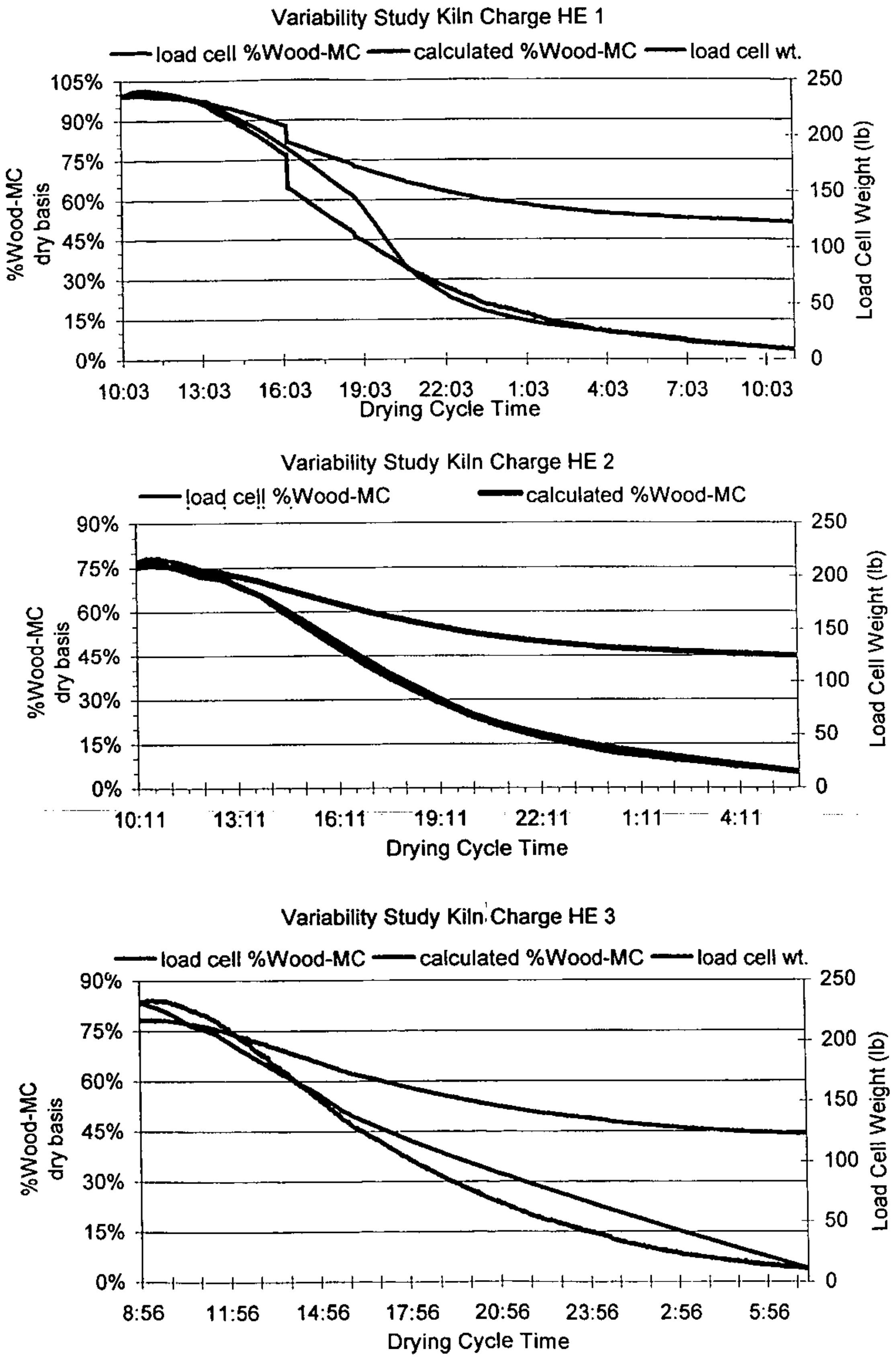
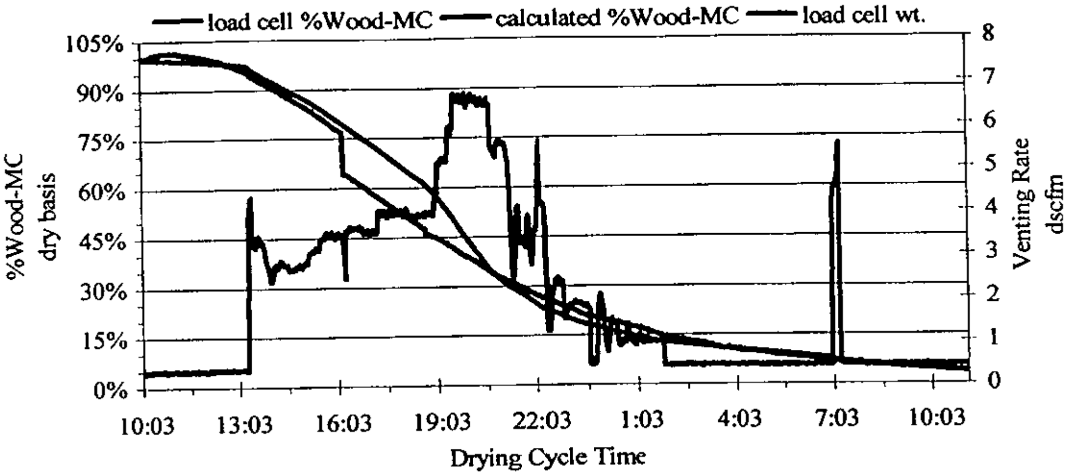
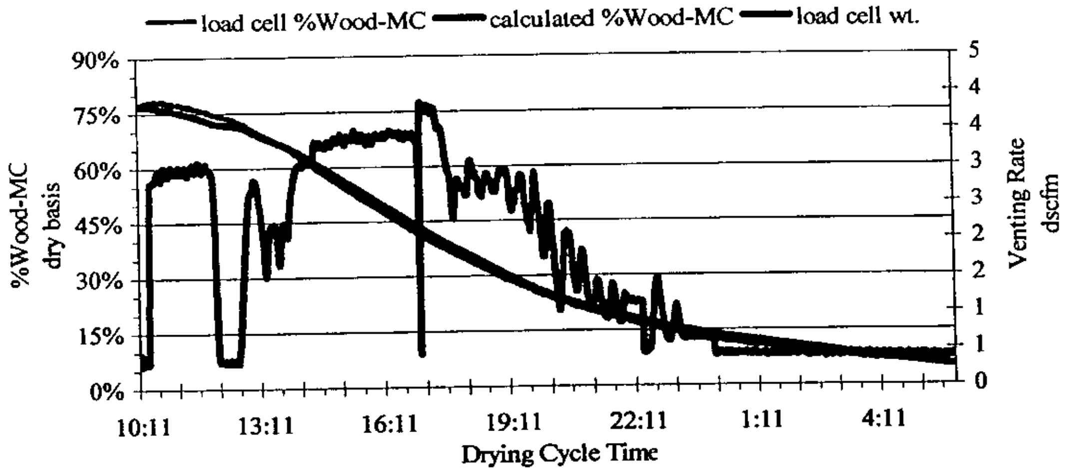


Figure 4.16. Comparison Between Load Cell and Calculated %Wood-MC Methods and Load Cell Weight
National Council for Air and Stream Improvement

Variability Study Kiln Charge HE 1



Variability Study Kiln Charge HE 2



Variability Study Kiln Charge HE 3

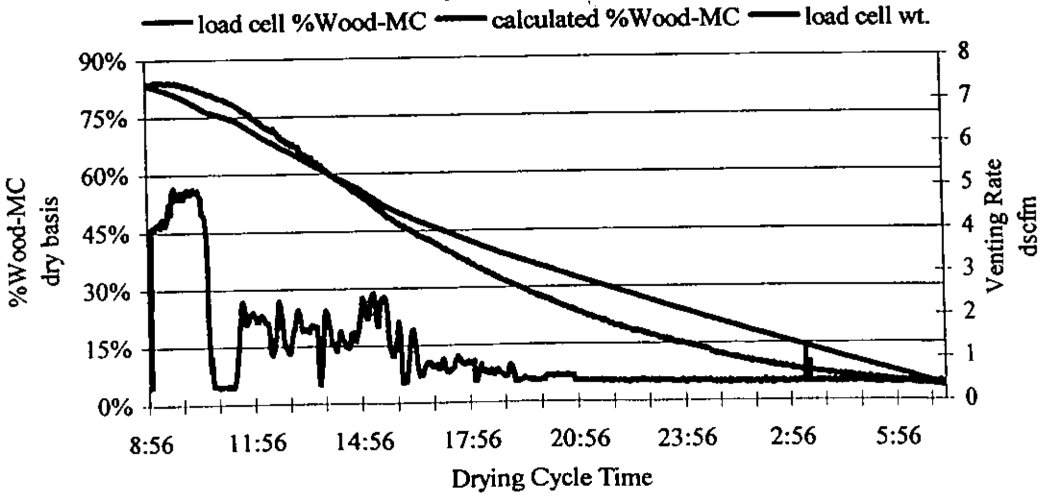


Figure 4.17. Comparison Between %Wood-MC Methods and Kiln Venting Rates

the pack itself, and along a single board. Moisture meter readings are helpful, but highly variable, as moistures of 10 to 25% can be determined from the same lumber pack or same board. As a result, the determination of when to stop a drying cycle at a full-scale kiln is as much art as it is science. The kiln operators involved with this study used subjective criteria, such as the burning sensation in their nose after inhaling the vapor coming off a hot packet of lumber, to gauge the end point of a charge. Other subjective methods included their knowledge of recent kiln cycle times and feedback from the lumber graders and personnel operating the planer mill. TDALs and moisture meters provide support for these less scientific "measurements."

4.3 Kiln Testing Configurations

4.3.1 *Direct-Fired Full-Scale Kiln*

Two 90 degree sampling ports existed on each stack of the direct-fired lumber kiln (Figure 4.18) prior to testing. A third sample port (not shown on figure) was installed 45° in between, and slightly below, the two existing ports so that the sampling probes would not have to be moved to obtain velocity measurements.

The distance between the stack fan and the sampling ports in each stack (Figure 4.19) did not meet the minimum criteria for optimum flow rate measurements. NCASI ruled out stack extensions because of safety concerns. Therefore, flow straightening vanes were used to minimize the cyclonic flow pattern within the stack. An "egg-crate" straightening vane design was used.

In order to obtain samples from the burner, NCASI installed one sample port prior to the junction of the burner conduit and the blend box (Figure 4.20). A water jacket and probe were inserted into the sample port to maintain the sample probe at a temperature below 300°F. Provisions were made to seal the burner port, water jacket and sample port to avoid drawing ambient air into the conduit. Velocity measurements were not conducted at this location. The flow rate from the burner was calculated using the F-factor instead of velocity measurements.

The stack fans for this kiln were sufficiently powerful to create a slight negative pressure inside the kiln. Due to this, fugitive emissions from the kiln were insignificant and measures to seal the kiln were unnecessary.

4.3.2 *Indirect-Fired Full-Scale Kiln*

Two sample locations were utilized at this kiln to avoid the possibility that pollutant emission rates would be affected by the heat exchanger. Parameters necessary for calculating a <u>dry mass flow rate</u> were measured at the <u>outlet side</u> of the heat exchanger. Parameters necessary for calculating <u>mass emission rates of the pollutants</u> were measured at the <u>inlet side</u> of the heat exchanger.

For the first kiln test (INDF1) NCASI installed a vertical stack extension over the original heat exchanger stack (Figure 4.21). Since the exhaust fan was positioned directly below the stack, a baffle was placed in the stack extension to decrease the cross sectional area of flow. Four sample ports were placed two duct diameters downstream from the baffle. A 16 point flow measurement grid was used to measure velocity from these four ports.

During the first kiln test it became obvious that the motor and fan blade assembly were not adequate to draw sufficient exhaust gas from the kiln for the testing purposes of this project. Even with the fan motor operating at 100% capacity, fugitive emissions were observed escaping the kiln.

After the first test charge was completed an additional exhaust fan was added to increase the kiln exhaust rate. In order to accommodate the additional exhaust fan, ductwork was installed to connect

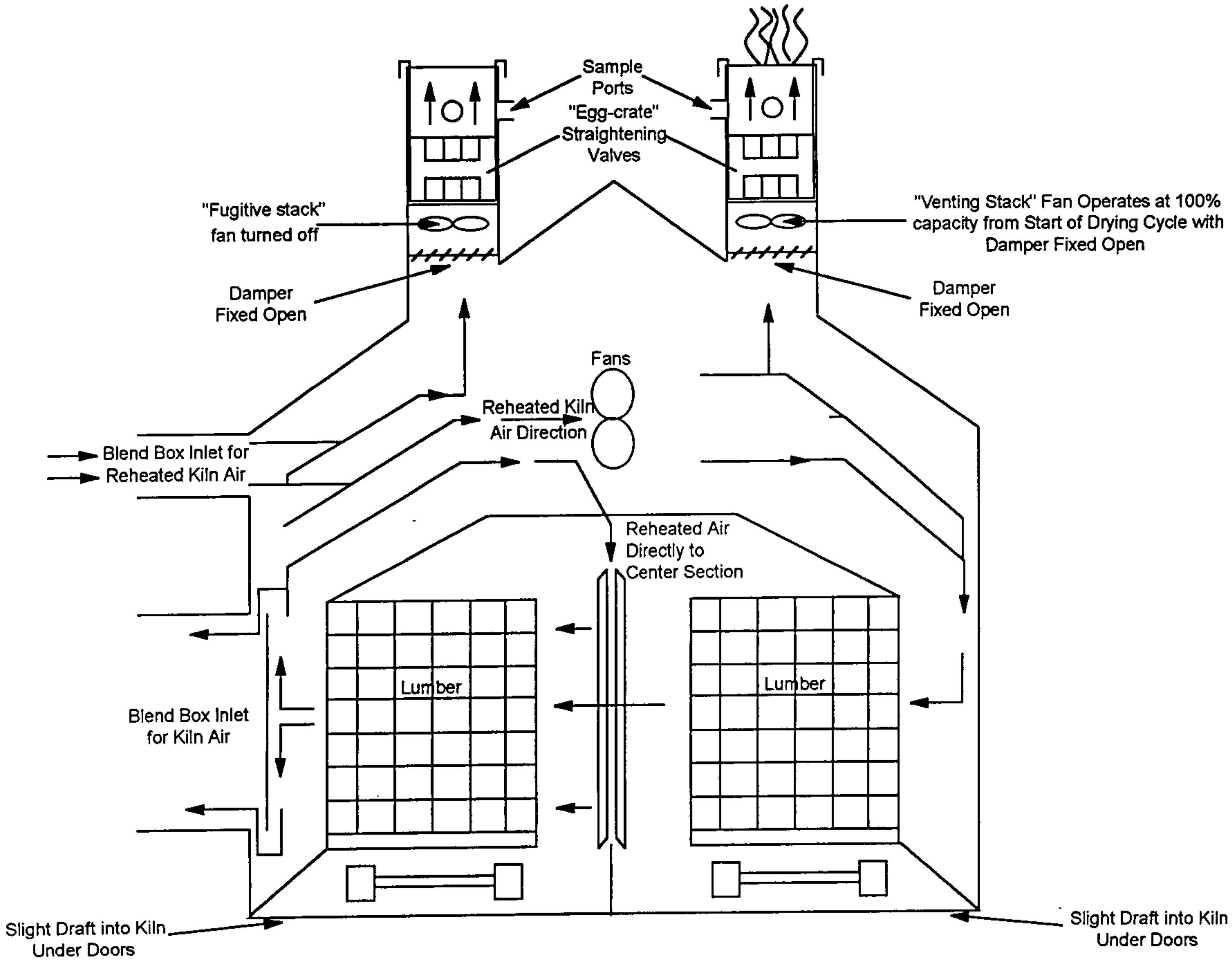


Figure 4.18. Direct-Fired Full-Scale Kiln with Power Vent System Modified for Kiln Testing

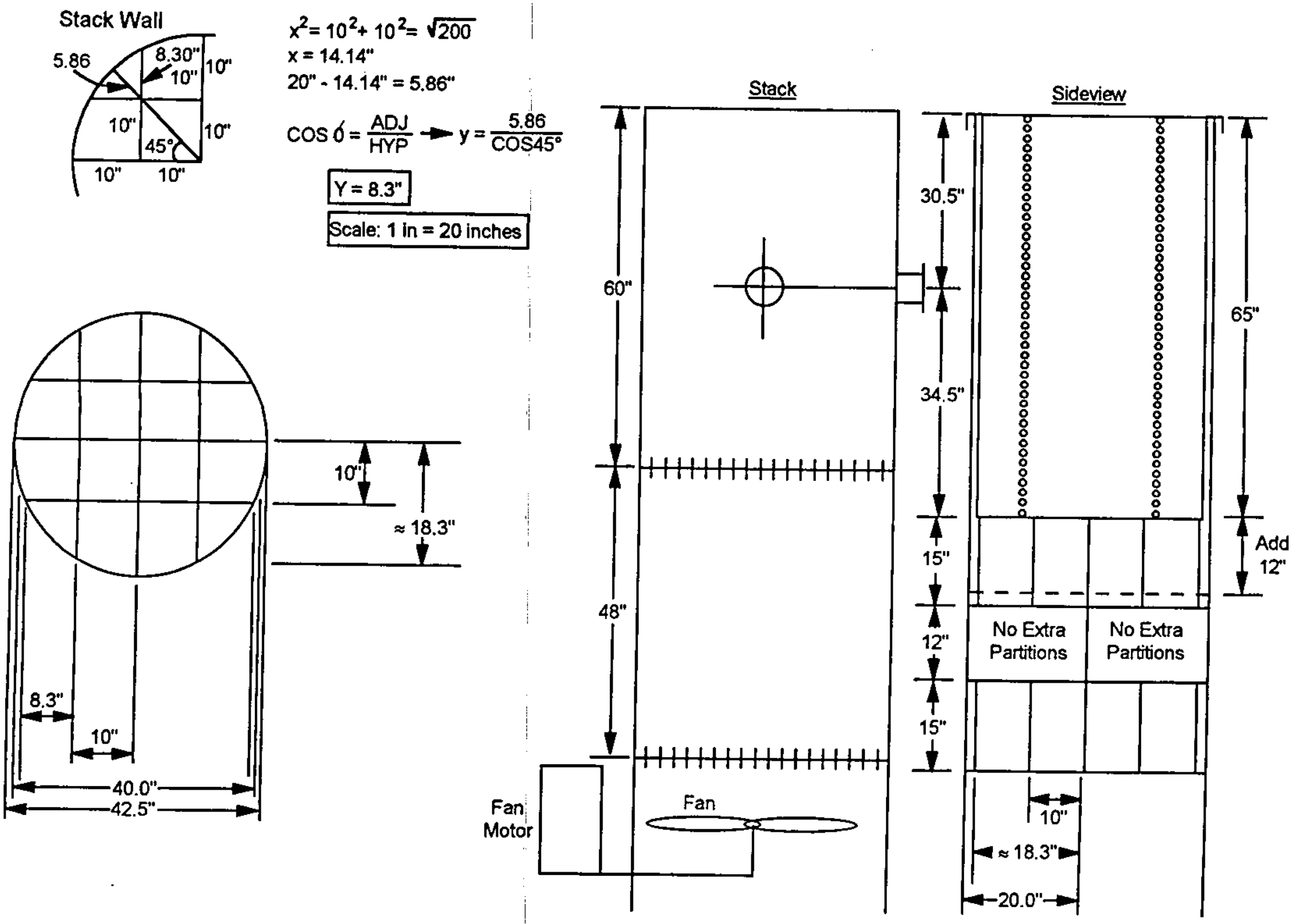


Figure 4.19. Straightening Vanes for the Direct-Fired Full-Scale Kiln Stacks

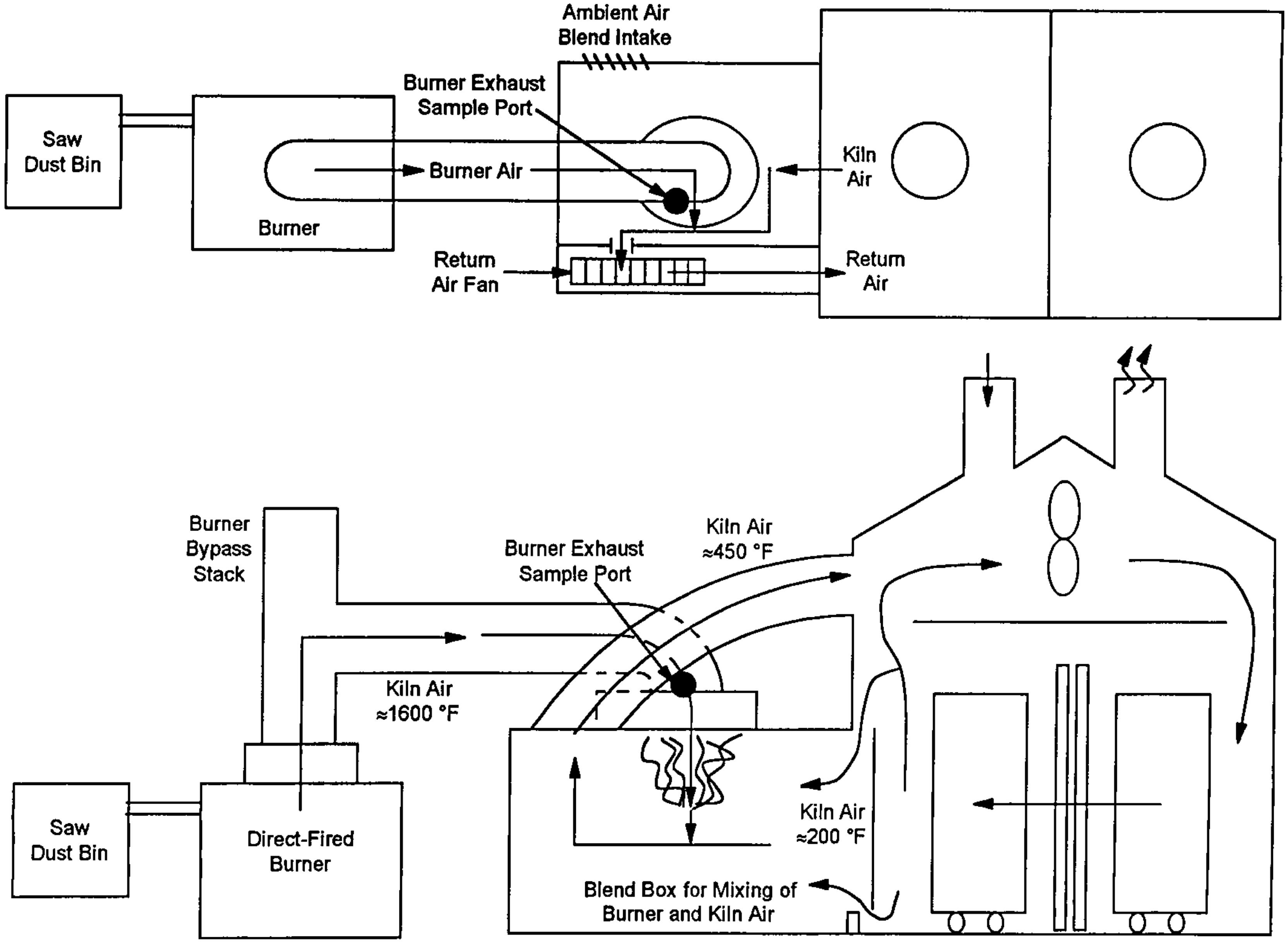


Figure 4.20. Location of Burner Sample Port for the Direct-Fired Full-Scale Kiln

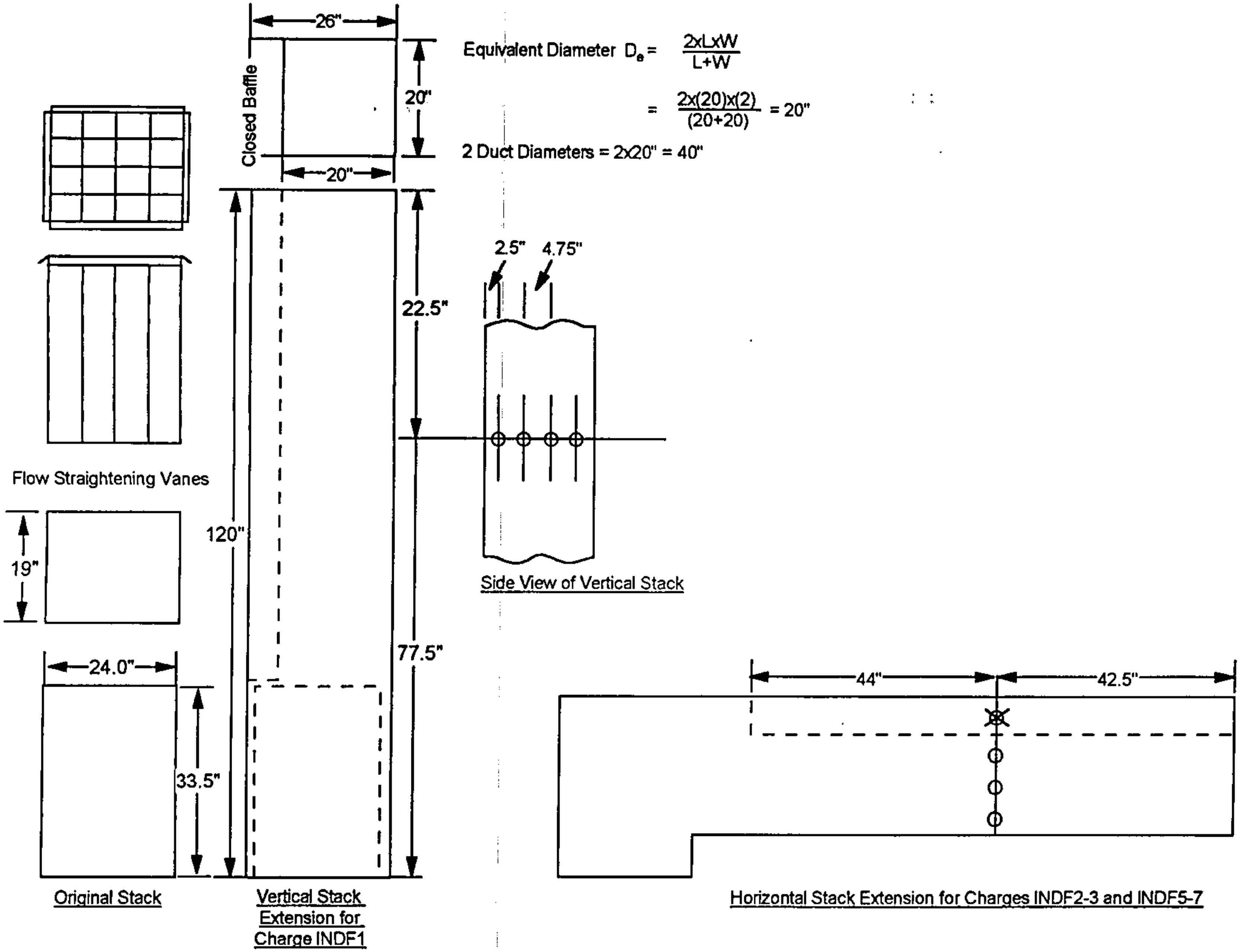


Figure 4.21. Stack Extensions used at the Steam-Heated Full-Scale Kiln

the original stack to the additional fan (Figure 4.22). All of the joints in the ductwork were insulated and sealed to minimize in-leakage into the system.

The flow rate measurements for the remaining test charges were conducted at the three sample ports installed in the horizontal section of ductwork shown in Figure 4.21. The flow measurement grid was changed from a 4x4 pattern to a 3x6 pattern.

Two 90 degree sample ports were installed in the vertical section of exhaust ductwork prior to the entrance of the heat exchanger (Figure 4.22). These ports were used for pollutant moisture measurements. Since flow rate measurements were not taken at this location, flow straightening devices were not required.

During the initial site visit to the steam kiln, substantial fugitive emissions were observed during drying. To minimize fugitive emissions, the seals around the main kiln doors were replaced prior to the first kiln test. NCASI also placed plastic sheeting and sand bags at the bottom of the kiln doors to create a better seal when the doors were closed. An attempt was also made to seal holes in the kiln walls and side access doors.

4.3.3 *Small-Scale Kilns*

No provisions were made to measure the exhaust flow rate from the small-scale kilns at MSU, OSU and Horizon Engineering (HE) because the inlet flow rate was monitored instead. The exhaust flow rate was, however, measured from the small-scale kiln at NCSU.

As mentioned in the kiln description of the NCSU kiln, two of the four roof vents were closed so that the kiln vented from only one roof vent at a time. Under this condition, the flow rate was increased to a reliable and measurable quantity. The flow rate from the kiln was measured using a technique which involved covering the roof vents with hoods (Figure 4.23). The hoods allowed enough room for the vent covers to open and close in a normal manner. The kiln exhaust captured by the hoods was directed through a stack containing a propeller anemometer to measure the actual wet flow rate leaving the kiln. The hoods were insulated and the distance from the kiln exit point to the anemometer was minimized to avoid problems with condensation of the kiln exhaust. A raked probe was located in the stack for sampling the kiln gas.

MSU used a 1.5 inch outlet vent on the left side of their kiln (Figure 4.24) as the sample port for concentration measurements. OSU and HE measured the concentration of the "exhaust" gas directly in the kiln. The sample port for both OSU (Figure 4.25) and HE (Figure 4.26) was a small hole in the side of the kiln wall big enough to accommodate the sample probe.

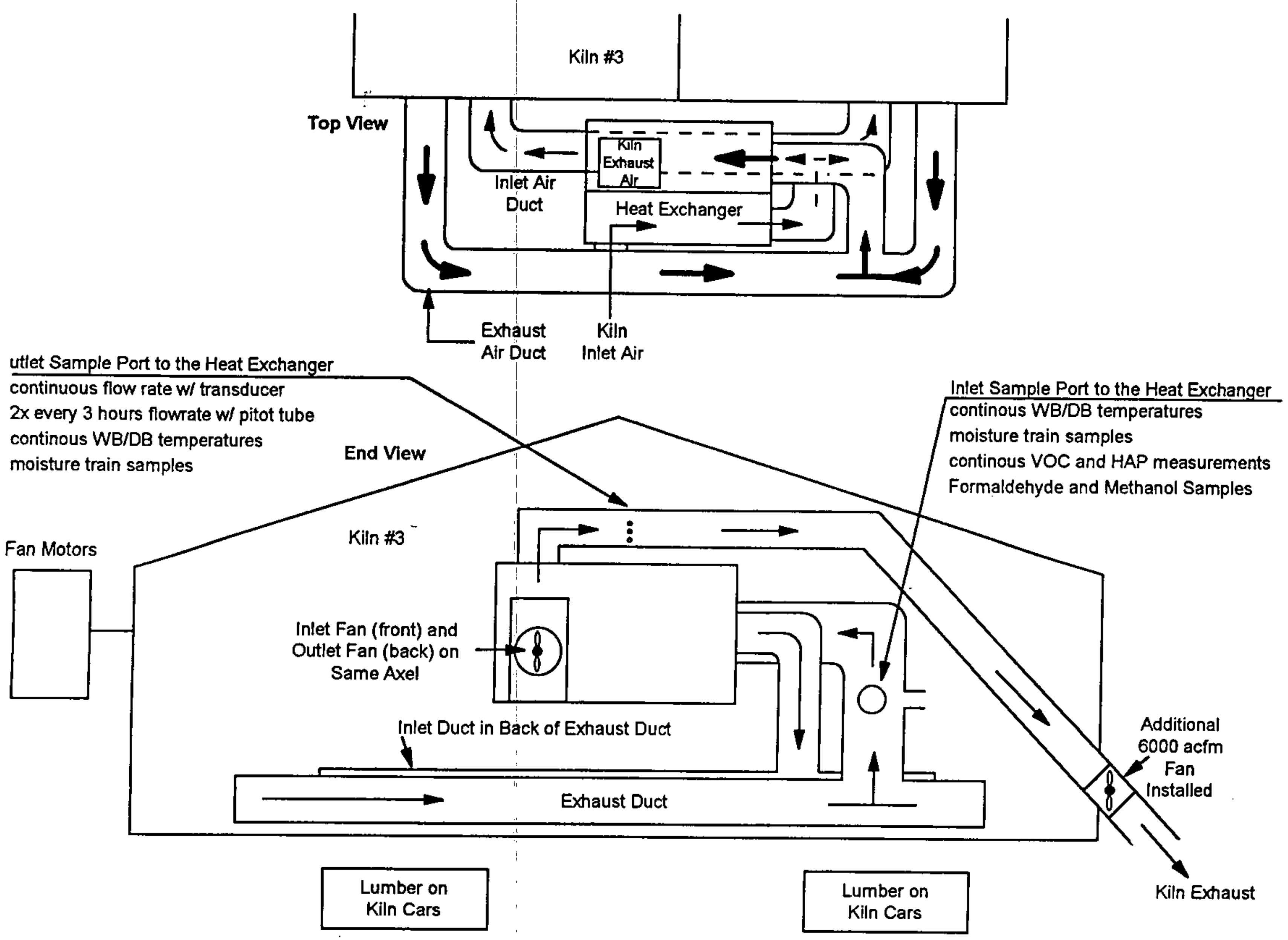


Figure 4.22. Steam-Heated Full-Scale Kiln with Vent-X-Changer System Modified for Kiln Testing

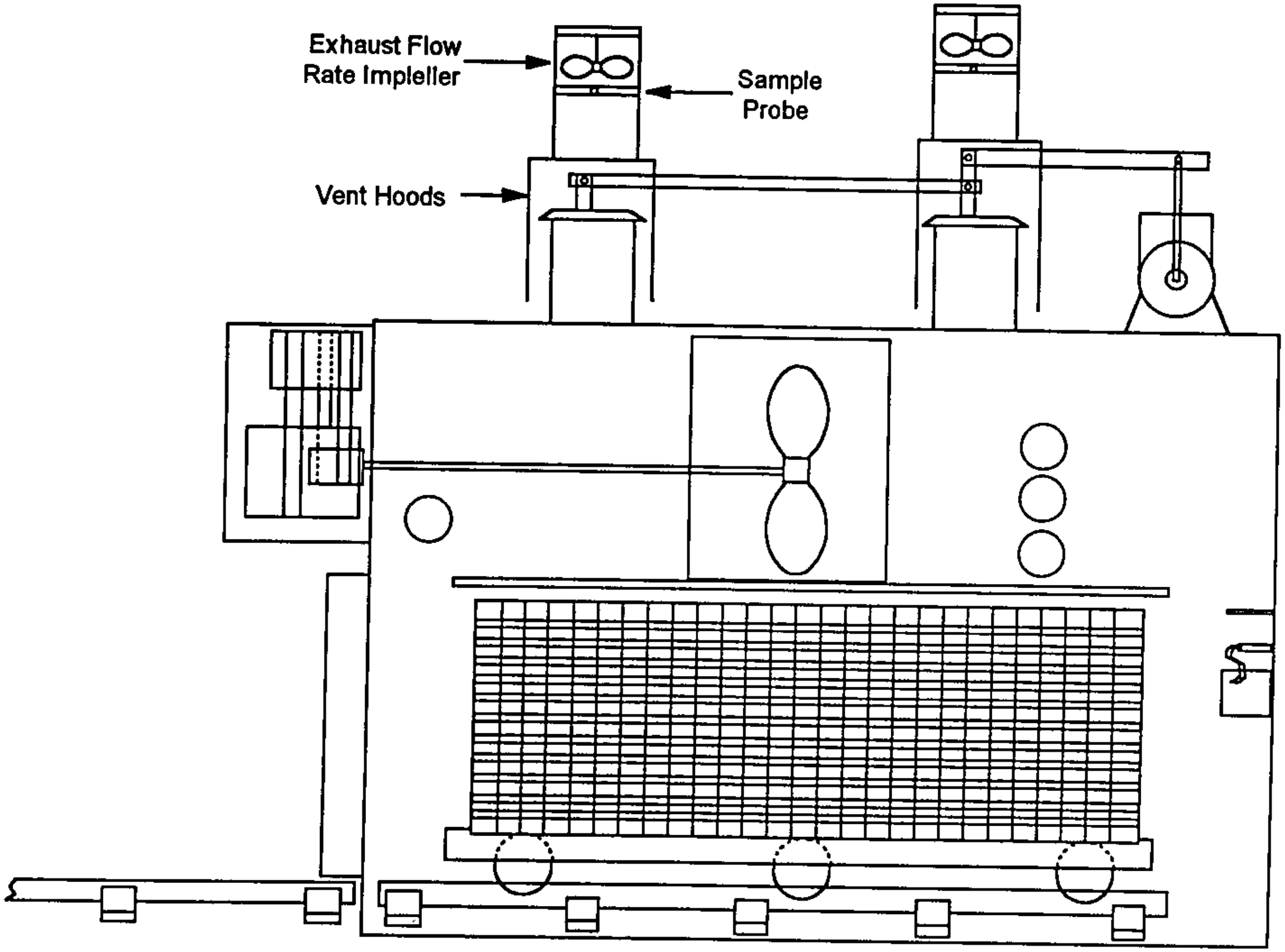


Figure 4.23. Small-Scale Kiln at NCSU Modified for Testing

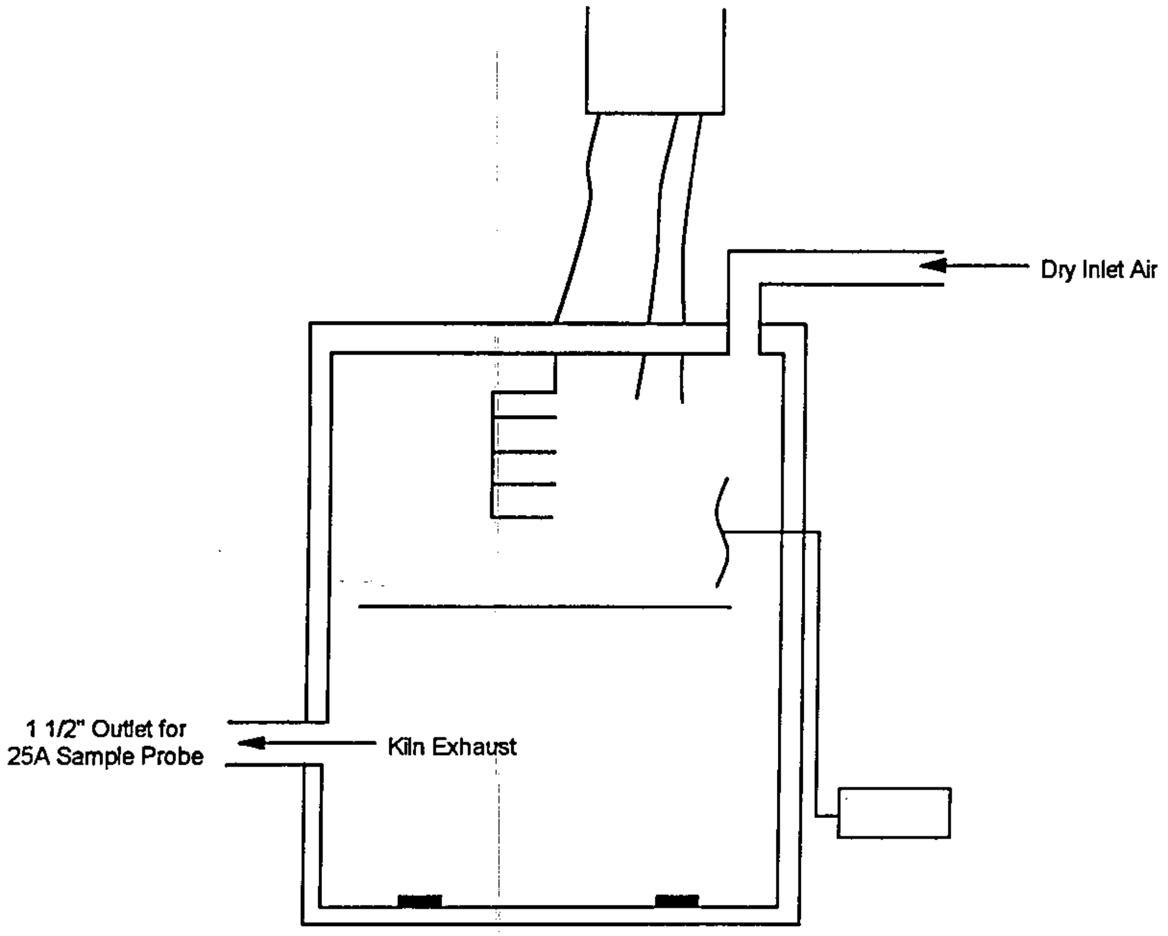


Figure 4.24. Location of the Sample Port for the Small-Scale Kiln at MSU

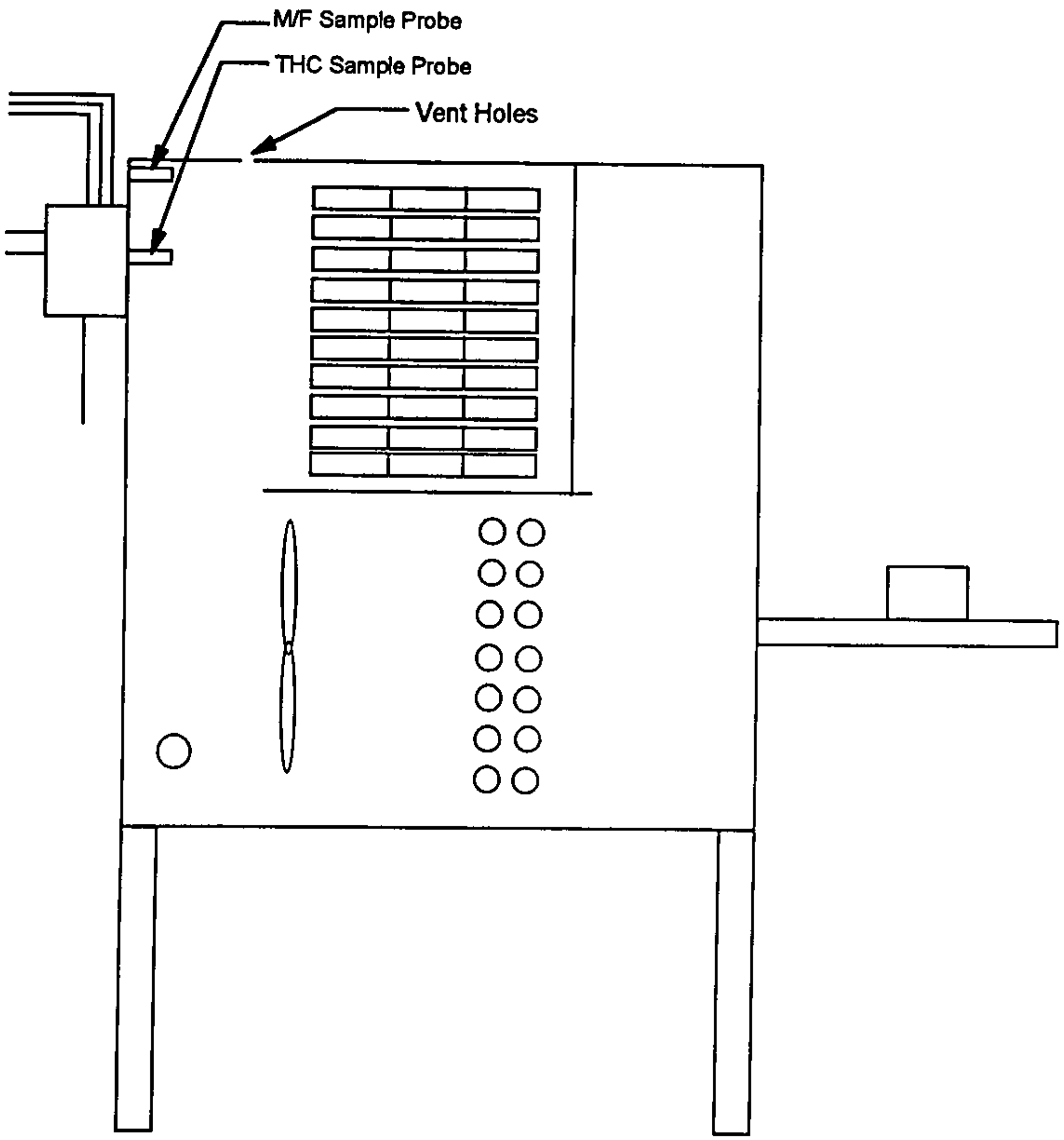


Figure 4.25. Location of the Sample Port for the Small-Scale Kiln at OSU

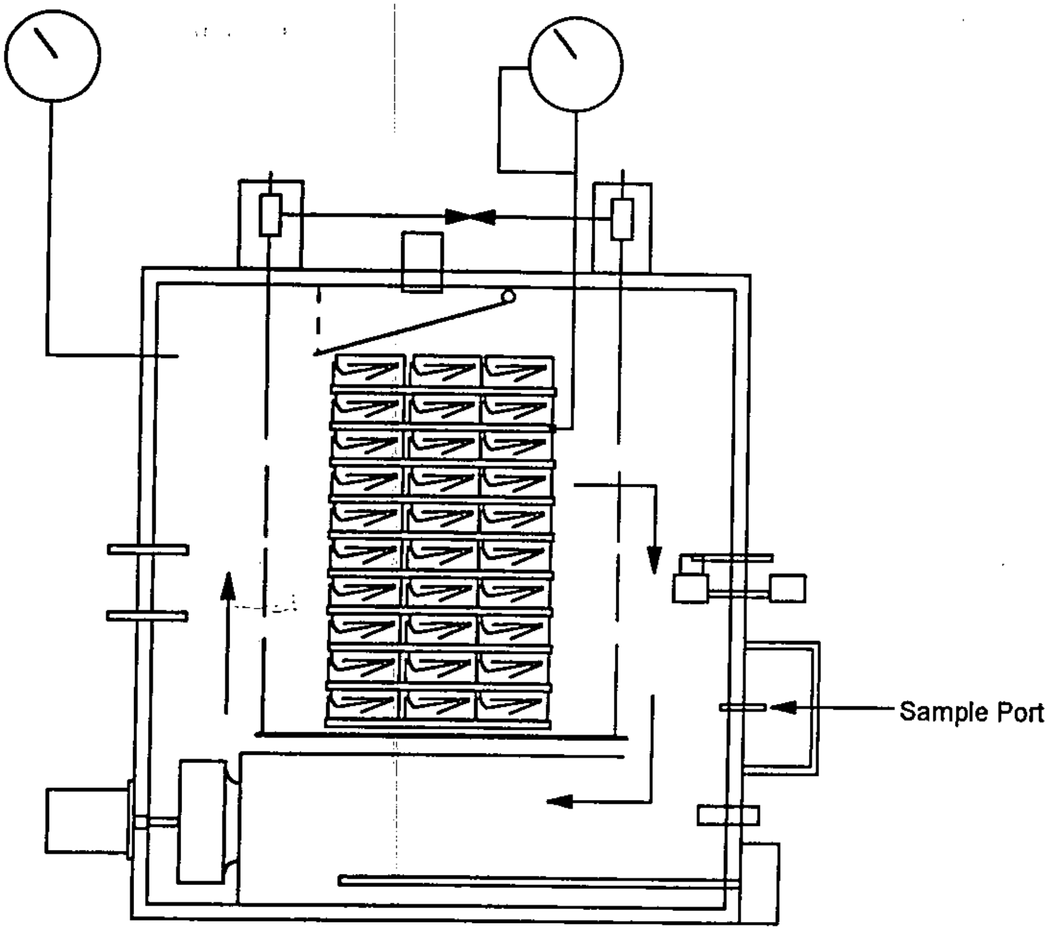


Figure 4.26. Location of the Sample Port for the Small-Scale Kiln at Horizon Engineering, Inc.

5.0 MATERIALS AND METHODS

5.1 Lumber Sampling Method

This project required lumber sampling methods capable of obtaining statistically equivalent lumber samples from the saw mills for the participating small-scale kilns. Because the Variability Study and Phase II portions of this project had different objectives, two separate lumber sampling methods were developed to achieve these separate objectives.

5.1.1 *Typical Saw Mill Operations*

The typical southern softwood saw mill receives a mix of plantation grown pine and "gate wood." The gate wood comes from a wide variety of habitats and is variable in size and age. Additionally, roundwood referred to as "southern pine" may be comprised of up to six different species.

Roundwood that is delivered to a saw mill is unloaded in a log yard to await processing. Generally there is no attempt to segregate the plantation pine from the gate wood. The roundwood pulled from the log yard is continuously mixed as it is processed into lumber. Once sawn, the lumber is sorted by dimension. In modern saw mills, an automated sorter keeps track of the number of boards sawn for any particular dimension until enough lumber has accumulated to construct a "packet" that will be used to build a kiln charge. A packet is a stack of lumber built in layers with spacers, or "stickers," placed between each layer. The layers are separated to allow the hot kiln air to pass through the charge during drying.

A southern pine lumber kiln typically takes from 18 to 28 hours to complete a drying cycle, depending on the type of dry kiln. Because the roundwood is processed continuously, the green lumber packets waiting to be kiln dried are either used to construct the next kiln charge or stacked in a green lumber storage yard.

5.1.2 *Variability Study Lumber Sampling Method*

The objective of the Variability Study was to compare the difference in the performance of five small-scale kilns drying matched batches of lumber. The lumber samples obtained for the Variability Study, therefore, had to be as similar as possible. This was achieved with significant help from the staff at G-P's Cross City, Florida, Chip-N-Saw mill and Forest Resources Area Procurement Division.

The roundwood acquired for the Variability Study was cut from a Dixie County, Florida, slash pine flatwood plantation. The age of the slash pine was 29 years. The average diameter of the tops was four inches. Five truckloads of this roundwood were delivered to the Cross City Chip-N-Saw mill. The test roundwood was marked with orange paint at the entrance gate and stored in a designated area of the log yard.

The saw mill emptied the production line of all existing lumber to accommodate the sawing of the test roundwood. This allowed the test roundwood to be processed in a batch, thereby ensuring the integrity of the origin of the test lumber. The test lumber was then stacked, without stickers, by the automated stacker and moved to a designated staging area where the lumber could be sorted into five differently sized sample piles. The small-scale kilns that participated in the Variability Study were MSU (30 BF), OSU (70 BF), Horizon Engineering (50 BF), and NCSU (1500 BF). The fifth kiln was FPL, Madison (1250 BF).

The lumber sampling method for the Variability Study is described below in three steps:

Step 1: Determine the Minimum Number of Test Boards

The table below summarizes the computations used to determine the minimum number of sample boards required by each small-scale kiln. An extra charge was sent to each small-scale kiln so that a trial run could be conducted to ensure that the kilns could match the operating parameters designated by this study. The trial run also provided a test of the kiln measurement equipment.

Small-Scale Kiln	Kiln Capacity (BF)	No. of Kiln Charges Required	Total No. of BF	No. of Boards Required*
MSU	30	4	120	22.5
Horizon Engineering	60	5	300	56.25
OSU	75	4	300	56.25
FPL Madison	1250	4	5000	937.5
NCSU	1500	4	6000	1125

*Volume of wood per 2"x4"x96" is 768 inches^3

Step 2: Determine the Actual Number of Test Boards Required

The actual number of boards delivered to each of the small-scale kilns was adjusted to the number that would fit appropriately onto 3-by-8 foot pallets. The table below shows the results of the calculation based on each pallet having a layer nine boards wide.

Small-Scale Kilns	No. of Boards Required	No. of Layers Required	No. of Layers Rounded	No. of Boards Delivered	No. of Pallets Required
MSU	22.5	2.5	4	36	1
Horizon Engineering	56.25	6.25	8	72	1
OSU	56.25	6.25	8	72	1
FPL Madison	937.5	104.17	106	954	7
NCSU	1125	125	128	1152	8

Step 3: Sort the Test Lumber into Five Equivalent Sample Batches

The method developed to sort 2,286 boards into five equivalent sample batches required that the lumber be arranged in columns. The columns, consisting of a specified number of boards, were randomly color coded for each small-scale kiln. The coded boards were then sorted into separate piles according to the color scheme for each small-scale kiln.

Ordinarily the mechanical lumber stacker places stickers between each layer of lumber that is stacked. For this method, however, the stickers were not used and the lumber was "dead stacked." The height of the dead stack was determined by the small-scale kiln with the least number of boards. In this case, MSU required 36 boards, so the height of the dead stack was restricted to 18 boards. This insured that MSU would get at least two random columns of lumber.

With each column of lumber restricted to 18 boards high and the total number of boards determined to be 2,286, the total number of lumber columns required for this method was calculated to be 127. The table below shows the number of columns and color code assigned to each small-scale kiln.

Small-Scale Kiln	Kiln Capacity (BF)	No. of Boards Delivered	No. of Lumber Columns Required	Color ID
MSU	30	36	2	Yellow
Horizon Engineering	60	72	4	Gray
OSU	75	72	4	Green
FPL Madison	1250	954	53	Orange
NCSU	1500	1152	64	Blue

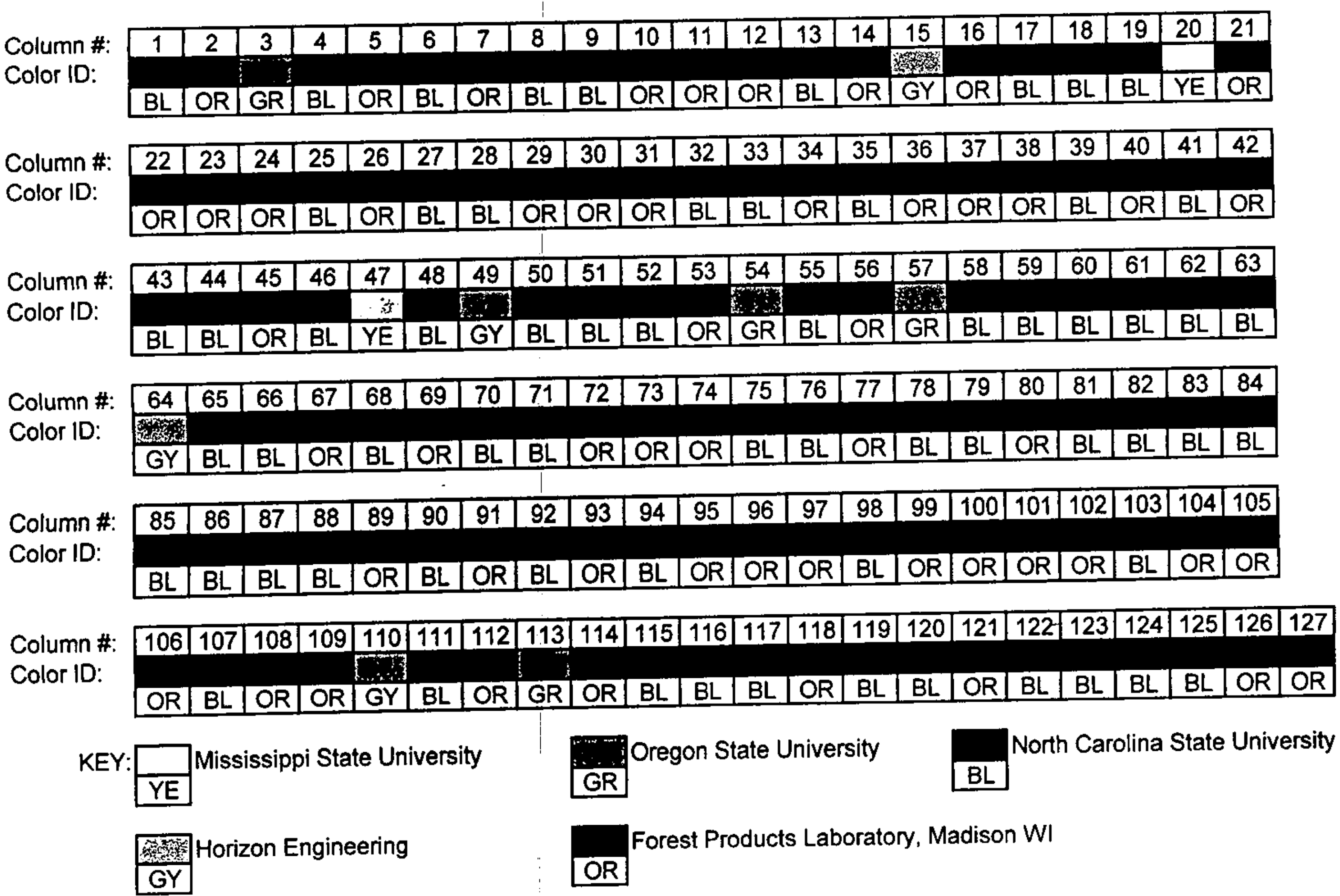
In a spreadsheet, each of the 127 columns of lumber was assigned a color code in proportion to the amount of lumber needed by each small-scale kiln. Each column/color code combination was then assigned a random number as shown in Table G.1, Appendix G. Next, the random number/column number/color code combinations were sorted by arranging the random numbers in numerical order. This step randomized the column/color code combinations.

At the saw mill, the 127 columns of lumber, each 18 boards high, were color coded according to the spreadsheet results as shown in Figure 5.1. This was done by starting at column 1 and painting each of the 127 columns in the order shown. For example, the first column was colored blue and assigned to NCSU and the fifty-fourth column was colored green to be delivered to OSU. After the columns were colored appropriately, the lumber was segregated into the five separate sample batches by color and stacked on pallets for transport to the small-scale kilns.

5.1.3 *Phase II Lumber Sampling Method*

The Phase II lumber sampling method had a different objective than the method used for the Variability Study. The method developed for Phase II was designed to obtain representative small-scale lumber charges from each full-scale charge tested. The method also had to extract lumber from two different saw mill process lines.

The Idabel, Oklahoma, saw mill facility had three simultaneously operating direct-fired kilns. The lumber packets for these kilns came from a single stacking operation, and no attempt was made by the facility to designate individual packets for any particular kiln. The lumber packets were usually constructed of different dimensions and were stored in a green lumber yard until needed. When enough packets of a certain dimension were available in the green lumber yard, the packets would be



Column #:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Color ID:	■	■	▨	■	■	■	■	■	■	■	■	■	■	■	▒	■	■	■	■	□	■
	BL	OR	GR	BL	OR	BL	OR	BL	BL	OR	OR	OR	BL	OR	GY	OR	BL	BL	BL	YE	OR

Column #:	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Color ID:	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	OR	OR	OR	BL	OR	BL	BL	OR	OR	OR	BL	BL	OR	BL	OR	OR	OR	BL	OR	BL	OR

Column #:	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
Color ID:	■	■	■	■	□	■	▒	■	■	■	■	▨	■	■	▨	■	■	■	■	■	■
	BL	BL	OR	BL	YE	BL	GY	BL	BL	BL	OR	GR	BL	OR	GR	BL	BL	BL	BL	BL	BL

Column #:	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Color ID:	▒	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	GY	BL	BL	OR	BL	OR	BL	BL	OR	OR	OR	BL	BL	OR	BL	BL	OR	BL	BL	BL	BL

Column #:	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
Color ID:	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	BL	BL	BL	BL	OR	BL	OR	BL	OR	BL	OR	OR	OR	BL	OR	OR	OR	OR	BL	OR	OR

Column #:	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
Color ID:	■	■	■	■	▒	■	■	▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	OR	BL	OR	OR	GY	BL	OR	GR	OR	BL	BL	BL	OR	BL	BL	OR	BL	BL	BL	BL	OR	OR

KEY:
□ YE Mississippi State University
▨ GR Oregon State University
■ BL North Carolina State University
▒ GY Horizon Engineering
■ OR Forest Products Laboratory, Madison WI

Figure 5.1. Color Code Scheme for the Variability Study Lumber Samples

transferred to kiln cars to become part of a kiln charge. Kiln charges were generally stacked and ready 24 to 48 hours prior to charging the kiln.

The saw mill facility in Bay Springs, Mississippi, also had one stacking operation for three simultaneously operating steam-heated kilns, but the stacking process was conducted differently. Because of the limited operating space at this facility, the kiln charges for each kiln were constructed approximately 12 hours prior to charging the kiln.

The kiln operators at both facilities accommodated this project by drying either 2-by-4 or 2-by-6 dimensioned lumber in the kilns tested. The lengths of the packets, however, varied from 8 feet to 20 feet.

A certain number of boards were randomly removed from each packet prior to the automated stacker. The sample board(s) and packet constructed were marked with the same unique identification number. The length of the board was also indicated on the sample board(s).

The sample boards selected from each packet were stacked with stickers and stored outside in a similar way the packets were treated for each full-scale kiln charge. Once the full-scale kiln test charge was assembled, the packet numbers were recorded and the sample boards with the corresponding numbers were selected for processing. The configurations of the full- and small-scale kiln lumber charges are shown in Appendix G, Tables G.2 through G.13.

The theory behind this representative lumber sampling method was to assemble the small-scale kiln charges from the same kind of lumber that comprised the full-scale kiln charges. By incorporating pieces from the different lengths of lumber into the small-scale kiln charges, it was thought that there would be a greater potential for including any age or structural differences in the wood. For example, Table 5.1 shows the configuration of the first direct-fired full-scale kiln charge

Table 5.1. FSK DF1 Lumber Charge Configuration

Packet Dimensions (in x in x ft)	No. of Packets in Charge	% Makeup of the Charge
2 x 6 x 10	3	8
2 x 6 x 12	6	18
2 x 6 x 14	6	21
2 x 6 x 16	6	24
2 x 6 x 18	3	14
2 x 6 x 20	3	15

Table 5.2 shows the number of pieces required from each of the lumber samples pulled from the first direct-fired test charge. Note that pieces from each type of sample board went into the small-scale kiln charge so that the make-up of the charge approximates the make-up of the full-scale kiln.

Table 5.2. OSU and MSU Charge Configurations for DF1

Lengths of the Lumber Samples	MSU DF1 (No. of 24-inch Pieces)	MSU DF1 (% Makeup in Charge)	OSU DF1 (No. of 48-inch Pieces	OSU DF1 (% Makeup in Charge)
10	1	7	1	5
12	3	20	4	20
14	3	20	4	20
16	4	27	5	25
18	2	13	3	15
20	2	13	3	15
Total	15		20	

As mentioned in the Kiln Description section, the length of the MSU charge was 23 inches, and the length of the OSU charge was 44 inches. For convenience, the sample board sizes were cut in either 24-inch or 48 inch-lengths to fit on standard 4-by-4 foot pallets. After the 48-inch long lumber samples were divided into the small-scale kiln sample charges, the charges were stacked on 4x4 shipping pallets, shrink-wrapped and stored for transport in a refrigerated trailer.

5.2 Volatile Organic Compound Measurement Systems

The emissions of total hydrocarbons or VOCs were measured using a total hydrocarbon analyzer (THA) equipped with a flame ionization detector (FID). The VOC measurement system withdraws samples continuously and conveys a diluted sample gas stream to the THA. Heated components maintain the gas stream at 250°F, or above, to avoid condensation of water vapor within the measurement system.

The standard VOC sampling protocol (Appendix H) provides details on the various components of the VOC measurement system. The actual measurement systems configured for use at the small-scale and full-scale kilns were inspected and approved prior to conducting the sampling efforts. A brief description of each configuration is provided below.

The measurement system constructed at MSU is shown in Figure 5.2. MSU modified their VOC measurement system to conduct leak checks and flow rate measurements through a test port connected to the sample probe. The standard sampling protocol recommends that leak checks be conducted at the three-way leak check valve at the rear of the VOC analyzer. MSU, however, pulled a vacuum on the measurement system at the test port with a hand-held pump to check for leaks. The flow rate measurements were also obtained through the test port instead of at the sample probe as the sampling protocol recommends. Another modification to the MSU measurement system was that the delivery lines for the dilution air and the calibration gases joined together to a common line before entering the heated filter box. The dilution air delivered to the heated filter box came from the same air source as the kiln's inlet air.

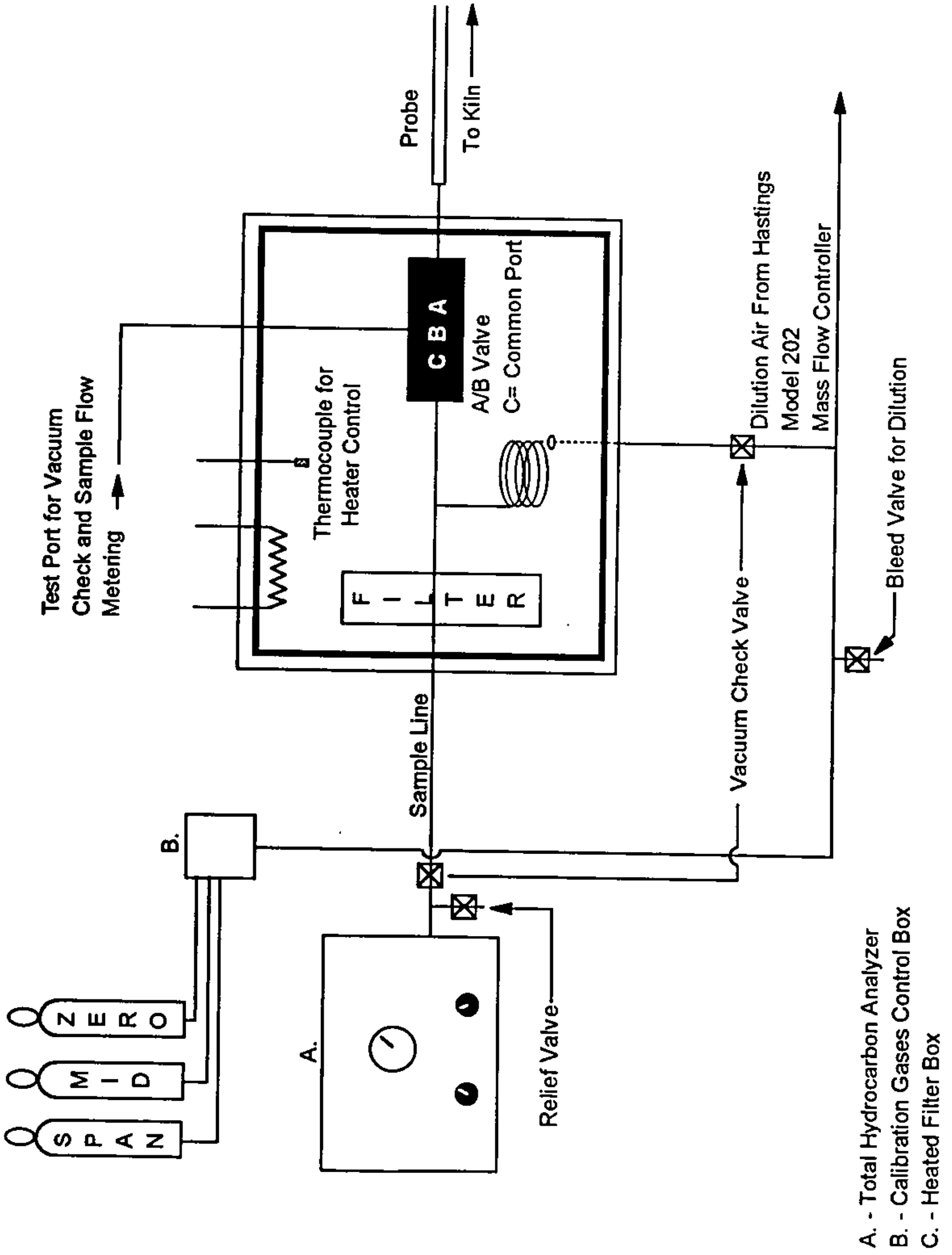


Figure 5.2. MSU VOC Measurement System

The heated sample probe and filter box assembled by OSU and Horizon Engineering, Inc. (HE) are shown in Figures 5.3 and 5.4. The sample probes were inserted directly through the kiln wall into the kiln, and the filter boxes were attached to the side of the kilns. The calibration gases and dilution air were delivered through separate lines to the heated filter box. HE and OSU measured flow rates in the same manner as MSU, but the leak checks were conducted near the VOC analyzer as shown in Figures 5.4 and 5.5.

DEECO configured a different VOC collection system that enabled them to sample from both of the modulating kiln vents at the NCSU small-scale kiln. The collection system consisted of two sampling stacks and two VOC measurement systems. Customized sample stacks were placed over each vent (Figure 5.6). Each stack housed a rake-type sample probe and a propeller anemometer. The propeller anemometer measured the exhaust gas velocity from the kiln and was periodically dried with nitrogen gas. For each stack, a short section of heated sample line conveyed the sample gas from the sample probe to a heated head pump located close to the stack (Figure 5.7). The pump then delivered the sample gas through a heated sample line to a stainless steel dilution chamber under positive pressure. Nitrogen gas was used to dilute the stack gas before being introduced into the VOC analyzer. The calibration gas line for each VOC measurement system was connected to the junction of the heated sample line and sample probe. DEECO performed leak checks by drawing nitrogen through the measurement system and analyzing for oxygen.

WESTON's VOC measurement systems were very similar to the system described in the VOC sampling protocol for sample lines greater than 50 feet in length (Figure 5.8). For the first three direct-fired kiln charges (FSK DF1 through FSK DF3), one VOC measurement system was set up to sample the burner output prior to entering the kiln, and a separate VOC measurement system measured the exhaust from the kiln stacks.

The sample probe measuring the kiln exhaust was always placed in the primary venting stack. When the kiln fans reversed directions, the sample probe was removed from one stack, the measurement system was calibrated, and the sample probe was placed in the second stack, which had commenced to vent.

This sampling plan was modified for the kiln charges FSK DF4 through FSK DF6 so that one measurement system was dedicated to each stack. With this new arrangement, every time the kiln fans reversed directions, one system could be brought off-line for calibration and the other system would commence sampling.

The sampling system at the steam kiln also had two complete VOC measurement systems for the kiln exhaust, but concentration was only measured at the inlet to the heat exchanger. For this case every 3 hours one system was removed from the sample port for calibration while the second system, having been previously calibrated, was replaced in the same sample port.

5.2.1 *Total Hydrocarbon Analyzers*

Shown below are the THAs used in the various measurement systems during the Variability Study and Phase II sampling efforts:

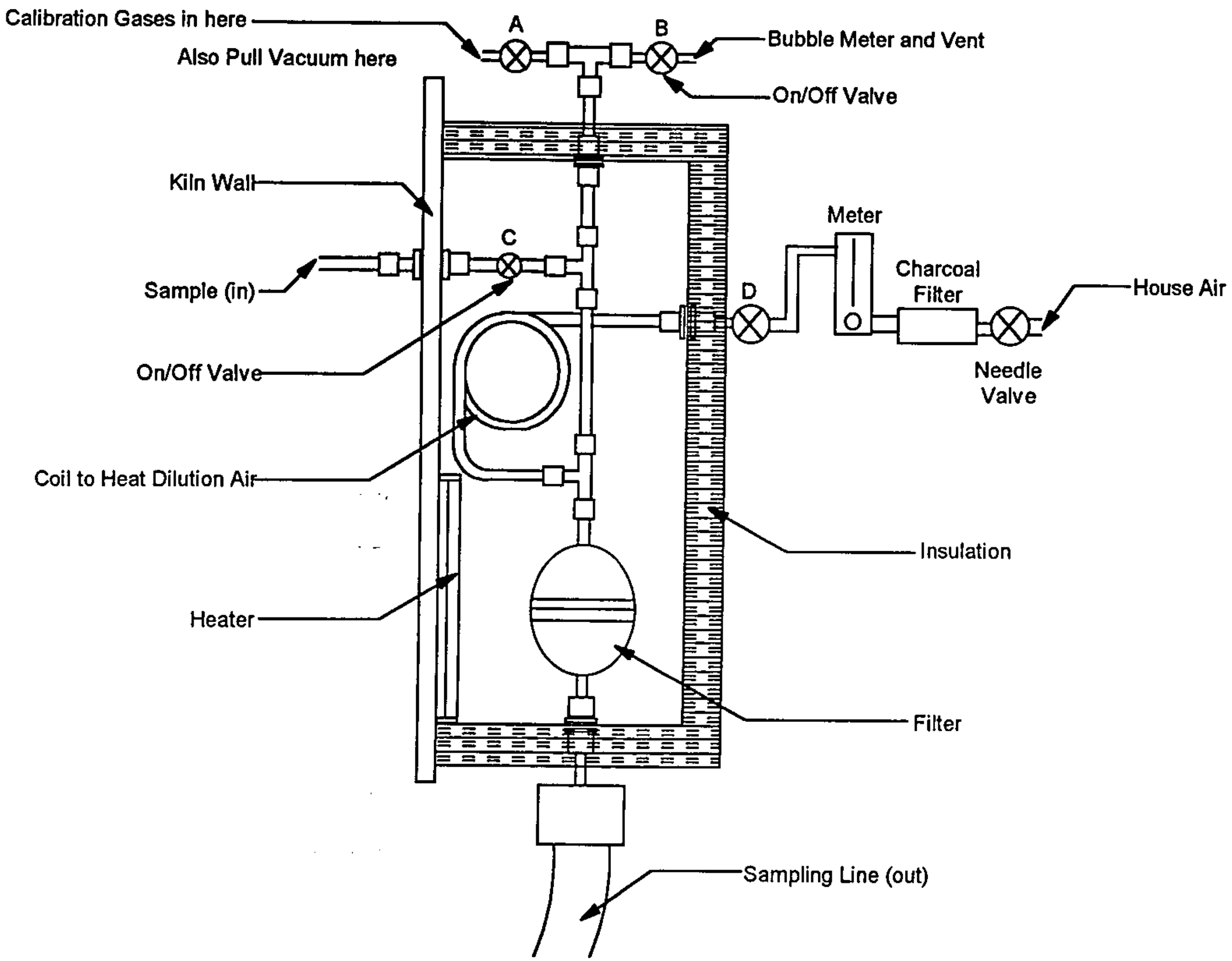


Figure 5.3. OSU VOC Measurement System

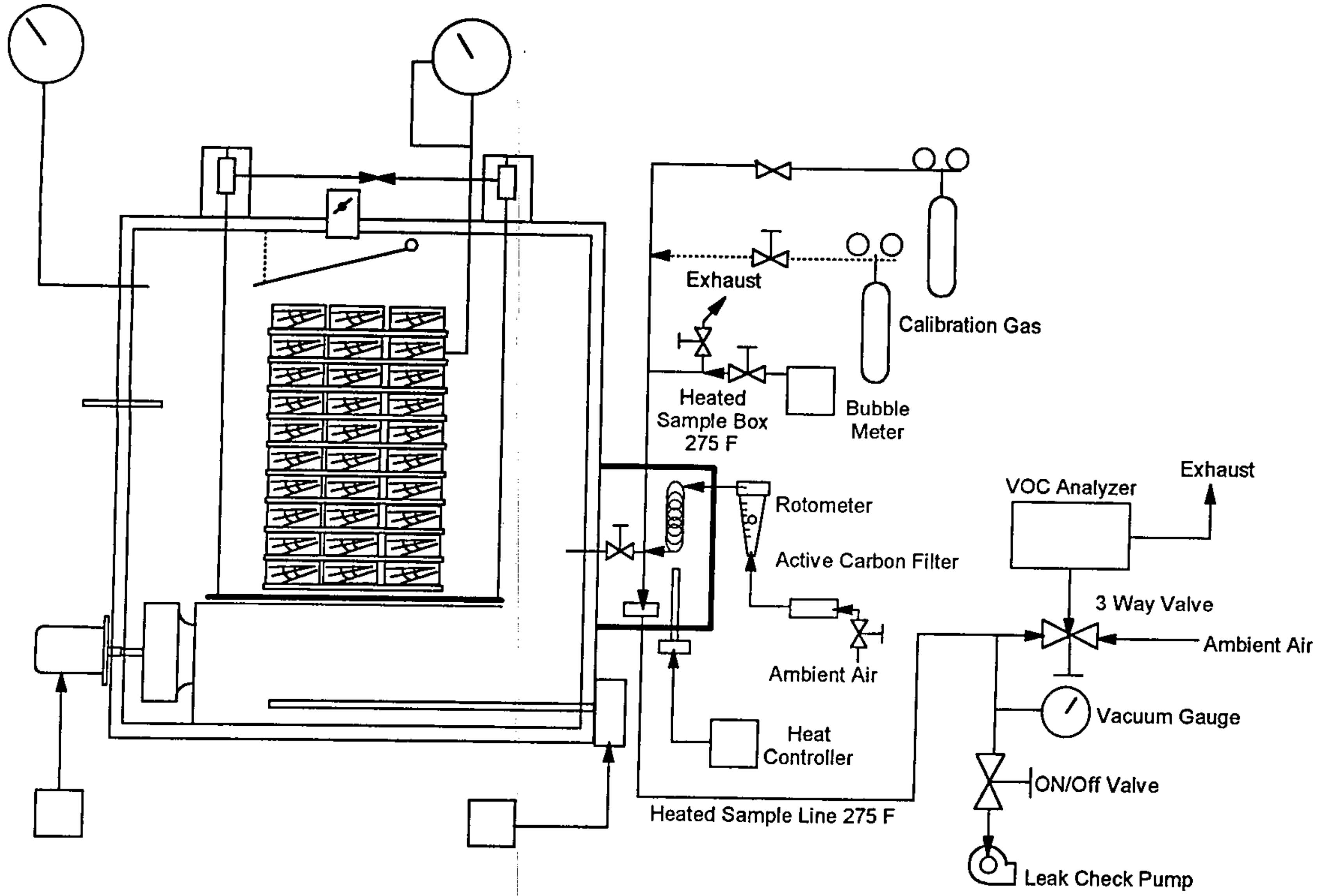


Figure 5.4. Horizon Engineering VOC Measurement System

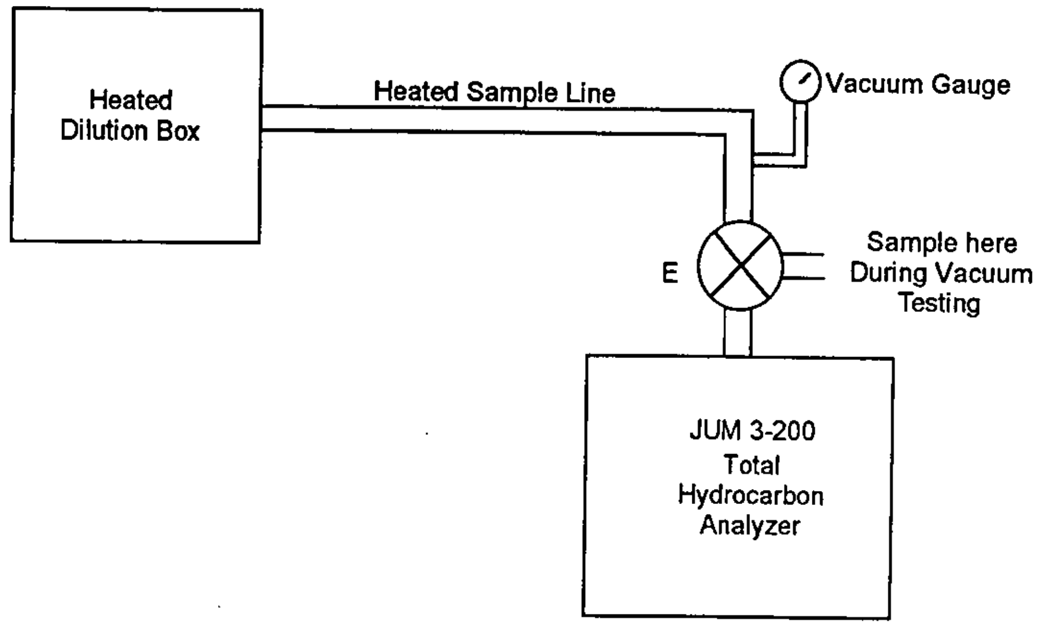


Figure 5.5. Leak Check Configuration for the OSU VOC Measurement System

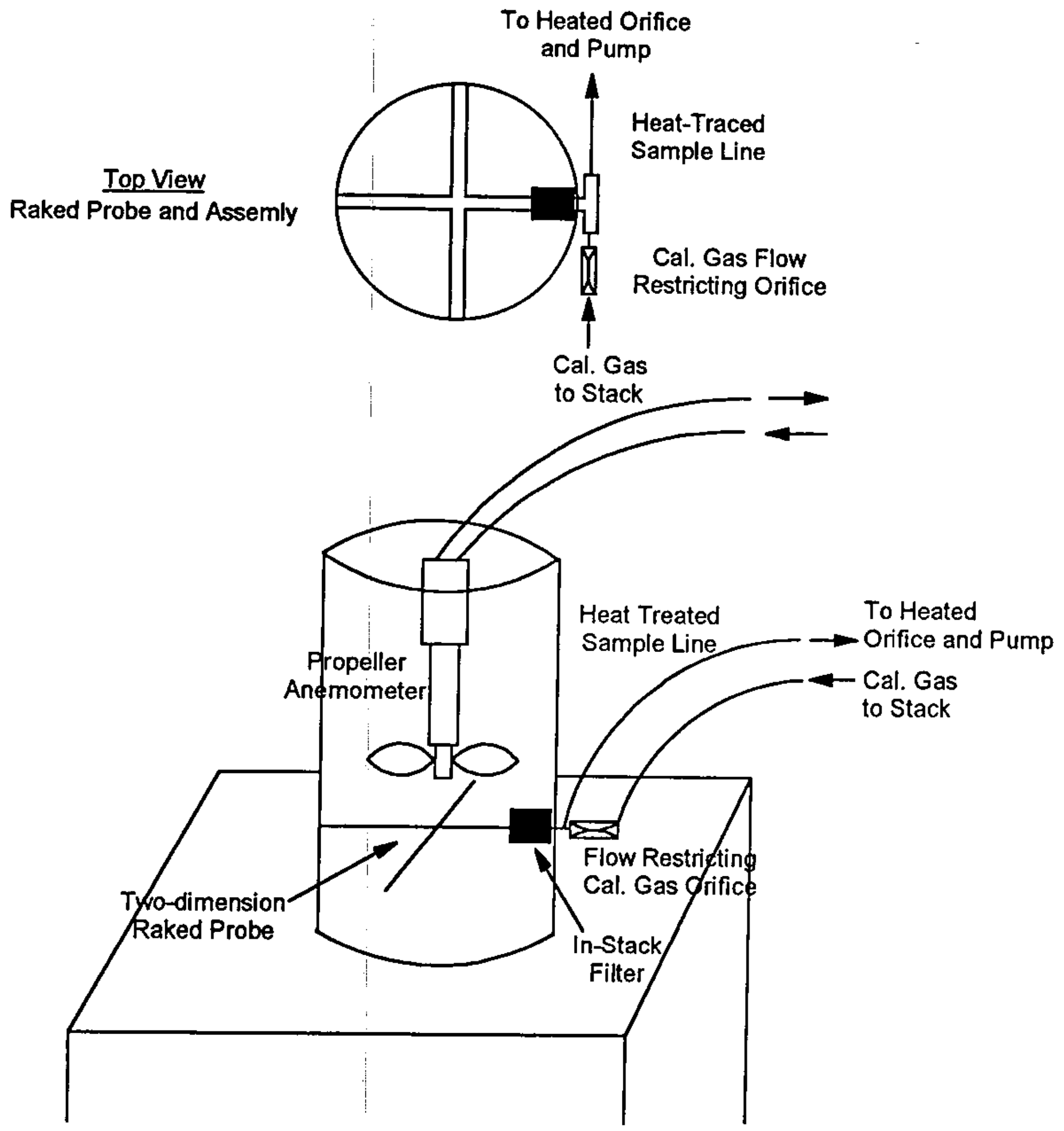


Figure 5.6. Schematic of DEECO's Stack Extension, Raked Probe, and Anemometer

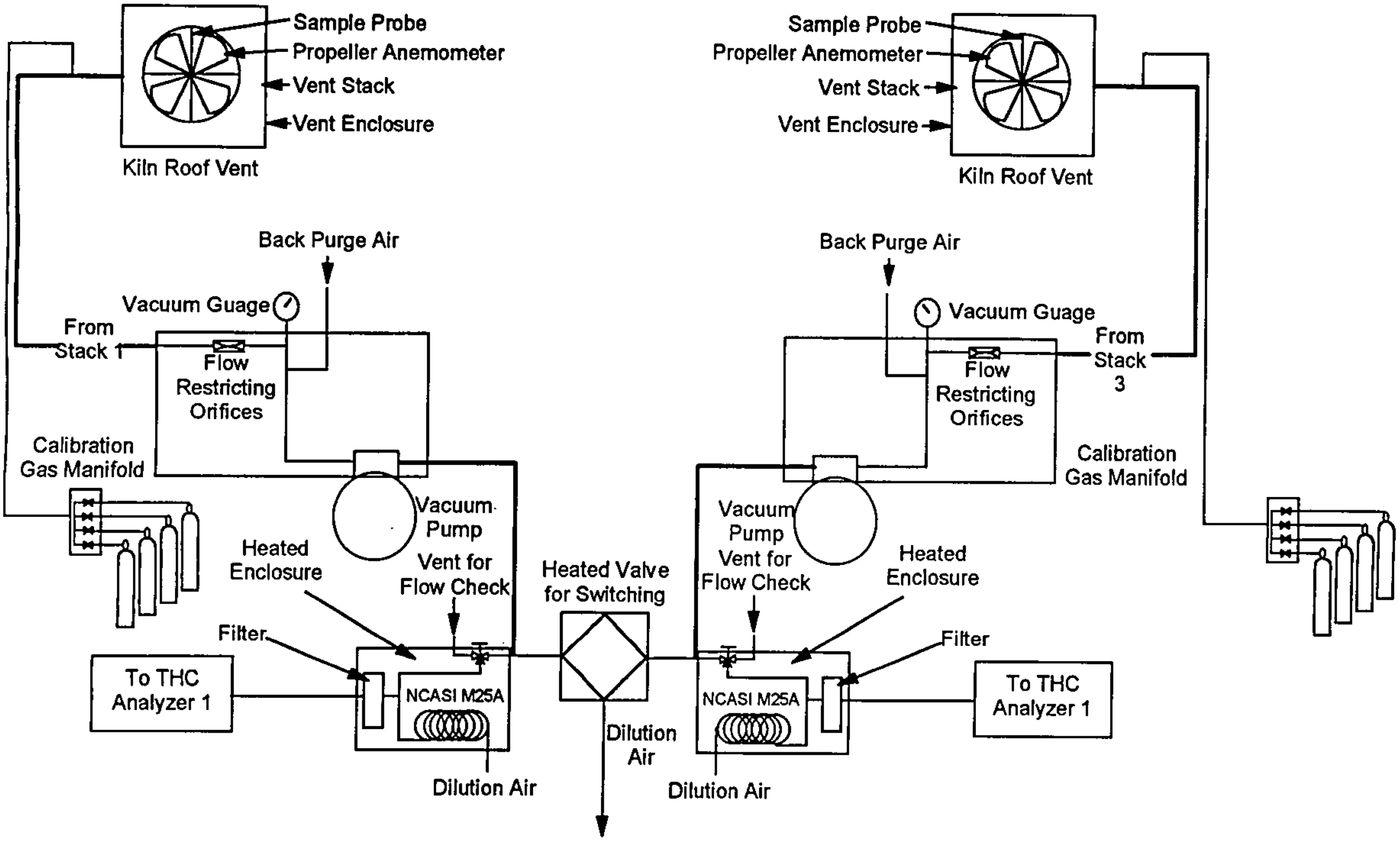


Figure 5.7. DEECO's VOC Measurement System

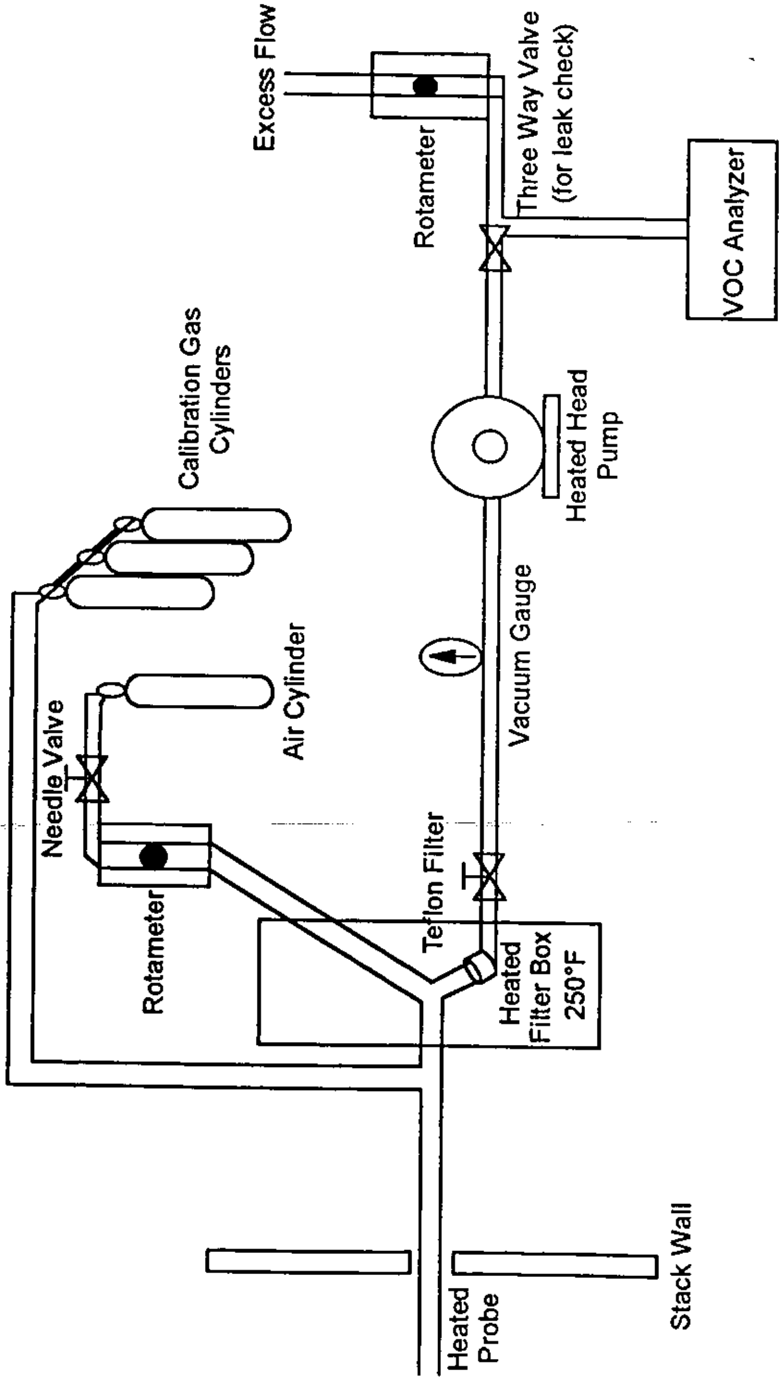


Figure 5.8. WESTON's VOC Measurement System

	Type of VOC Analyzer	Type of Datalogger	Type of Fuel
MSU	TECO Model 51	PC with Keithley Metrabyte DAS 1601 Card/Test Point Software	Hydrogen
OSU	JUM 3-200	PC with software developed by OSU	Hydrogen
HDHE	TECO Model 51	PC with Keithley Metrabyte DAS 801 Card/Test Point Software	Hydrogen/ Helium
NCSU/DEECO	JUM Model VE-7	Molytek Model 2702 Analog/ Digital Datalogger	Hydrogen/ Helium
WESTON	JUM Model VE-7	PC with software developed by WESTON	Hydrogen

5.3 Formaldehyde and Methanol Sampling Systems

This project used a modified version of the NCASI Chilled Impinger Method as the standard sampling protocol for formaldehyde and methanol. This protocol has been included in Appendix I.

As with the VOC measurement system, there were slight differences between the chilled impinger trains configured for this project and the system recommended by the standard protocol. The variations in measurement systems have been summarized below:

- MSU and DEECO substituted a dry gas meter for the rotameter at the end of the sampling train (Figures 5.9 and 5.10).
- OSU measured the flow rate of the sample system with a rotameter located at the front end of the system (Figure 5.11).
- HE replaced the Teflon® sample probe with a 3/8th inch stainless steel probe (Figure 5.12).
- The sampling train configured by WESTON included the additional inline pump shown in Figure 5.13.

5.4 NCASI Impinger/Canister Sample Collection Train

In addition to determining the mass emission rates for VOCs, formaldehyde, and methanol, the scope of work developed for this project required that one full-scale and two small-scale kiln charges be assessed for the following selected compounds:

Acetaldehyde
Acrolein
Benzene
Methyl ethyl ketone
Methyl isobutyl ketone
Phenol
Propionaldehyde
Styrene
Toluene
m & o-Xylenes

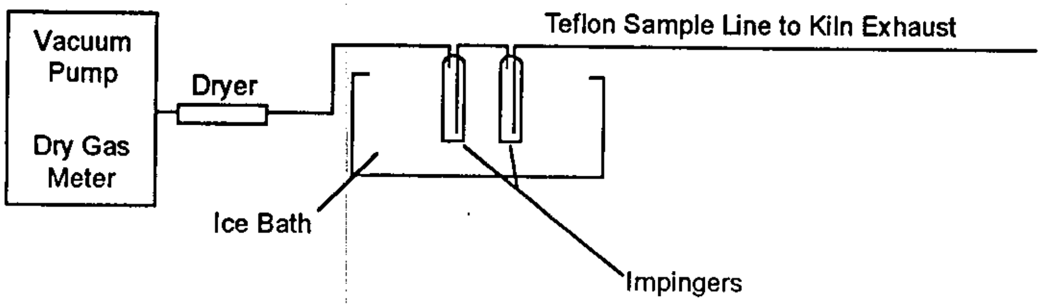


Figure 5.9. Formaldehyde and Methanol Sampling Train used by MSU

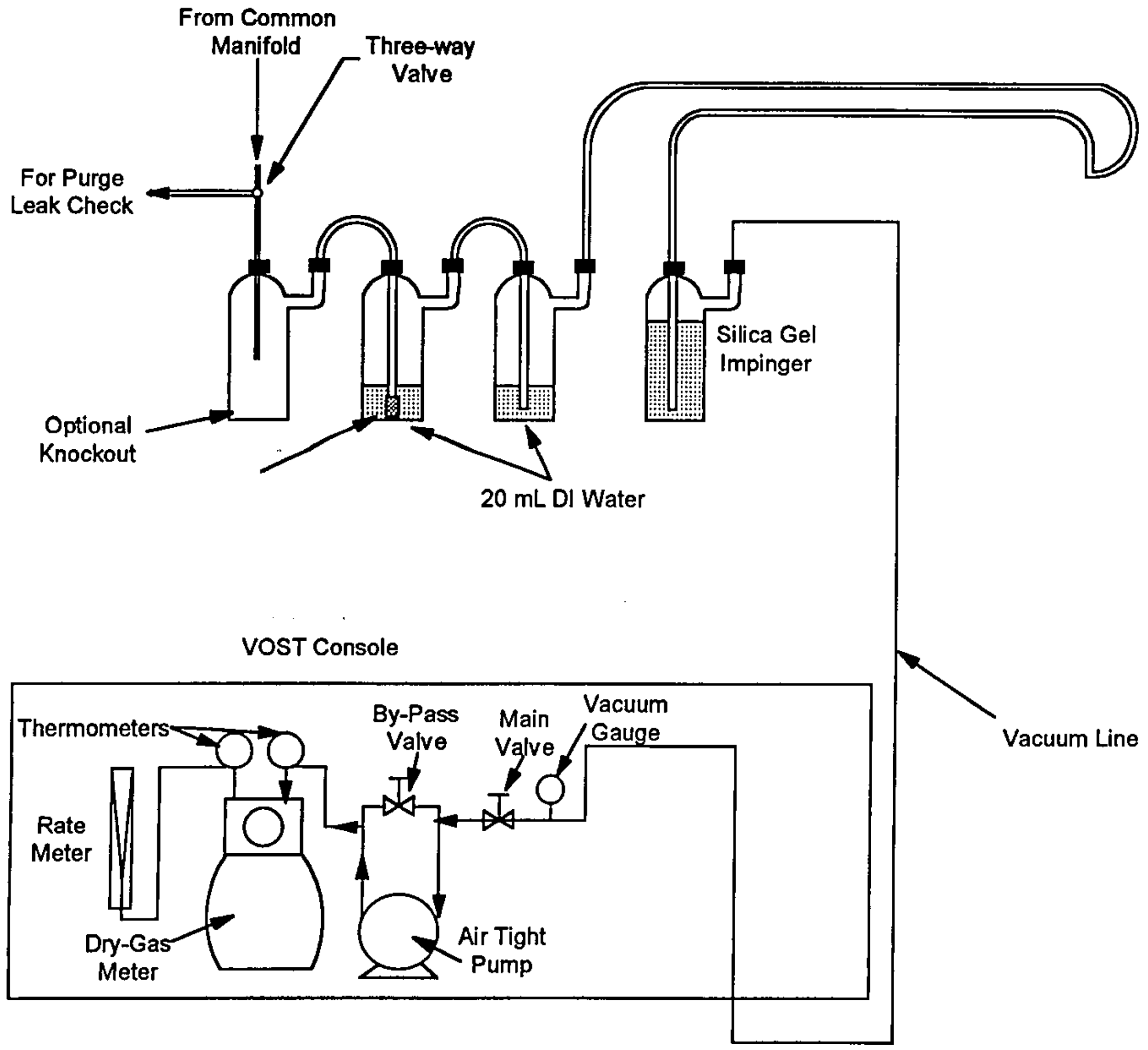


Figure 5.10. Formaldehyde and Methanol Sampling Train used by DEECO

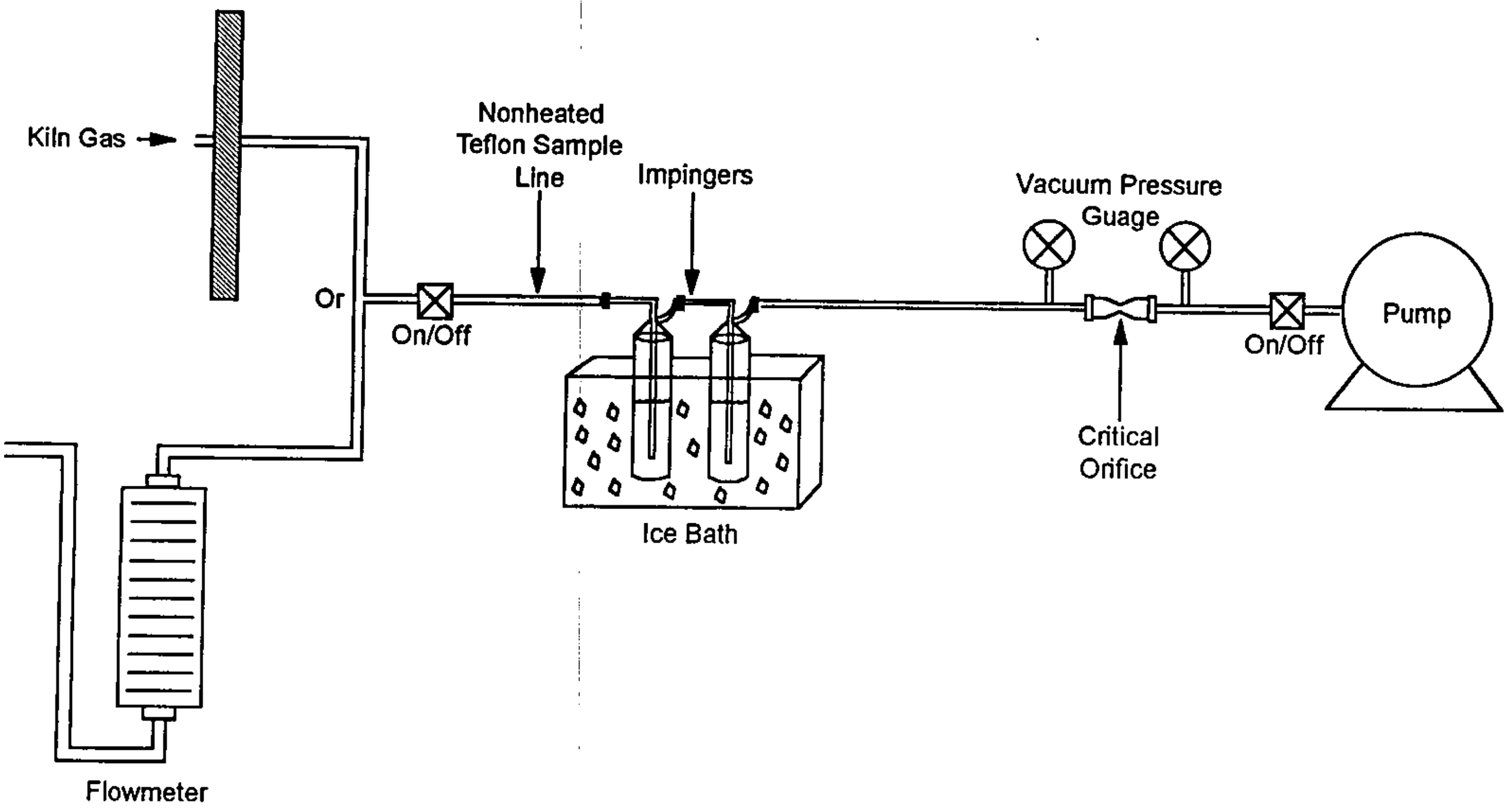


Figure 5.11. Formaldehyde and Methanol Sampling Train used by OSU

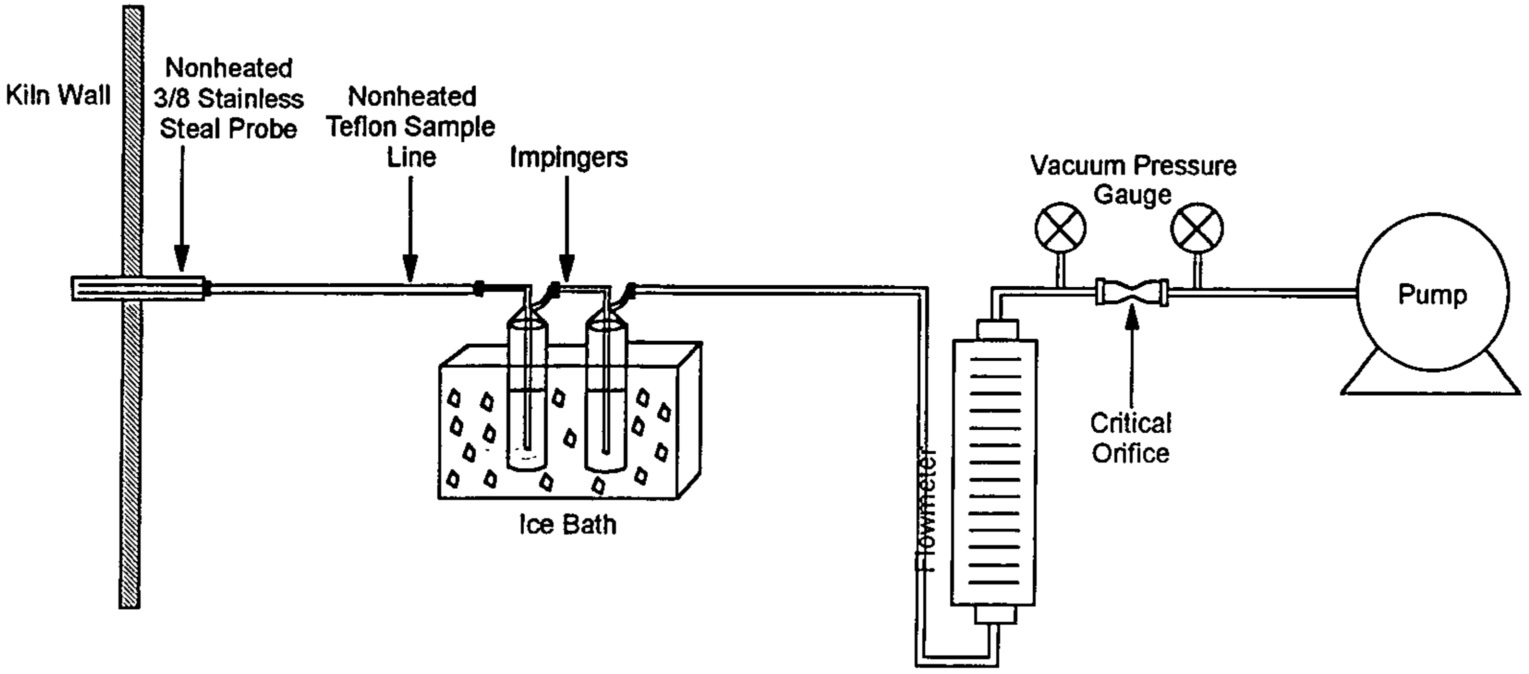


Figure 5.12. Formaldehyde and Methanol Sampling Train used by Horizon Engineering

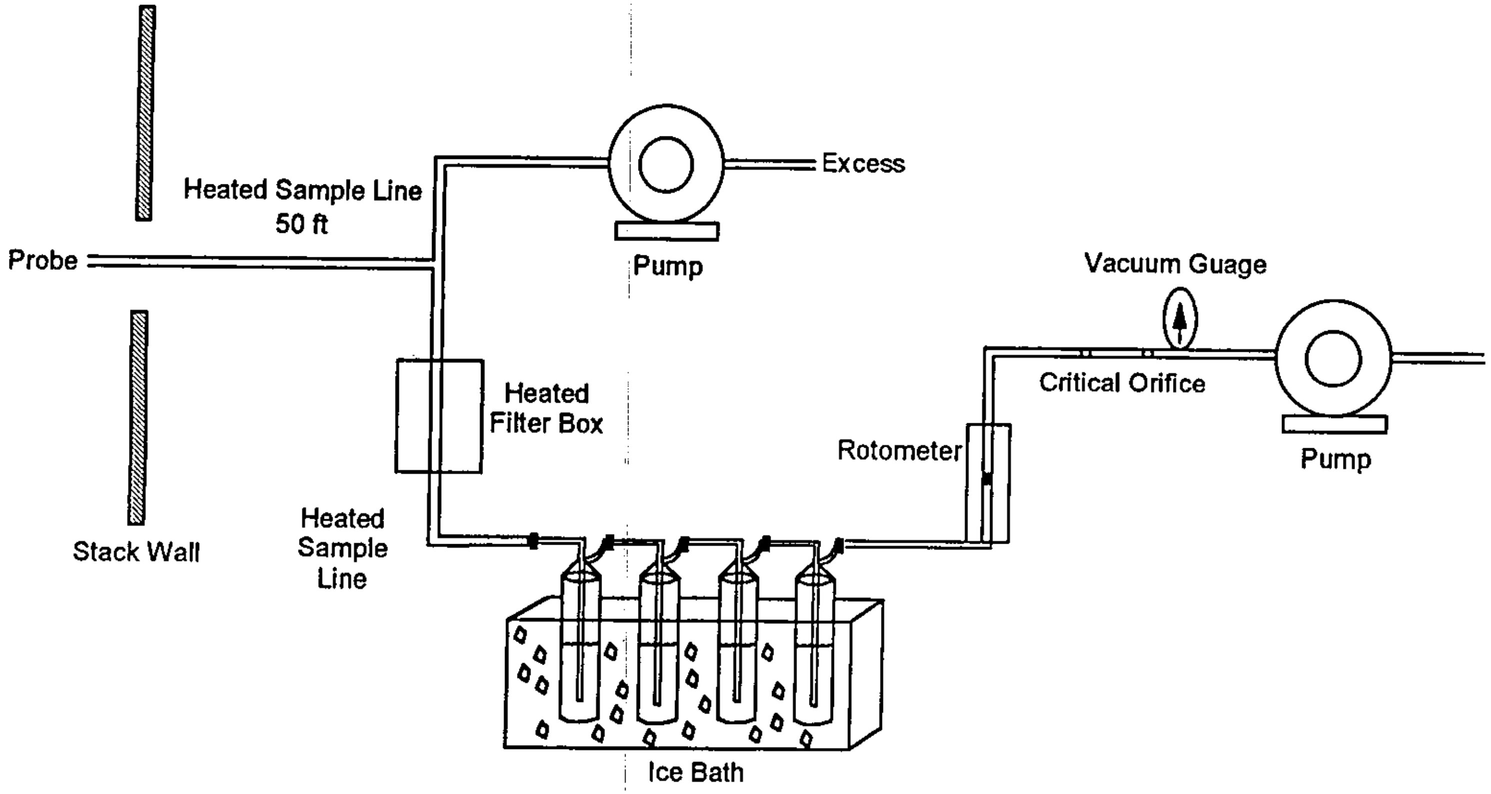


Figure 5.13. Formaldehyde and Methanol Sampling Train used by WESTON

The measurement method used to collect samples of compounds was based on the NCASI Impinger/Canister Method. The sample collection system consisted of a series of aqueous impingers followed by a 6.0 L polished stainless steel SUMMA™ canister. This sampling train and configuration is designed to separate compounds according to each compound's solubility in water. The water soluble compounds are captured in the aqueous impingers, the moderately water soluble compounds are split between the impinger and canister, and the non-water soluble compounds are captured in the canister.

One small-scale kiln charge was sampled at NCSU by DEECO for the speciated VOC compounds during the Variability Study. DEECO developed an extensive kiln gas collection system (Figure 5.14) that pulled enough sample gas from the kiln exhaust to supply two THAs, a formaldehyde/methanol sampling train, a PVOC sampling train, an EPA Method 4 moisture train, a GC/FID analysis system, and the impinger/canister sampling train. The heated valve shown in Figure 5.14 regulated which stack supplied sample gas to a common heated glass manifold. The front end of DEECO's impinger/canister sampling train was connected to one of the outlets from the common manifold by a Teflon® sample line with three chilled midget impingers arranged in series. The first impinger served as a moisture knockout, and deionized (DI) water was added to the second and third impingers. A fritted stem was placed in the second impinger to improve gas/liquid contact. A portion of the dry sample gas leaving the third impinger went to the evacuated SUMMA™ canister. The flow rate to the canister was maintained at 33 mL/min by a metering valve that required manual adjustment as the canister pressure increased over the three-hour sampling period. The remaining sample gas went to a dry gas meter where the sample volume of the system was measured. Figure 5.15 shows a diagram of this measurement system.

One steam kiln and one OSU kiln charge were sampled for speciated VOCs during Phase II. The front end of the NCASI sampling train (Figure 5.16) consisted of a heated probe, filter box (maintained at 250°F), and a Teflon® sample line that was followed by a set of three chilled midget impingers in series. DI water was placed in the first two impingers and a fritted stem was used in the first impinger. The impingers were followed by a flow meter, a critical orifice, and a Teflon® head pump to draw the stack gas through the system. The purpose of the critical orifice was to maintain a consistent flow rate through the aqueous impingers. A portion of the exit gas from the pump was routed to the evacuated SUMMA™ canister. The flow rate to the canister was maintained at 33 mL/min by a manually controlled needle valve and rotameter. The canister pressure was monitored by an inline digital pressure gauge.

5.5 Standard Procedure for Calculating Mass Emission Rates

The primary objective of this project was to determine the feasibility of using small-scale kilns to predict mass emission rates from full-scale southern pine lumber kilns. In order to achieve this objective, standard sampling protocols were developed to measure mass emission rates of VOCs and the other selected compounds specified. Measured mass emission rates are reported in terms of lb/MBF of lumber.

The standard sampling protocols issued to the small-scale kilns for the Variability Study did not specify a procedure for calculating mass emission rates. Consequently, results reported by the small-scale kilns were not directly comparable due to different calculation methods. Variability in reported mass emission rates was due, in part, to the following differences:

- Data for the initial 3-hour warm-up period were not collected by all facilities.
- Different methods were used to fill in data gaps created during calibration periods.

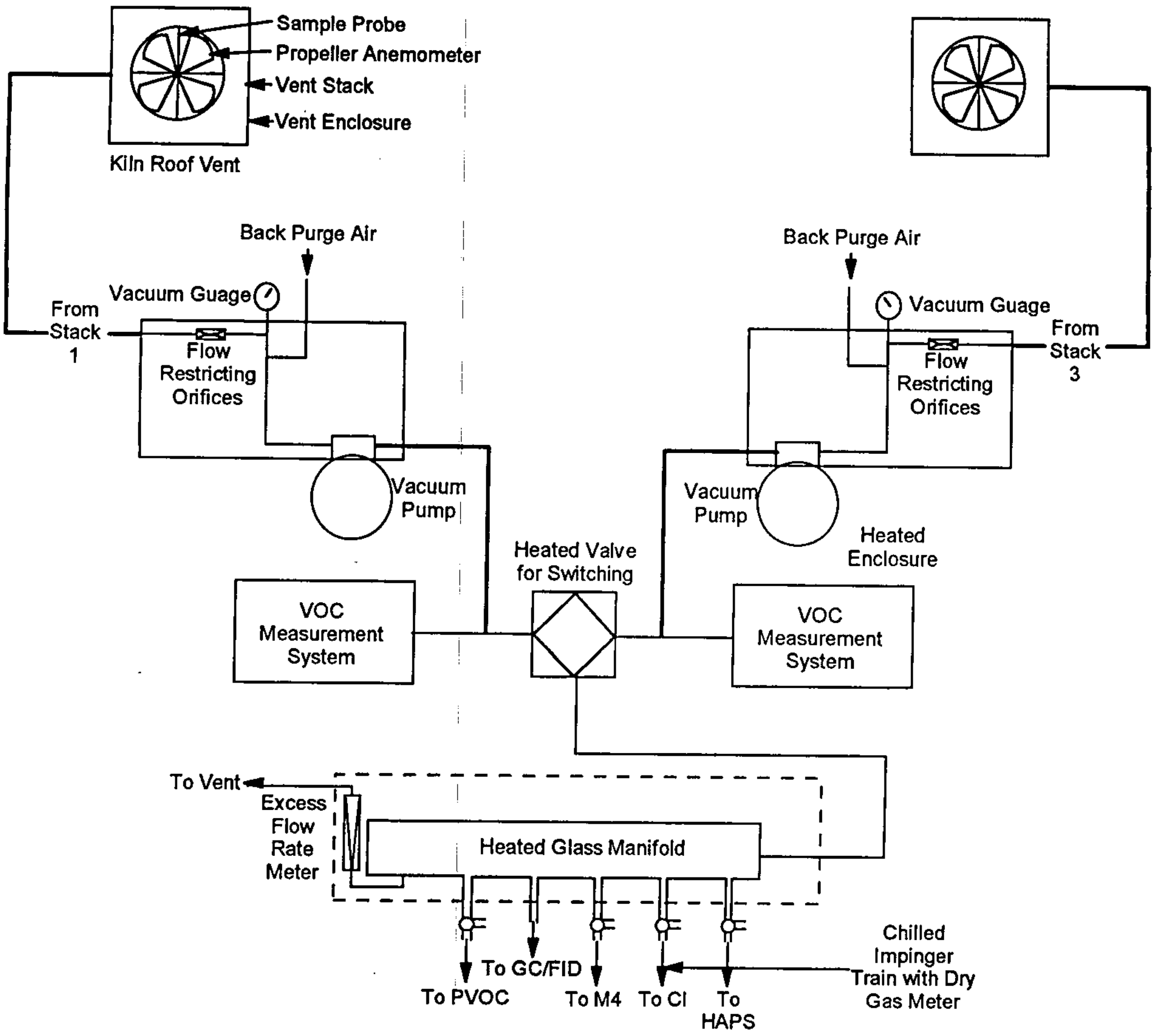


Figure 5.14. Kiln Gas Coll[illegible] System used by DEECO

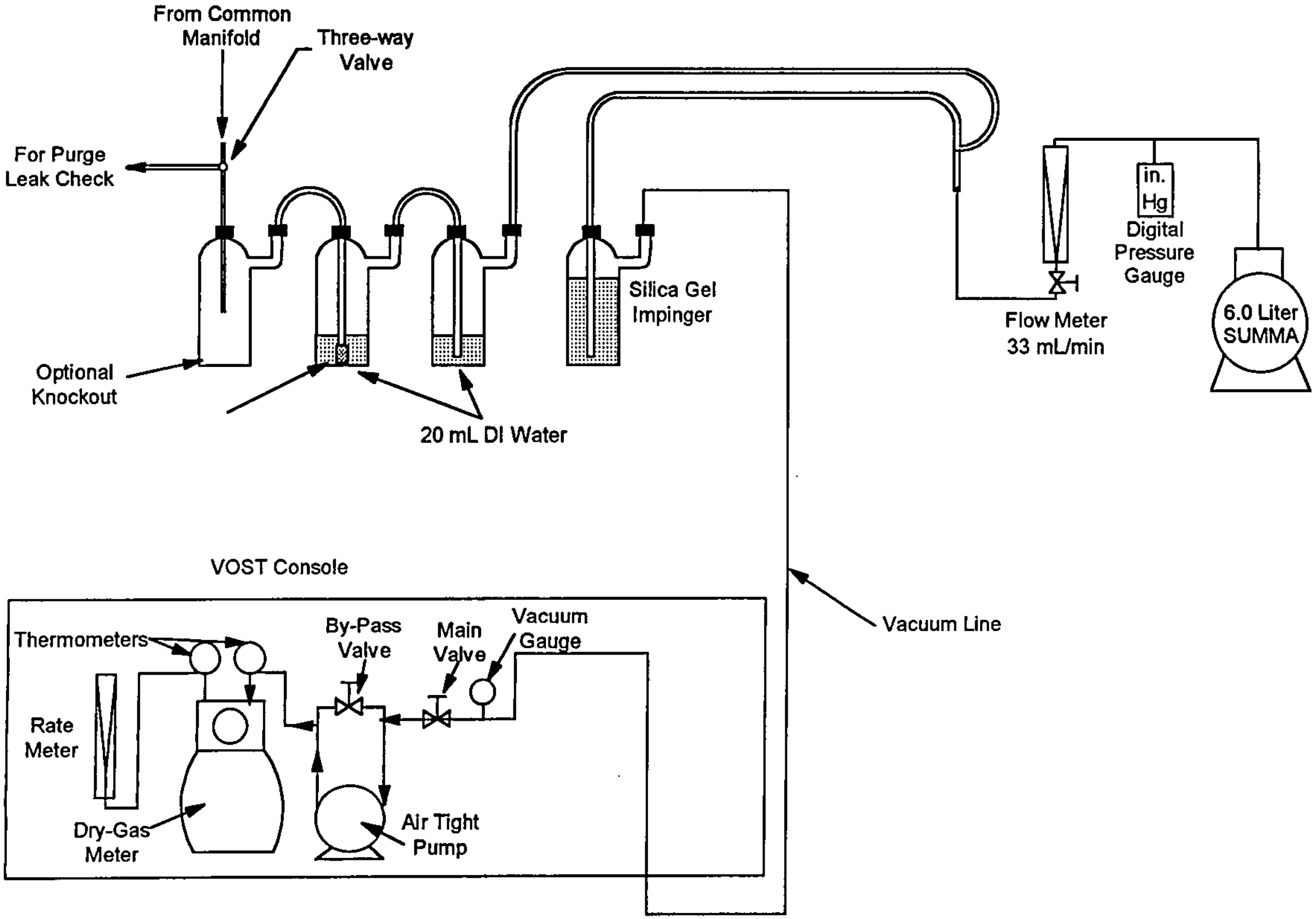


Figure 5.15. HAP Sampling Train used by DEECO

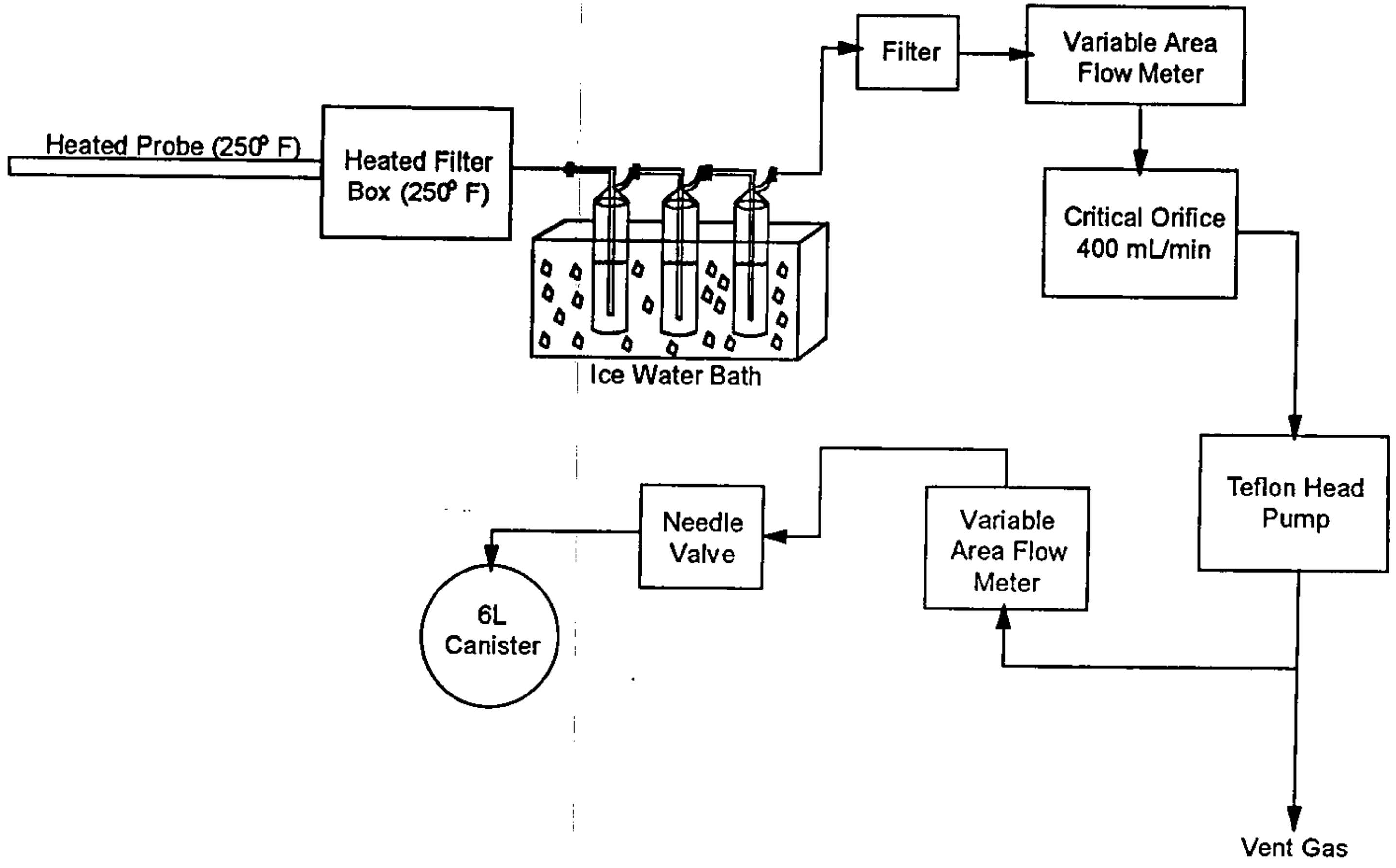


Figure 5.16. NCASI Combined Impinger and Canister Sampling Train

- Different standard temperatures were used.
- Different approaches were used to determine the moisture content of the lumber which affected the termination point of the data.
- Different equations were used for determining the moisture content by volume of the kiln exhaust which in turn yielded different results for the same wet/dry bulb temperatures.
- Different methods were used to evaluate the overall final mass emission rate values (lb target compound/MBF).

In reviewing the various approaches used during the Variability Study, it became apparent that two standard calculation procedures were needed to evaluate the VOC and impinger/canister data in a consistent manner to yield comparable mass emission rates. Thus procedures were developed to standardize the results obtained from the Variability Study and Phase II portions of this project. Those procedures were based on the following four parameters:

1. the concentration of target compound in the kiln exhaust gas;
2. a dilution ratio which was based on two calibration values, the undiluted span concentration and the diluted span concentration (VOC data only);
3. the lumber kiln exhaust flow rate standardized to 1 atmosphere and 68°F; and
4. the percent moisture content by volume (v/v) of the kiln exhaust gas.

These four parameters were either measured or calculated and used in Equation 1 (for VOCs) and Equation 2 (for the impinger/canister compounds) to determine the mass emitted from the kiln over each sample interval. The sample interval for most of the VOC data was one minute. The sample interval for the impinger/canister data ranged from 40 minutes to 3 hours.

$$\frac{\begin{array}{c}\text{lb VOC}\\ \text{as carbon}\end{array}}{\text{sample interval}} = \frac{\text{THA concentration}}{10^6} \times \text{dilution ratio} \times \frac{\text{exhaust flow rate}}{\text{sample interval}} \times \frac{\text{lb mole}}{385.5\text{ scf}} \times \frac{12\text{ lb carbon}}{\text{lb mole}}$$

[Equation 1]

$$\frac{\begin{array}{c}\text{lb of target}\\ \text{compound}\end{array}}{\text{sample interval}} = \frac{\begin{array}{c}\text{concentration of}\\ \text{target compounds}\end{array}}{10^6} \times \frac{\text{average exhaust flow rate}}{\text{sample interval}} \times \frac{\text{lbmole}}{385.5\text{ scf}} \times MW_{\text{target compound}}$$

[Equation 2]

The mass calculated from either of the above equations was divided by size of the lumber charge to yield an incremental mass emission rate per MBF. The incremental values were then summed over the duration of the drying cycle to calculate the total mass emission rate per MBF.

All of the data, calculations, and results have been compiled on the compact disk that accompanies this report. There are two directories in the compact disk, one for the Phase I Variability Study data and one for the Phase II data. Within each directory, there are multiple sub-directories that organize the data by the different kiln facilities and drying cycles. The spreadsheets that present the data for each drying cycle begin with the raw data that were collected and end with the resulting mass emission rate for that cycle. The majority of the effort put into each spreadsheet went to manipulating the measured data into the four standard parameters used in Equations 1 and 2 above. A detailed description of the various procedures used to manipulate the data will not be covered in this report because of the complexities involved. Those procedures can be examined by accessing the information on the compact disk.

The information presented below, however, will provide an overview of the methodology that went into transforming the reported data from the six kilns into mass emission rates of VOCs and impinger/ canister compounds.

5.5.1 *Standard Procedure for Calculating the VOC Concentration*

The four parameters required for the standard VOC calculation procedure were the THA concentration, the dilution ratio, the kiln exhaust flow rate, and the exhaust gas moisture content by volume. These parameters were either measured or calculated on a per minute basis except for the data from OSU. The data from OSU was measured at intervals less than one minute and reported as three minute averages.

5.5.1.1 The THA Concentration Parameter

The concentration of VOCs was measured by a total hydrocarbon analyzer (THA) in parts per million (ppm) of propane on a wet basis for all cases, except the data collected by Horizon Engineering, which was in terms of carbon. Additionally, the THA response represented the diluted VOC concentration of the sampled gas in all cases except the data collected by DEECO. DEECO adjusted their THA output to yield an undiluted propane response.

During a site visit conducted prior to the first three test charges at the direct-fired kiln, it was determined that the kiln exhaust concentration would be measured from one of the two stacks that was actively venting the kiln. During the testing of the first kiln charge (FSK-DF1), however, significant kiln exhaust was observed from the "non-venting" stack (fugitive stack). A limited assessment of the difference in concentration between the exhaust gas from the venting and fugitive stacks was conducted 6.5 hours (Table J.1, Appendix J) and 10 hours (Table J.2, Appendix J) into the drying cycle of FSK DF1. The assessment indicated that there was no significant difference in the measured concentration at the two stacks. This conclusion was confirmed by data collected during test charges FSK DF4 through DF6. For these test charges, data was collected from both stacks simultaneously over short periods of time throughout all three sampling events. This was possible because there was one dedicated VOC measurement system for each stack. The percent difference between the concentration data measured in the venting stack and the concentration measured in the fugitive stack is presented in Table J.3, Appendix J.

As mentioned in the Kiln Description section of this report, the steam-heated full-scale kiln was equipped with a Vent-X-Changer™ system. Although the heat exchanger elements were removed, condensation of the kiln exhaust gas was still occurring in the heat exchanger. Measuring the VOC concentration at the exhaust stack of the heat exchanger was ruled out because of the negative bias that might occur from condensation of the exhaust gas. Instead, the VOC concentration was measured at a location prior to the inlet side of the heat exchanger.

5.5.1.2 The Dilution Ratio Parameter

The standard VOC sampling protocol provides a detailed explanation of the steps required to establish the correct dilution ratio for the VOC measurement system. This parameter is used to correct the diluted concentration of the measured sample gas to the undiluted value needed for calculations.

The dilution ratio used in the Variability Study was based on the total flow rate and sample flow rate of the VOC measurement system. These flow rates were measured at the sample probe tip and recorded during the quality assurance (QA) procedures before and after each sample run. The equation is shown below:

$$\text{Dilution Ratio} = \frac{\text{PreTFR} + \text{PostTFR}}{\text{PreSFR} + \text{Post SFR}}$$

[Equation 3]

Where: Pre- = measurement taken before the sample run
Post- = measurement taken after the sample run
TFR = flow rate of the VOC measurement system at the probe tip with the dilution air turned OFF
SFR = flow rate of the VOC measurement system at the probe tip with the dilution air turned ON

The dilution ratio used for Phase II was based on the diluted and undiluted span gas concentrations measured during the QA procedures. The equation is shown below:

$$\text{Dilution Ratio} = \frac{\text{Pre[span]} + \text{Post[span]}}{\text{Pre[diluted span]} + \text{Post[diluted span]}}$$

[Equation 4]

Where: [span] = span gas concentration, ppm
[diluted span] = diluted span gas concentration, ppm

Unlike the other three parameters in Equation 1, the dilution ratio will be calculated once for each 3-hour sample run.

5.5.1.3 The Kiln Exhaust Flow Rate Parameter

Small-Scale Kilns

The small-scale kilns at MSU, OSU and Horizon Engineering were not equipped with conventional kiln roof vents. Instead, the exhaust gas was forced out of the kiln by the inlet air pumped in. The assumption was made for these kilns that the flow rate of the dry inlet air was equal to the flow rate of the dry exhaust gas since, under normal operating conditions, a slight positive pressure was maintained within each kiln.

The inlet air for the kilns at MSU and OSU was supplied by a compressor and controlled by a calibrated mass flow controller. The mass flow controller at both facilities yielded flow rate measurements at 32°F and 1 atm. Therefore, the only adjustment required was to standardize the flow rate to 68°F. For the purposes of this project, the relative humidity of the inlet air was considered negligible and was not used in calculations.

The inlet air for the small-scale kiln at Horizon Engineering was supplied by a primary and secondary source. The primary air source was maintained at a constant flow rate of 0.2 actual cfm and was measured by a dry gas meter. The primary air flow rate measurements were adjusted to standard conditions. The secondary inlet air source provided a variable flow rate to control the wet bulb temperature inside the kiln. The secondary flow rate was measured indirectly by pressure drop across a calibrated orifice. The pressure drop measurements were converted to standard flow rate values by the calibrated orifice equation shown below:

$$\text{dscfm} = 2.8 \times \Delta P^{0.53} \times \left[\left(\frac{T_{\text{ambient}}}{T_{\text{calibrated}}}\right) \times \left(\frac{P_{\text{calibrated}}}{P_{\text{ambient}}}\right)\right]^{0.50} \qquad \text{[Equation 5]}$$

Where: 2.8 and 0.53 = coefficients determined by calibration of orifice meter
ΔP = Pressure drop measured across the orifice, in Hg
$T_{\text{calibrated}}$ = The temperature of the ambient air when the orifice meter was calibrated, °F
T_{ambient} = The temperature of the ambient air during kiln testing, °F
$P_{\text{calibrated}}$ = The ambient pressure when the orifice meter was calibrated, °F
P_{ambient} = The ambient pressure during kiln testing, °F

The total inlet flow rate for the small-scale kiln at Horizon Engineering was then computed by combining the standardized measurements for the primary and secondary sources.

DEECO measured the actual wet exhaust flow rate from the small-scale kiln at NCSU. Although the kiln at NCSU had four conventional roof vents, two of the vents were sealed to obtain reliable flow rate measurements. DEECO measured the flow rate exiting each NCSU kiln vent with a propeller anemometer. The anemometer voltage measurements were converted to actual wet cubic feet per minute by the equation shown below:

$$Q_{\text{wacfm}} = V_a \times P_c \times A \qquad \text{[Equation 6]}$$

Where: V_a = Anemometer output, volts
P_c = Propeller coefficient, 3,543.31 ft/min/volt
A = Area of the stack

Direct-Fired Full-Scale Kiln

The original sampling plan devised for the direct-fired kiln was to collect sample data from the venting stack only. This plan was modified to include the mass emission contribution from the fugitive stack. The computation of the actual wet exhaust flow rate from the direct-fired kiln was therefore based on the combined flow rates of the venting and fugitive stacks:

$$Q_{\text{wacfm, Combined}} = Q_{\text{wacfm, Venting Stack}} + Q_{\text{wacfm, Fugitive Stack}} \quad \text{[Equation 7]}$$

The flow rate for each stack, Q_{wacfm}, was calculated from the stack area, A_s, and the stack velocity, V_s:

$$Q_{\text{wacfm}} = A_s\,(\text{ft}^2) \times V_s\ (\text{ft/sec}) \times \frac{60\ \text{sec}}{\text{min}} \qquad \text{[Equation 8]}$$

The area of each stack at the direct-fired kiln was determined to be 9.73 ft^2. The air velocity, however, was different for each stack. The stack fans switched between operating (venting) and dormant (fugitive) modes approximately every three hours during kiln operation.

The venting stack fan operated at 100% capacity while the fugitive stack fan was dormant with fugitive exhaust escaping the stack. The velocity for each stack was, therefore, computed separately by the following equation:

$$V_s = K_p \times C_p \times \text{mean\_sqrt}(\Delta P) \times \left(\frac{459.6 + T_{\text{dry}}}{P_s \times MW_s}\right)^{1/2} \qquad \text{[Equation 9]}$$

Where: K_p = 85.48 ft/sec (lb/lb mole•R)$^{0.5}$
Cp = pitot tube correction factor, 0.84
ΔP = pitot velocity head, inches of water
T_{dry} = dry bulb temperature of stack gas
P_s = stack pressure, in Hg
MW_s = molecular weight of the stack gas, lb/lb mole

The molecular weight of the stack gas was determined by:

$$MW_s = MW_{\text{dry stack gas}} \times \frac{(100 - \%MC)}{100} + MW_{\text{water}} \times \frac{(\%MC)}{100} \qquad \text{[Equation 10]}$$

Where:

$$MW_{\text{dry stack gas}} = 0.28 x \frac{(100\% - O_2\% - CO_2)}{100} + 0.32 x \frac{O_2\%}{100} + 0.44 x \frac{(CO_2\%)}{100}$$

[Equation 11]

MW_{water} = 18 lb/lb mole
%MC = The percent moisture content, by volume, of the stack gas. This parameter will be discussed in a separate section below.

As mentioned previously, short periods of concentration data were collected from the fugitive stack to compare with the data collected from the venting stack. Along with the concentration parameter, flow rate data were also collected from the fugitive stack for comparison purposes. The air velocity components measured from the fugitive stack were $O_2\%$, $CO_2\%$, static pressure, and wet/dry bulb temperatures. The values presented in Table J.3, Appendix J, for the fugitive stack were deemed sufficiently equivalent to the values measured from the venting stack. Therefore, all of the air velocity components shown in Equation 9, except for the pitot velocity head, were based on the data collected from the venting stack. The pitot velocity head, ΔP, was measured separately for the venting and fugitive stacks.

The ΔP component was measured two ways: by the standard manual traverse method and on a continuous basis utilizing a pressure transducer. The manual method obtained pitot tube measurements along two perpendicular traverses across the inside diameter of each stack. The continuous measurement method involved placing a second pitot tube at one traverse point for the entire sample run. A pressure transducer measured the relative change in velocity of the flow during the sample run. The relative transducer readings were collected to verify that the velocity from the venting stack did not fluctuate significantly during each sample run.

The manual traverse measurements obtained from the venting and fugitive stacks were used in Equation 9 to compute the velocity for each stack. For kiln charges FSK DF1 through FSK DF3, the traverse data were collected once per sample run on both the venting and fugitive stacks. This scheme was modified to twice per sample run for the remaining three test charges at the direct-fired kiln and for all of the test charges at the steam kiln. The average square root of the pitot velocity head (ave_sqrt(ΔP)) obtained from the traverse measurements for each sample run are presented in Tables K.1 and K.2, Appendix K.

An analysis of variance (ANOVA) was conducted on the ave_sqrt(ΔP) values from the venting stack to determine the variability of the measurements. The result computed for FSK DF1 through DF3 (Table K.3, Appendix K) indicated that there was no statistical difference in the individual ave_sqrt(ΔP) measurements collected during each sample run. Therefore, the mean_sqrt(ΔP) value for these three test charges, 0.4782, was used in Equation 9. The ANOVA test for FSK DF4 through DF6 (Table

K.4, Appendix K) also resulted in the same conclusion, but the mean_sqrt(ΔP) was computed to be 0.5330. The measurements for the FSK DF1 through DF3 were analyzed separately from the values obtained for FSK DF4 through DF6 because the testing of these six charges was split into two different sampling efforts.

Statistical analysis was not conducted on the ave_sqrt(ΔP) values for the fugitive stack data because of the observed variability in the measurements. A fugitive mean_sqrt(ΔP) value was, instead, computed for each stack from the ave_sqrt(ΔP) values measured during each test charge. For example, the mean_sqrt(ΔP) value computed for the East fugitive stack during test charge FSK DF2 (shown in Table K.1, Appendix K) was 0.2095, while the value for the West fugitive stack was computed to be 0.1850. Depending on which stack was venting during FSK DF2, these two values were used in Equation 9 to determine the fugitive flow rate component of Equation 5.

Steam-Heated Kiln

The flow rate from the steam kiln was measured the same way as the flow rate from the venting stack of the direct-fired kiln; data for both the manual traverse and continuous method were collected at the exhaust stack. The manual traverse results from all six steam kiln sampling efforts (FSK INDF1 through INDF7) are shown in Table K.5, Appendix K. These data did not pass the ANOVA test (Table K.6, Appendix K), indicating that the traverse measurements for each test charge were not as consistent as those measured from the direct-fired kiln. Therefore, a mean_sqrt(ΔP) was computed for each test charge.

Although Equation 9 was used to compute the stack gas velocity at both the direct-fired and steam kilns, the molecular weight of the stack gas was derived differently. Equation 11 was used to determine the dry molecular weight of a combustion air source. In this case, however, the inlet air for the steam kiln was ambient air and the value of $MW_{dry\ stack\ gas}$ was determined to 28.84 lb/lb mole for all of the steam kiln mass emission rate calculations.

5.5.1.4 The Exhaust %MC Parameter

The moisture content of the kiln exhaust gas, $\%MC_{exh}$, is defined as the volume of water vapor divided by the combined volumes of the water vapor and dry gas. The $\%MC_{exh}$ was computed from exhaust gas measurements of the wet/dry bulb temperatures and moisture train measurements. This parameter was used to compute the amount of dilution required by the VOC sampling protocol and to adjust the exhaust flow rate measurements for moisture content.

Wet/Dry Bulb Temperature Measurements

A standard equation was chosen to convert the wet/dry bulb temperature measurements to percent moisture content in order to treat each data set equivalently. The Variability Study reports demonstrated that there are several possible approaches to calculating moisture from wet bulb/dry bulb data. The method used for this study is not meant to establish a standard, it was developed simply to treat all data sets on a equivalent basis.

The standard wet/dry bulb conversion equation is shown below:

$$\%MC_{Kiln} = \frac{Pp_w}{P_{amb}} \qquad \text{[Equation 12]}$$

Where: Pp_w = Partial pressure of water vapor below saturation point, in Hg
P_{amb} = Ambient pressure, in Hg

The partial pressure of water vapor below saturation point was determined by Equation 13:

$$Pp_w = P_c \times 10^{K_w(1-T_c/T_w)} - 0.000367\left[1+\left(\frac{t_w-32}{1{,}571}\right)\right] \times P_{amb} \times \left(t_d - t_w\right) \times \frac{\text{in Hg}}{25.4 \text{ mm Hg}}$$

[Equation 13]

Where: P_c = Critical pressure of water = 166,818 mm Hg
K_w = Wet bulb temperature dependent parameter, dimensionless
T_c = Critical temperature of water = 1,165.67°R
T_w = Wet bulb temperature, °R
t_w = Wet bulb temperature, °F
t_d = Dry bulb temperature, °F
P_{amb} = Ambient pressure, mm Hg

The temperature dependent parameter in Equation 13 was derived from the wet bulb temperature equation presented below:

$$K_W = \left(-8.833 \text{x} 10^{-10} \text{x} T_W{}^3\right) + \left(3.072 \text{x} 10^{-6} \text{x} T_W{}^2\right) - \left(3.4969 \text{x} 10^{-3} \text{x} T_W\right) + 4.39553$$

[Equation 14]

Moisture Train Measurements

The moisture train measurements collected for this project were based on EPA Method 4. The volume of water and dry gas collected for each moisture train sample run was converted to an average percent moisture content by the standard Method 4 equations.

Determination of the Exhaust Gas Moisture Content from the Small-Scale Kilns

The moisture content of the exhaust gas from the small-scale kilns at MSU, OSU, and Horizon Engineering was computed using the wet/dry bulb temperatures measured inside each kiln. An assumption was made that moisture levels inside the kiln were equivalent to moisture levels in the exhaust gas. Conventional EPA Method 4 moisture train measurements were conducted by DEECO at the NCSU small-scale kiln.

An example of the %MC profile achieved by the each small-scale kiln during the Variability Study has been included in Appendix L.

Determination of Moisture Content Levels at the Full-Scale Kilns

WESTON collected both continuous wet/dry bulb temperature data and moisture train data from both full-scale kilns. WESTON modified the standard EPA Method 4 moisture train by substituting a calibrated flow meter for the dry gas meter.

The moisture content of the exhaust gas from the direct-fired kiln was based on the measurements obtained from the venting stack only. Figure 5.17 shows a comparison of the uncorrected moisture content profiles obtained from the wet/dry bulb temperature and moisture train data for the direct-fired kiln data.

Since the steam kiln was equipped with a Vent-X-Changer™, the sampling plan called for the collection of moisture data from both the inlet and outlet of the Vent-X-Changer™ unit. Figure 5.18 shows an example of the raw data collected from the inlet and outlet sides of the heat exchanger.

Using the data collected by both the wet/dry bulb temperature and moisture train measurements, a standard method was derived to manipulate the raw data to yield a continuous percent moisture content profile (corrected %MC) for use in the mass emission rate calculation. This standard method was applied to the data sets collected at both full-scale kilns. An example of the corrected %MC profiles for both kilns are shown in Figures 5.19 through 5.21.

The process for calculating the corrected %MC profiles essentially involved comparing the results from the wet/dry bulb temperature and moisture train %MC methods. Each sample interval was analyzed to determine which method yielded a realistic value. If the %MC values from the wet/dry bulb temperature data were chosen for a particular time period, then the values were used directly because these data were collected on a per minute basis.

The results from the moisture train, however, yielded averaged values for each moisture train sample period. If the result from the moisture train was chosen for the corrected %MC value, then the averaged value was placed at the mid-point of the moisture train sample period. The corrected %MC values prior to and after the mid-point value were interpolated. Tables M.1 and M.2, Appendix M, show examples of how the %MC data were adjusted.

An example of the corrected %MC profiles for the direct-fired and steam schedules followed by both the full- and small-scale kilns is shown in Figures 5.22 and 5.23.

As part of the standard %MC method, the wet/dry bulb temperature data collected at both full-scale kilns were also corrected to calculate the flow rates and %MCs. An example of the corrected wet/dry temperature profiles for both kilns is shown in Figure 5.24. Note that these profiles are different from the temperature profiles that were presented in the kiln operating parameters section of this report.

5.5.1.5 Mass Emission Rate Equations For The Six Kilns

The preceding information provided an overview of the various methods used to transform the reported data from the six kilns into the standard VOC mass emission rate equation, Equation 1. The equations presented below summarize the modifications made to Equation 1 to fit each individual data set:

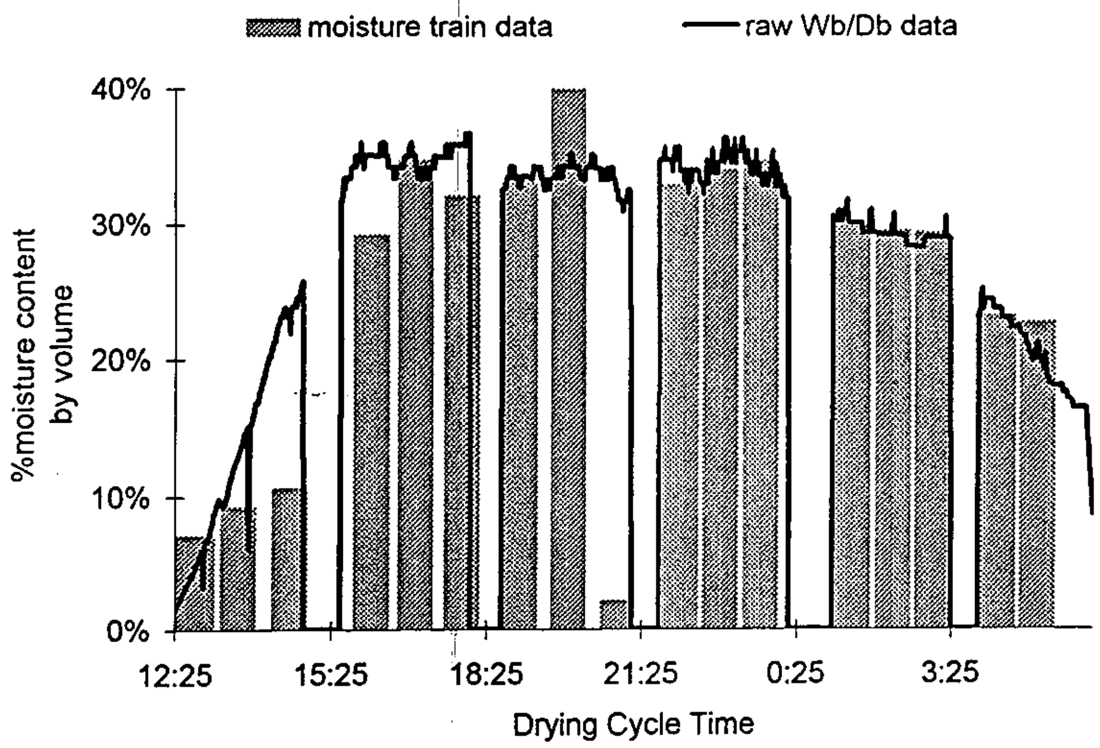


Figure 5.17. Comparison of WB/DB Data to Moisture Train Data (Kiln Charge FSK-DF2)

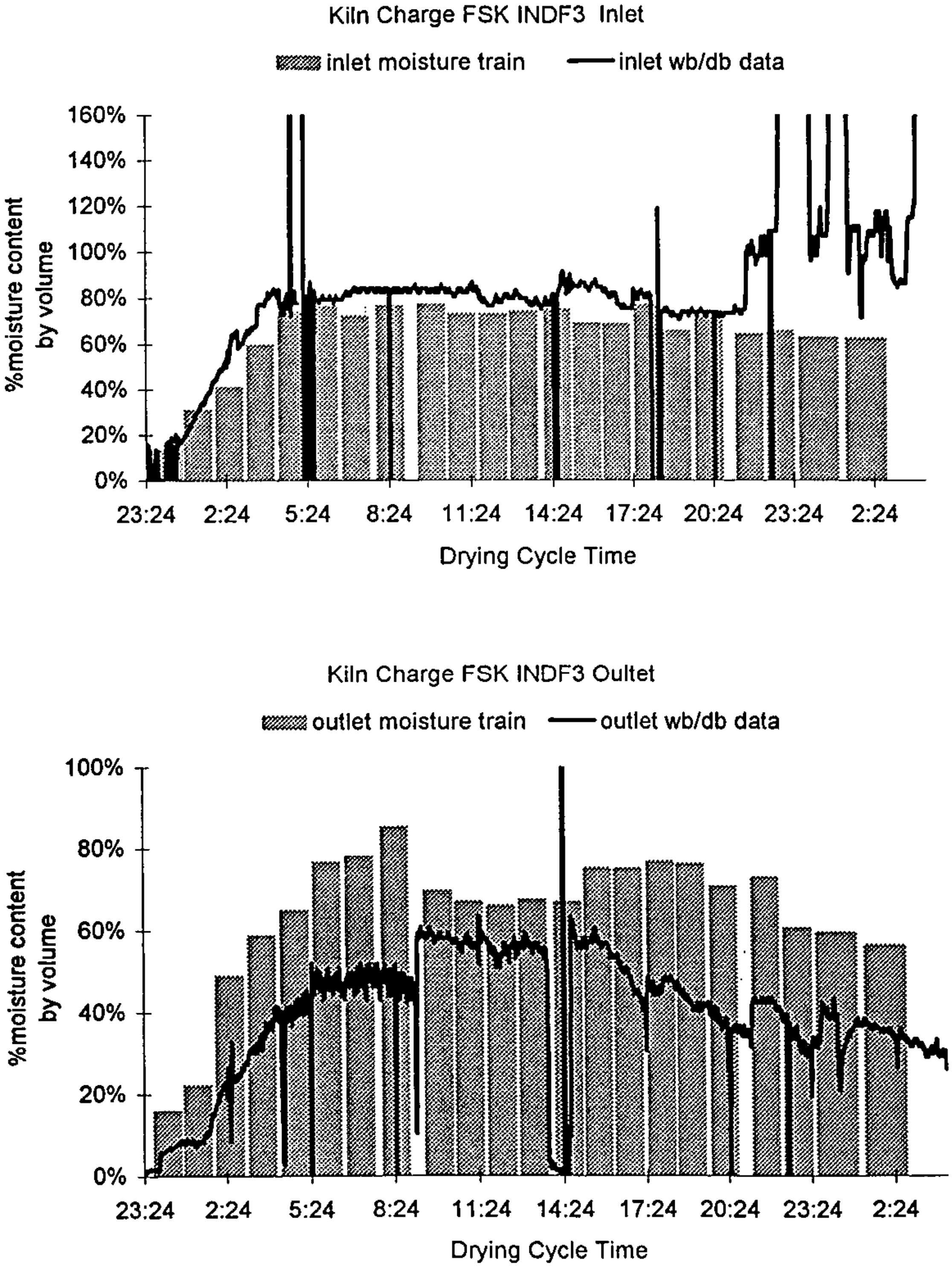
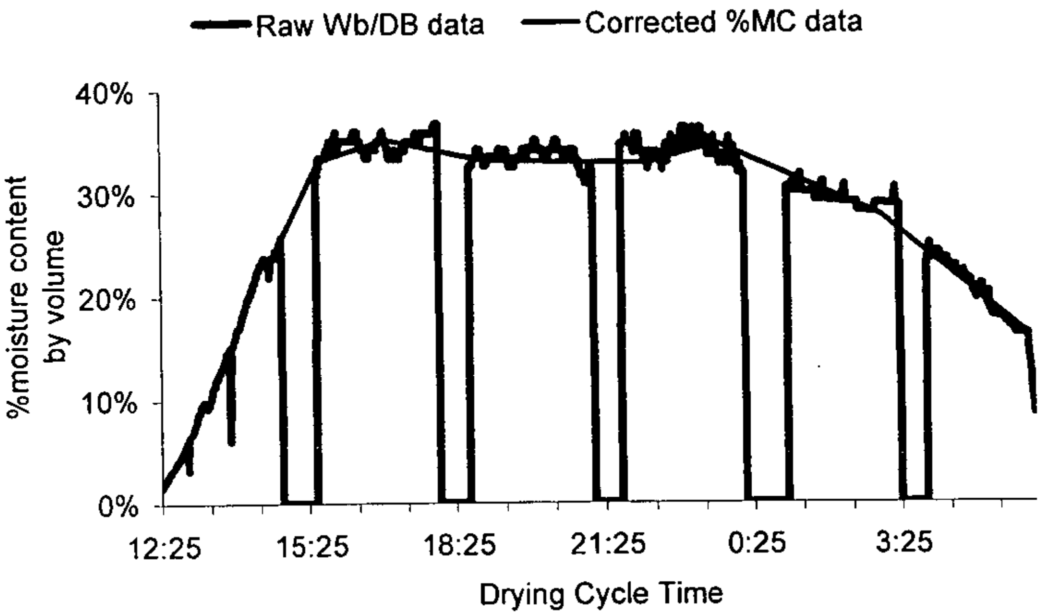
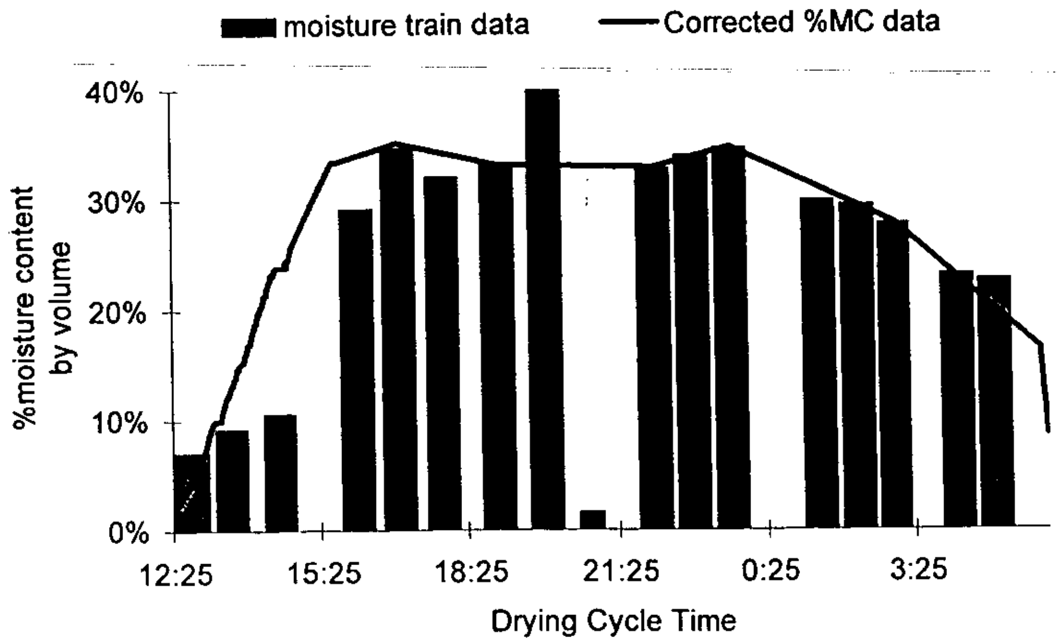


Figure 5.18. Comparison Between Moisture Train and Raw WB/DB Data



Kiln Charge FSK-DF2
Corrected %MC Data to Wb/Db Data



Kiln Charge FSK-DF2
Corrected %MC Data to Moisture Train Data

Figure 5.19. Comparison Between Corrected %MC, WB/DB, and Moisture Train Data

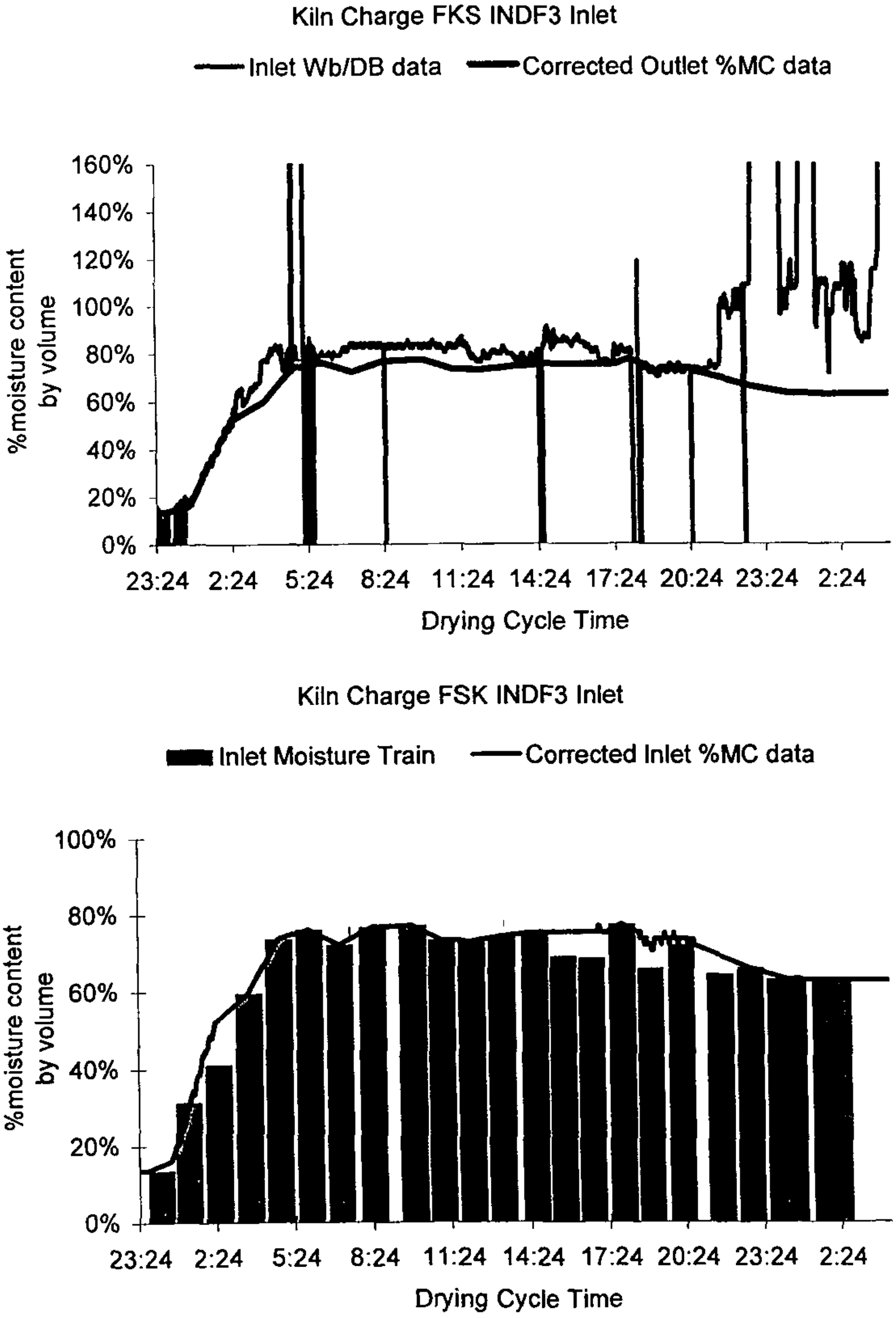


Figure 5.20. Comparison Between Corrected %MC, WB/DB Temp., and Moisture Train Data

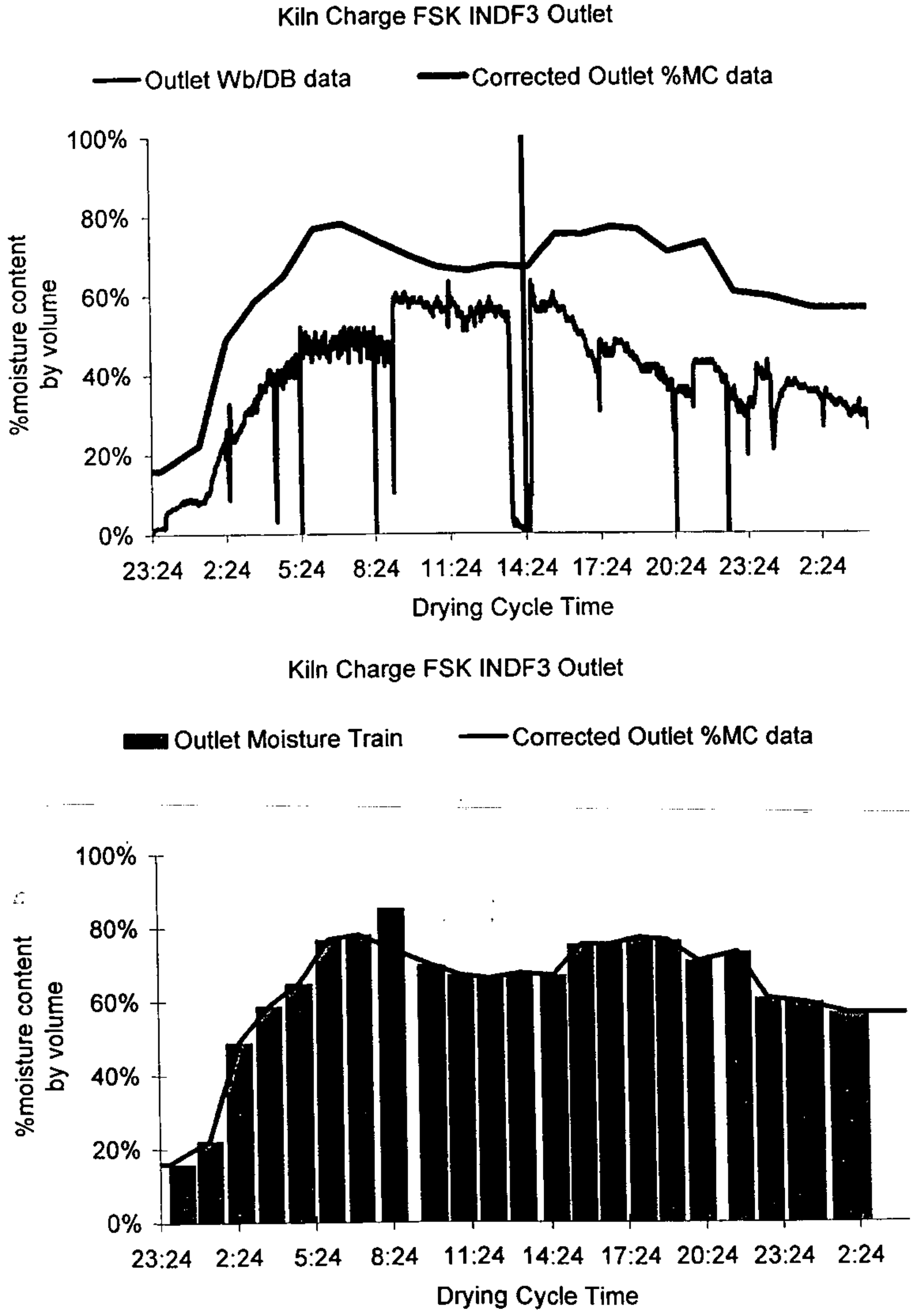


Figure 5.21. Comparison Between Corrected %MC, WB/DB Temp., and Moisture Train Data

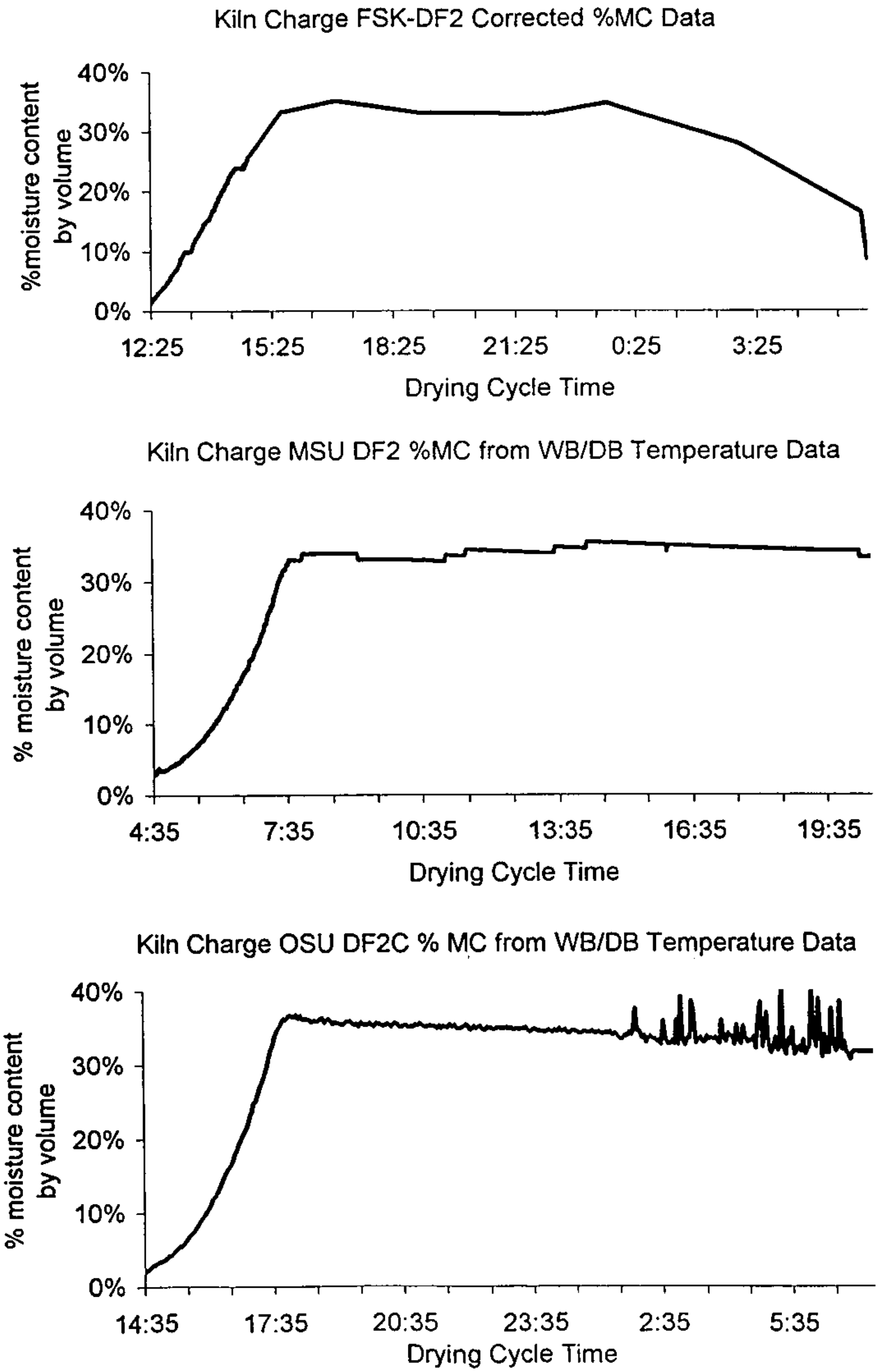
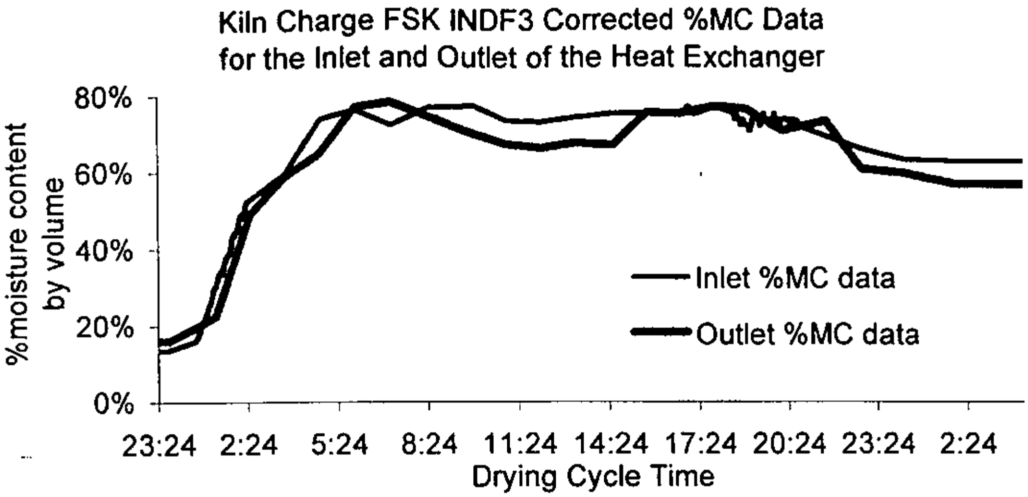
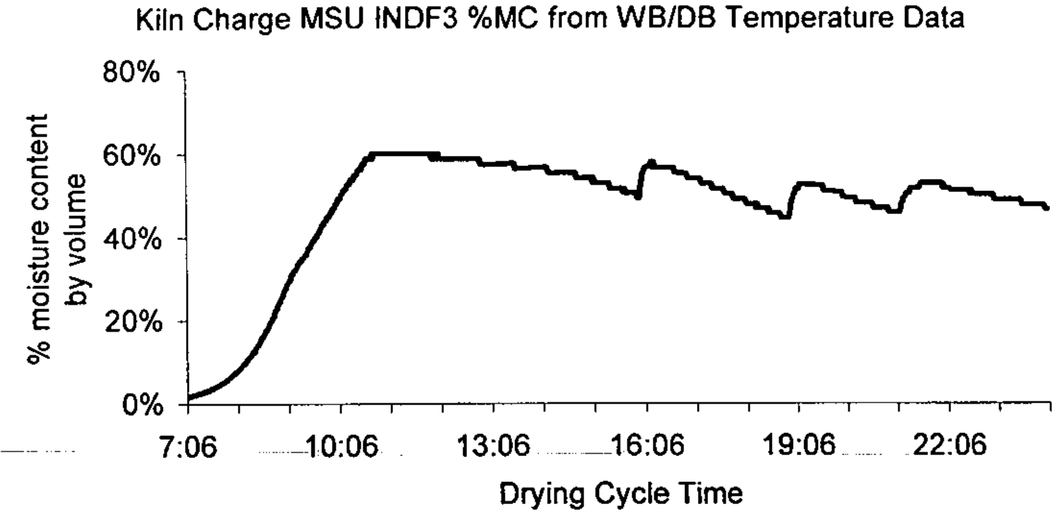


Figure 5.22. %MC by Volume of Kiln Exhaust for the Direct-fired Temperature Schedule

National Council for Air and Stream Improvement





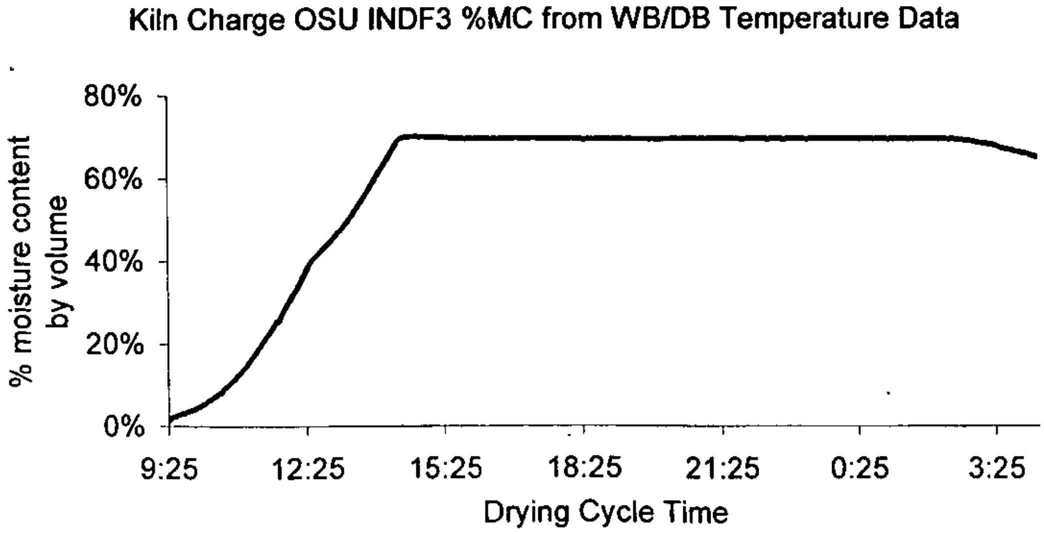
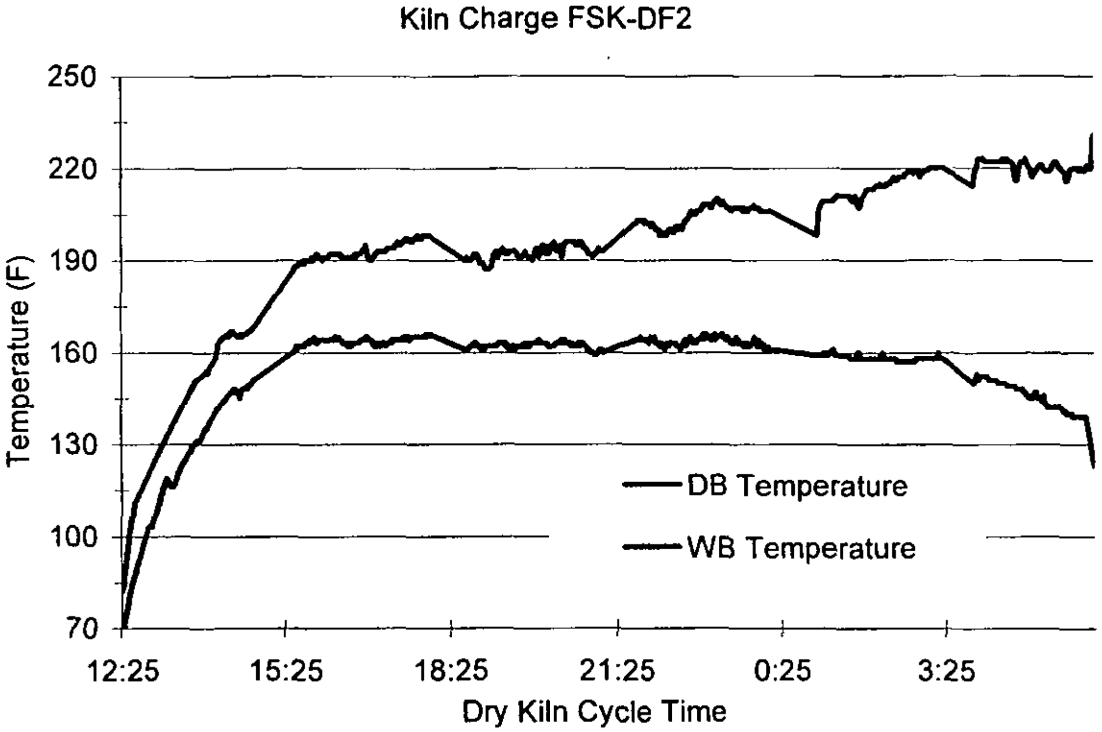


Figure 5.23. %MC by Volume of Kiln Exhaust for the Steam-Heated Temperature Schedule


Kiln Charge FSK-DF2

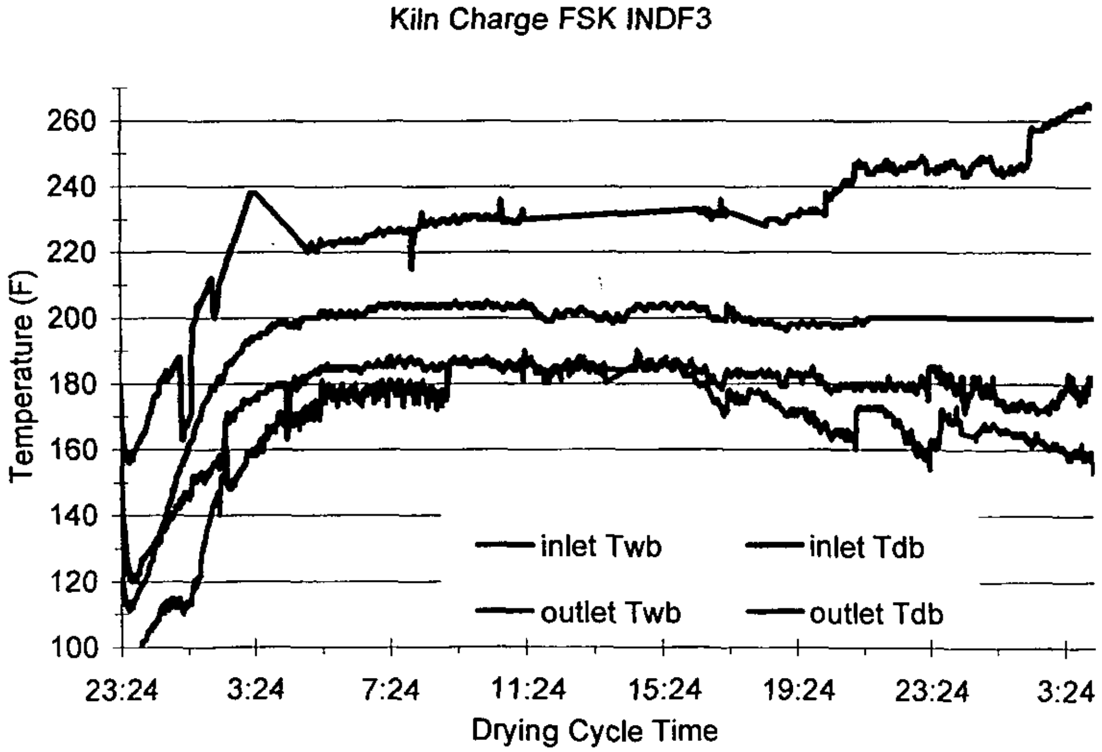

Kiln Charge FSK INDF3

Figure 5.24. Corrected WB/DB Temperatures of the Kiln Exhaust

- The mass emission rate equation used for the MSU data:

$$\frac{\begin{array}{c}\text{lb of VOC}\\ \text{as Carbon}\end{array}}{\text{min}}[i] = \frac{\begin{array}{c}\text{diluted}\\ \text{propane, ppmw}\end{array}}{10^6}[i] \times \text{dilution ratio} \times \frac{3\text{ carbons}}{1\text{ propane}} \times \frac{\text{dscfm}[i] \times 100}{100 - \%\text{MC}_{\text{exh}}[i]} \times \frac{1\text{ lbmole}}{385.6\text{ scf}} \times \frac{12\text{ lb carbon}}{\text{lbmole}}$$

- The mass emission rate equation used for the OSU data:

$$\frac{\begin{array}{c}\text{lb of VOC}\\ \text{as Carbon}\end{array}}{\text{sample interval}}[i] = \frac{\begin{array}{c}\text{diluted}\\ \text{propane, ppmw}\end{array}}{10^6}[i] \times \text{dilution ratio} \times \frac{3\text{ carbons}}{1\text{ propane}} \times \frac{\text{dscfm}[i] \times 100}{100 - \%\text{MC}_{\text{exh}}[i]} \times \frac{3\text{ mins}}{\text{sample interval}} \times \frac{1\text{ lbmole}}{385.6\text{ scf}} \times \frac{12\text{ lb carbon}}{\text{lb mole}}$$

- The mass emission rate equation used for the Horizon Engineering data:

$$\frac{\begin{array}{c}\text{lb of VOC}\\ \text{as Carbon}\end{array}}{\text{min}}[i] = \frac{\begin{array}{c}\text{diluted}\\ \text{carbon , ppmw}\end{array}}{10^6}[i] \times \text{dilution ratio} \times \frac{\left(1^{\circ}\text{ dscfm}[i] + 2^{\text{nd}}\text{ dscfm}[i]\right)}{1 - \dfrac{\%\text{MC}_{\text{exh}}[i]}{100}} \times \frac{1\text{ lbmole}}{385.6\text{ scf}} \times \frac{12\text{ lb carbon}}{\text{lb mole}}$$

- The mass emission rate equation used for the DEECO data:

$$\frac{\begin{array}{c}\text{lb of VOC}\\ \text{as Carbon}\end{array}}{\text{min}}[i] = \left[\left(\frac{\begin{array}{c}\text{diluted}\\ \text{propane, ppmw}\end{array}}{10^6}[i] \times \text{wscfm}_{[i]}\right)_F + \left(\frac{\begin{array}{c}\text{diluted}\\ \text{propane, ppmw}\end{array}}{10^6}[i] \times \text{wscfm}_{[i]}\right)_B\right] \times \frac{3\text{ carbons}}{1\text{ propane}} \times \frac{1\text{ lbmole}}{385.6\text{ scf}} \times \frac{12\text{ lb carbon}}{\text{lbmole}}$$

Where: F = data from the front vent
B = data from the back vent

- The mass emission rate equation used for the direct-fired kiln data:

$$\frac{\text{lb of VOC as Carbon}}{\text{min}}[i] = \frac{\text{diluted propane, ppmw}}{10^{6}}[i] \times \text{dilution ratio} \times \frac{3\ \text{carbon}}{1\ \text{propane}} \times \frac{\left(\text{Vent dscfm}[i] + \text{Fug dscfm}[i]\right)}{1 - \frac{\%MC_{exh}[i]}{100}} \times \frac{1\ \text{lbmole}}{385.6\ \text{scf}} \times \frac{12\ \text{lb carbon}}{\text{lb mole}}$$

Where: The THA concentration, dilution ratio, and $\%MC_{exh}$ parameters are based on the values determined from the venting stack.
Vent = parameter calculated from the venting stack data
Fug = parameter calculated from the fugitive stack data

- The mass emission rate equation used for the steam kiln data:

$$\frac{\text{lb of VOC as Carbon}}{\text{min}}[i] = \frac{\text{diluted inlet propane, ppmw}[i] \times 100}{10^{6} \times \left(100 - \%MC_{inlet}[i]\right)} \times \text{dilratio} \times \frac{3\ \text{carbons}}{1\ \text{propane}} \times \left(\text{wscfm}_{outlet}[i] \times \left(\frac{100 - \%MC_{outlet}[i]}{100}\right)\right) \times \frac{1\ \text{lbmole}}{385.6\ \text{scf}} \times \frac{12\ \text{lb carbon}}{\text{lbmole}}$$

5.5.2 Standard HAPs Calculation Procedure for the Impinger/Canister Compounds

The 'hazardous air pollutants' (HAPs) sampled for in this project were:

Acetaldehyde
Acrolein
Benzene
Formaldehyde
Methanol
Methyl ethyl ketone
Methyl isobutyl ketone
Phenol
Propionaldehyde
Toluene
Styrene
m & o-Xylenes

In addition to these compounds, acetone, alpha-pinene and beta-pinene were quantified.

As mentioned in the Sampling Methodology section of this report, the NCASI Chilled Impinger Method was issued to provide a standard protocol for collecting and analyzing formaldehyde and methanol samples. Although the sampling procedure for the remaining compounds listed above was not specified, the NCASI Chilled Impinger/Canister Method was used to sample for these compounds at the steam kiln and the OSU small-scale kiln.

In reviewing the different formaldehyde and methanol calculation procedures used by each small-scale kiln that participated in Variability Study, it became apparent that a standard calculation procedure was needed to manipulate the HAPs data in a consistent manner that would yield comparable mass emission rates. The standard calculation procedure that was developed for both the Variability Study and Phase II was based on the following two parameters:

1. The concentration of target compound in the kiln exhaust gas, ppmd, and;
2. The average dry exhaust flow rate over each impinger/canister sample run standardized to 1 atmosphere and 68°F.

These two parameters were calculated and used in Equation 15 to determine the average mass emitted per MBF from the kiln over each impinger/canister sample run:

$$\frac{\text{lb of target compound}}{\text{sample run}} = \frac{\dfrac{\text{average concentration of compound in kiln gas, ppmvd}}{10^6}}{\text{sample run}} \times \frac{\text{average dscfm}_{\text{exh}[i]}}{\text{sample run}} \times \frac{\text{lb mole}}{385.5\ \text{scf}} \times \text{MW}_{\text{compound}} \times \frac{1}{\text{MBF}}$$

[Equation 15]

The maximum duration for each impinger/canister sample run was specified to be no longer than three hours.

The Average Concentration Parameter

The total concentration of a target compound in the kiln exhaust gas was determined by Equation 16:

$$\text{compound concentration in kiln gas, ppmvd} = \text{total mass, g}_{[i]} \times \frac{1}{\text{MW}} \times \frac{24.04\ \text{L}}{\text{gmole}} \times \frac{1}{\text{dsL}_{[i]}}$$

[Equation 16]

The total mass parameter shown in Equation 16 depended on the mass captured in the impinger water and air canister for a particular sample run:

$$\text{Total mass}_{[i]} = \text{mass captured in impinger sample}_{[i]} + \text{mass captured in canister sample}_{[i]}$$

[Equation 17]

The mass captured in the impinger sample for a particular sample run was calculated by the concentration, µg/mL (ppmw), determined by the laboratory analysis and the volume of water in the impingers, including any rinse.

The water in the impingers at the end of a sample run was the initial water in the impingers plus water condensed from the total sample volume that passed through the impingers. The entire volume of sample leaving the impinger train, however, was not collected by the 6.0 liter SUMMA canister. Instead, a slip stream of sample gas, at 33 ml/min, was diverted to the canister during the sample run (approximately three hours). Therefore, the mass of any compound captured in the canister would only represent a fraction of the mass that entered the sample system. In order to correct for the volume difference, a mass correction factor was computed for each canister sample and applied to the canister concentration determined by laboratory analysis for that sample run. The mass of target compound in the dry gas volume that passed through the sampling train during each sample run was determined by Equation 18:

$$\text{mass in can, ug}_{[i]} = \frac{\text{Analyte concentration in can, ppbw}[i]}{10^9 \times \left(1 - \frac{\%MC_{can}}{100}\right)} \times \left(\frac{T_{std}}{T_{lab}}\right) \times \left(\frac{P_{lab}}{P_{std}}\right) \times 6\,\text{L} \times \frac{\text{mole}}{24.04\ \text{L}} \times \text{MW} \times \frac{10^6\ \text{ug}}{\text{g}} \times \text{mass correction factor}_{[i]}$$

[Equation 18]

Where: $\%MC_{can}$ = The amount of moisture in sample gas after leaving the last impinger. If the average temperature of the sample gas leaving the last impinger is assumed to be at 38° F, then %MC of saturated air is 0.78%.

The total standard sample volume collected (dsL) during each sample run was determined by Equation 19:

$$\text{dsL}_{[i]} = \text{run time}_{[i]} \times \text{ave. sample train flow rate}_{[i]} \times \frac{T_{std}}{\text{Tave}_{amb[i]}} \times \frac{\text{Pave}_{amb[i]}}{P_{std}} \times \frac{P_{std} - P_{sat}[i]}{P_{std}}$$

[Equation 19]

The last expression in Equation 19 uses the saturation vapor pressure, P_{sat}, to convert the wet standard flow rate of the sampling train to a dry standard flow rate and is included only when a bubble flow meter is used. The assumption made in Equation 19 is that the ambient air entering the bubble flow meter becomes saturated as it passes the over the fluid reservoir. Using this assumption, the saturation vapor pressure for the average ambient temperature was calculated by the following expression:

$$P_{sat} = P_c \times 10^{K_{amb}\left(1 - T_c/T_{amb}\right)} \times \frac{\text{in Hg}}{25.4\ \text{mm Hg}}$$

[Equation 20 (Pallady and Healey 1984)]

Where: P_c = Critical pressure of water = 166,818 mm Hg
K_{amb} = Temperature dependent parameter, dimensionless
T_c = Critical temperature of water = 1,165.67 °R
T_{amb} = Ambient temperature, °R

The temperature dependent parameter in Equation 21 was derived from the ambient temperature equation presented below:

$$K_{amb} = \left(-8.833 x 10^{-10} x T_{amb}{}^{3}\right) + \left(3.072 x 10^{-6} x T_{amb}{}^{2}\right) - \left(3.4969 x 10^{-3} x T_{amb}\right) + 4.39553$$

[Equation 21]

The preceding equations are used in Appendix N to calculate the formaldehyde and methanol concentrations for the first sample run FSK INDF3.

The Average Dry Standard Exhaust Flow Rate (average $dscfm_{exh[i]}$) Parameter

Since individual compound concentrations were calculated on a dry basis, the dry standard exhaust flow rate from the kiln was required for Equation 15. Furthermore, the kiln gas concentration values represented the average concentrations obtained over each sample run. As a consequence, an average dry exhaust flow rate was determined for each sample run. Table N.3, Appendix N, shows the dry flow rates computed for each of the sample runs for FSK INDF3.

The average dry standard flow rate and the kiln gas concentrations for each sample run were combined in Equation 15 to calculate the mass emission rate per sample run. This computation is shown in Table N.4, Appendix N for the mass emission rate/sample run of formaldehyde and methanol. Note that kiln charge FSK INDF3 had a production rate of 156.1 MBF.

This same procedure was followed for all of the other target compounds listed in this section except alpha- and beta-pinene. The concentrations of these two compounds were reported in the canister as ppmw instead of ppbw.

All of the calculations that went into determining the parameters mentioned in this section are on the compact disk for review.

5.5.3 The Standard Procedure for Calculating the Mass Emission Rate

The resulting mass emission rate for each kiln drying cycle was determined by:

- the interpolation of the calibration periods and measurement system anomalies;
- the termination point of the measured data set for each drying cycle; and
- the integration of the incremental mass emission rate data.

Interpolation of Measured Data

One of the objectives of this project was to continuously collect air sample data from lumber kilns drying southern pine. In this project, drying cycle times ranged from 18 to 28 hours. The sampling protocols, however, specified that all continuous periods of sample collection (sample runs) should be no longer than three hours. Typically there were gaps in the data while measurement systems were either recalibrated or replaced with new systems at the end of each 3-hour sample run. Furthermore, due to the gradual nature of the drying process, sudden changes in the recorded data are usually associated with anomalies in the measurement system instead of sudden changes in the operation to the kiln. Regardless of the cause, missing data or anomalies were interpolated using the valid data points on both sides of the segment of data in question. The result of the interpolation was a smoother continuous curve. An example of the comparison between the raw VOC mass emission rate data and the corrected VOC data is shown in Figure 5.25 for FSK DF2.

Interpolation of the averaged methanol mass emission rate data is also shown in Figure 5.25 for the same test charge. In this case, the mid-points for each methanol sample run were joined by interpolation to form the continuous mass emission rate curve shown.

Termination Point of Measured Data Set

The termination point for each small-scale kin drying cycle was determined by the percent moisture content (dry basis) of the lumber charge (%Wood-MC$_{dry}$). For example, the termination point for the Variability Study was determined to be 15%Wood-MC. Since load cells were used by only one small-scale kiln in this study, a standard method was devised to calculate the time during the drying cycle when the lumber charge reached the moisture content of 15%.

The final kiln-dry moisture content of the lumber was used as a reference point to calculate the point in time that the lumber charge had an average moisture content of 15% (termination point). The final kiln-dry moisture content was determined by Equation 22.

$$\%\,\text{Wood-MC}_{\text{dry}[i]} = \frac{\text{Charge weight}_{[i]} - \text{oven dry weight}}{\text{oven dry weight}} \times 100$$

[Equation 22]

Where:

Oven dry weight = the totally dry weight of the whole lumber charge. The totally dry weight is determined by oven drying the wood until there is no discernible change in weight of the lumber charge.

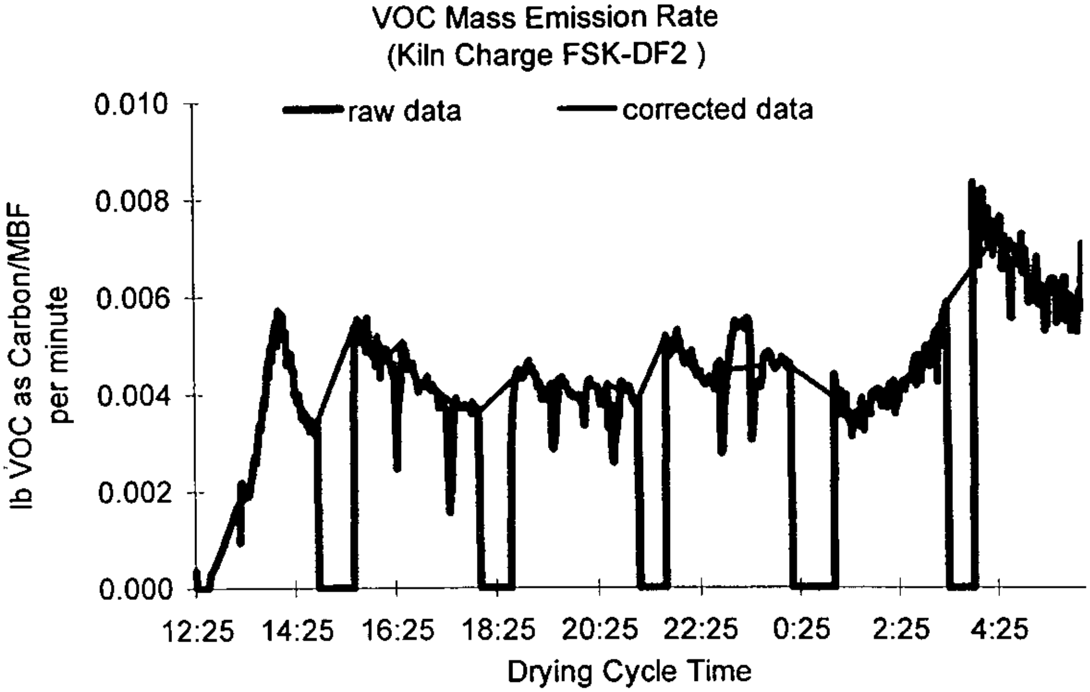
Starting with the final lumber moisture content, the termination point was calculated through the following procedure:

1. Calculate the Absolute Humidity of the exhaust gas at time [i]:

$$\frac{\text{moles water vapor}}{\text{moles whole}} = \frac{\text{volume of water vapor}}{\text{volume of whole gas}} = \%\text{MC}_{\text{exh}}$$

$$\frac{\text{moles dry air}}{\text{moles whole}} = \frac{\text{volume whole gas}}{\text{volume whole gas}} - \frac{\text{volume of water vapor}}{\text{volume whole gas}} = 1 - \%\text{MC}_{\text{exh}}$$

$$\text{Absolute Humidity}_{[i]} = \frac{\%\text{MC}_{\text{exh}[i]}}{1 - \%\text{MC}_{\text{exh}[i]}} \times \frac{18\,\text{lb water}}{\text{lbmole}} \times \frac{\text{lbmole}}{28.97\,\text{lb dry air}} = \frac{\text{lb water}}{\text{lb dry air}_{[i]}}$$



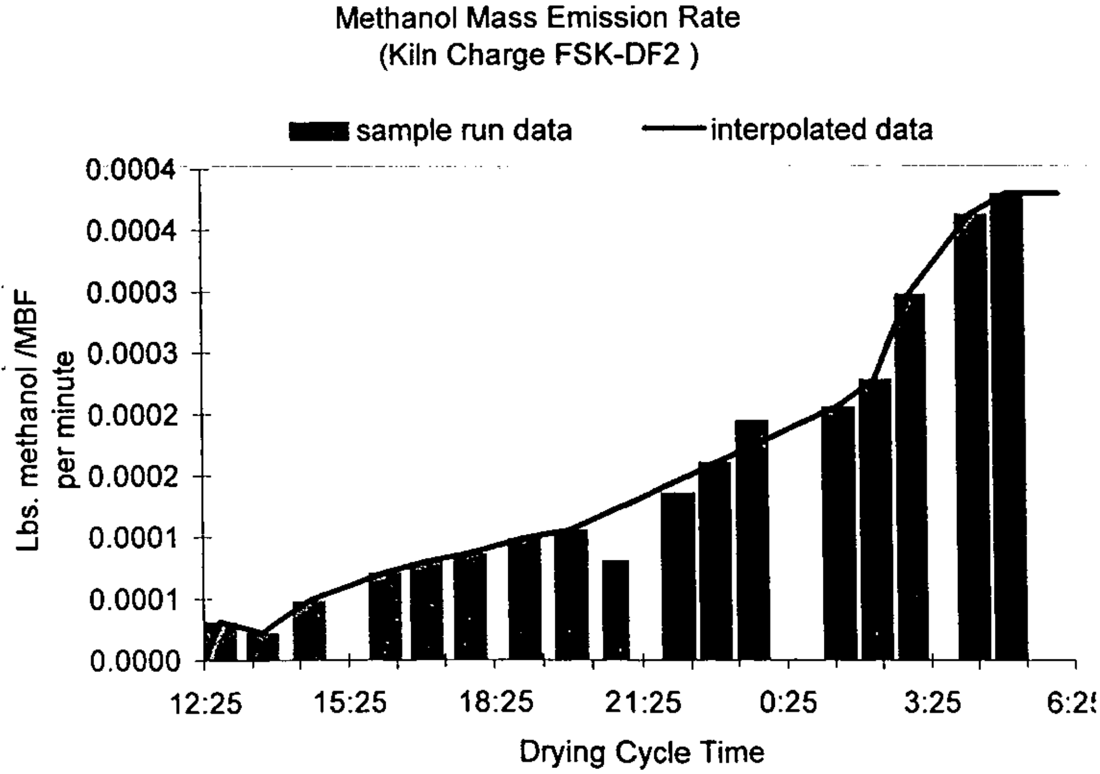


Figure 5.25. Comparison of Mass Emission Rates Between Raw and Corrected Data

2. Calculate the weight of water exhausted from kiln for each data interval [i]:

$$\text{Weight of water exhausted, lb} = \frac{\text{lb water}}{\text{lb dry air}_{[i]}} \times \text{dsfcm}_{[i]} \times \frac{\text{lb mole}}{385.6\,\text{scf}} \times \frac{28.97\ \text{lb}}{\text{lb mole air}}$$

For each sample interval [i], the weight of water vapor exhausted from the kiln was assumed to be equivalent to the weight of water extracted from the lumber charge due to drying.

3. Sum the weight of water extracted from the lumber starting from the last data point recorded and working toward the start of the drying cycle.

$$(\text{Cumulative water weight}_{[i]}, \text{lb}) = (\text{weight of water exhuasted}_{[i]}, \text{lb}) + (\text{cumulative water weight}_{[i+1]}, \text{lb})$$

4. Estimate the weight of the lumber charge at time [i]:

$$(\text{Charge weight}_{[i]}, \text{lb}) = (\text{cumulative water weight}_{[i]}, \text{lb}) + (\text{kiln dry weight, lb})$$

The kiln dry weight of the lumber charge is the weight of the charge at the end of the drying cycle when the lumber is taken out of the kiln.

5. Calculate the %Wood-MC$_{dry}$ of the lumber charge at any time [i]:

$$\%\ \text{Wood-MC}_{\text{dry}[i]} = \frac{\text{Charge weight}_{[i]} - \text{oven dry weight}}{\text{oven dry weight}} \times 100 \qquad \text{[Equation 22]}$$

6. Adjust the calculated weights in the cumulative water data column if the weight of the charge calculated at the start of the data set does not match the measured charge weight reported by the small-scale kiln.

7. Choose the appropriate %Wood-MC$_{dry}$ where emissions data are to be truncated (termination point), then note the corresponding time associated with the chosen %Wood-MC$_{dry}$.

The termination point for the Variability Study was 15%Wood-MC$_{dry}$. The termination points in Phase II ranged between 12% and 15%. Data were included below the 15%Wood-MC mark because the packet weight measurements recorded for the first three direct-fired kiln charges (Table F.1, Appendix F) indicated that the kiln dry %Wood-MC values were 12%, 15%, and 13%.

The termination points for the MSU and OSU Phase II data sets were set at the end of the hour period in which the lumber was dried to a moisture content of 15%. Although this introduced some variability, it simplified the procedure for integrating the incremental mass emission rates by keeping the integrated data in hourly blocks of time.

In order to provide a better understanding of how this standard %Wood-MC method was implemented, an example calculation has been provided in Appendix O.

Integration of the Incremental Mass Emission Rates

The overall mass emission rate was calculated for each drying cycle once the incremental mass emission rate data points were calculated, adjusted for calibration periods and anomalies, and the termination point for each drying cycle was determined. The data set for VOCs (and HAPs if applicable) for each drying cycle was integrated by summing hourly blocks of incremental mass emission rate values from the start of the sampling event to the designated termination point.

6.0 RESULTS

6.1 Small-Scale Kiln Variability Study Results

The Variability Study had two primary objectives. The first was to evaluate variability among small-scale kilns and among sampling events at individual small-scale kilns. The second objective was to assess the emission measurement and lumber drying capabilities of the participating facilities - MSU, OSU, H. D. Project Management/Horizon Engineering (HDHE), and North Carolina State University (NCSU). DEECO conducted the air sampling at NCSU. The results of this assessment were intended to facilitate selection of the two sites for participation in the Phase II portion of the study.

The four participants in the Variability Study each dried three kiln charges of southern pine lumber to a wood moisture content of 15%-dry. At each facility, VOC, formaldehyde and methanol emissions data were collected. The data in Tables 6.1 and 6.2 provide a comparison of the drying cycles and the corresponding mass emission rates for VOC, formaldehyde, and methanol.

The small-scale kiln at MSU dried their four kiln charges to an average kiln-dry wood moisture content of 12%-dry in 14.72 hours[1]. OSU and HDHE extended their drying cycles to approximately 24 hours to reach kiln-dry moisture contents of 6.4%-dry and 4.3%-dry, respectively. NCSU, however, had difficulty judging the length of time required to reach 15%-dry moisture content. Of their three lumber charges, the lowest moisture content reached was 18%-dry in 23 hours.

The drying cycle hours previously mentioned were total hours from the start of the cycle until the lumber was kiln-dry. Variability Study participants were instructed to begin data collection after the kilns had reached the wet/dry bulb set point temperatures or within the first three hours. Consequently, data collection began at different times for each small-scale kiln. In order to treat the emissions data in a consistent manner, all calculated data sets began at three hours into the drying cycle and were terminated when the wood reached a moisture content of 15%-dry. The NCSU data, however, could not be adjusted to the moisture content of 15%-dry.

Using this criteria and the standard calculation procedure for determining the 15% termination point described in Section 5 of this report, the mass emission rate values for MSU and HDHE were based on 11 hours of sampling time. The emission rate values for OSU and NCSU/DEECO were based on 15.3 and 21.2 hours, respectively.

The last column of Table 6.1 presents the mass emission rates of VOC over the data collection periods previously mentioned. The mass emission rate values represent the lb VOC as C/MBF emitted from each lumber charge. The VOC mass emission rate values ranged from 0.94 lb VOC as C/MBF to 3.20 lb VOC as C/MBF. OSU had the highest average VOC mass emission rate of 3.0 lb VOC as C/MBF. The lowest average, 1.81 lb VOC as C/MBF, was calculated for the small-scale kiln operated by HDHE. MSU and NCSU/DEECO had approximately the same VOC emission rates, 2.10 and 2.25 lb VOC as C/MBF, respectively. The stickers used by these small-scale kilns were sufficiently kiln dried so as to not bias the results.

Although the facilities were required to test three kiln charges for VOC mass emission rates, they were required to test only one kiln charge for formaldehyde and methanol emission rates. As can be seen in Table 6.2, MSU and OSU collected and reported formaldehyde and methanol data from an additional

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[1] Kiln-dry is defined as the condition of the lumber when the charge was removed from the kiln at the end of the drying cycle.

Table 6.1. Small-Scale Kiln Variability Study Results for VOC

Small-Scale Kiln	Kiln Charge Size (BF)	Kiln Charge Code Designation	Kiln Dry Wood Moisture Content (%)	Total Drying Cycle Time (Hours)	%Wood Moisture Content Adjusted To	Sample Event Duration (Hours)*	VOC Mass Emission Rate (lb VOC as Carbon/MBF)*
Mississppi State University	32	MSU 1	12.2%	14.77	15%	11.13	1.93
		MSU 2	13.3%	14.78	15%	12.12	2.53
		MSU 3	11.1%	14.97	15%	10.73	1.90
		MSU 4	10.8%	14.37	15%	10.23	2.03
		Average	11.8%	14.72	15%	11.05	2.10
Oregon State University	49	OSU 3	6.4%	24.05	15%	15.28	3.09
		OSU 4	6.4%	23.95	15%	15.43	3.20
		OSU 5	6.3%	24.00	15%	15.08	2.71
		Average	6.4%	24.00	15%	15.27	3.00
H.Dettinger Project Manag. & Horizon Engineering	50	HDHE 1	3.5%	25.07	15%	11.72	1.84
		HDHE 2	5.3%	21.50	15%	10.28	1.78
		HDHE 3	4.0%	22.37	15%	15.12	0.94
		Average	4.3%	22.98	15%	11**	1.81**
North Carolina State University & DEECO	1536	NCSU 2/DEECO 1	38%	19.50	38%	17.03	1.53
		NCSU 3/DEECO 2	22%	24.20	22%	21.47	2.46
		NCSU 4/DEECO 3	18%	23.13	18%	20.98	2.05
		Average	20%	22.28	20%	21.23***	2.25***

Notations:

* Values do not include data from the 3-hour kiln warm up period and are adjusted to the 15% wood moisture content termination point.

** Averaged value based on kiln charges HDHE 1 and 2.

*** Averaged value based on kiln charges NCSU 3 and 4.

Table 6.2. Small-Scale Kiln Variability Study Results for Formaldehyde and Methanol

	Kiln Charge Code Designation	Formaldehyde Mass Emission Rate (lb/MBF)*	Methanol Mass Emission Rate (lb/MBF)*
Mississppi State University	MSU 3	0.0201	0.0232
	MSU 4	0.0170	0.0254
	Average	0.0186	0.0243
Oregon State University	OSU 3	0.0252	0.2209
	OSU 4	0.0263	0.1824
	Average	0.0257	0.2017
H.Dettinger Project Manag. & Horizon Engineering	HDHE 3	0.0092	0.1293
North Carolina State University & DEECO	NCSU 3/DEECO 2	0.0126	0.1822

Notations:

* Values do not include data from the 3-hour kiln warm up period and are adjusted to the 15% wood moisture content termination point.

lumber charge. Formaldehyde and methanol sampling were conducted concurrently with VOC sampling, thus information in Table 6.2 can be matched by charge number to cycle times provided in Table 6.1.

The values determined for the mass emission rate of formaldehyde ranged from 0.0092 lb/MBF to 0.0263 lb/MBF. Since MSU and OSU collected formaldehyde data from two kiln charges, the values reported in Table 6.2 for these small-scale kilns were averaged at 0.0186 lb/MBF and 0.0257 lb/MBF, respectively. The lowest emission rate, 0.0092 lb/MBF was calculated from the data collected by HDHE during their third kiln charge. This same drying cycle also corresponded to the lowest VOC emission rate reported in Table 6.1. The data collected by DEECO at the NCSU small-scale kiln yielded a formaldehyde mass emission rate of 0.0126 lb/MBF.

The methanol emission rates presented in Table 6.2 range from 0.0232 lb/MBF to 0.221 lb/MBF for all of the sampled data. The lowest value was obtained by MSU and the highest value by OSU. The methanol emission rates calculated for HDHE and NCSU/DEECO were 0.129 lb/MBF and 0.182 lb/MBF, respectively.

6.2 Lumber Sampling Method

This project developed a lumber sampling method for the Variability Study and another lumber sampling method for the Phase II effort. The lumber samples for both sampling efforts were stacked on pallets and shrink-wrapped. The Variability Study lumber samples were transported by refrigerated truck the same day the round wood was processed at the saw mill. The delivery time for the Variability Study lumber samples ranged from 10 hours for MSU to five days for OSU. The Phase II lumber samples were stored at 35°F in a refrigerated trailer which was kept on-site during the sampling efforts. The storage time prior to shipping for the direct-fired lumber samples was five days and for the steam kiln lumber samples it was nine days. The amount of time required to deliver steam kiln charges was the same as for the direct-fired samples.

A limited investigation was conducted during the Variability Study to determine what effect the refrigerated environment had on the lumber samples. Table 6.3 below shows the results of the lumber samples that were weighed prior to shipping and then again when delivered to each small-scale kiln. The lumber samples for the Variability Study were all 2 by 4 inches by 8 feet long.

The average moisture loss for these samples was calculated to be 0.35 lb of water or 0.07 lb/BF of sample.

The objective of the lumber sampling method used for the Variability Study was to randomly divide 12,192 board feet of 20-year old slash pine lumber into five differently sized samples. Each sample represented four kiln charges worth of lumber for the small-scale kilns at MSU, OSU, Horizon Engineering, NCSU, and the Forest Products Laboratory in Madison, Wisconsin.

The weights reported by MSU, OSU and Horizon Engineering for each of the sample charges shown in Table 6.4 have been normalized to pounds per board foot (lb/BF) to aid in assessing the ability of the lumber sampling method to configure equivalent charges. NCSU did not weigh each of their charges to calculate the green, kiln-dried, and oven dried moisture contents. Instead, those parameters were assessed using moisture sections from each of the kiln charges.

Table 6.3. Moisture Loss During Shipment

Board Sample Number	Original Weight (lb)	Delivered Weight (lb)	Weight loss (lb)	Weight Loss per BF (lb/BF)
MSU 01	23.00	22.50	0.50	0.09
MSU 02	24.00	24.00	0.00	0.00
OSU 01	25.00	24.16	0.84	0.16
OSU 02	24.75	24.67	0.08	0.01
HE 01	24.25	23.80	0.45	0.08
HE 02	21.75	21.20	0.55	0.10
NCSU 03	24.50	24.50	0.00	0.00
NCSU 04	24.50	24.24	0.26	0.05
NCSU 05	24.50	23.91	0.59	0.11
NCSU 06	23.25	22.73	0.52	0.10
NCSU 07	23.25	22.64	0.61	0.11
NCSU 08	24.75	24.40	0.35	0.07
NCSU 09	24.25	23.86	0.39	0.07
NCSU 10	26.25	26.25	0.00	0.00
NCSU 11	24.75	24.57	0.18	0.03

The data indicate that MSU received green lumber charges that ranged from 4.35 lb/BF to 4.48 lb/BF. The three sample charges sent to OSU had very similar green weight densities that averaged 4.50 lb/BF. Horizon Engineering, however, reported green wood densities of 4.19, 4.35, and 4.72 lb/BF for their three Variability Study sample charges.

The results from the NCSU moisture sections indicated that the green moisture content of the three lumber charges dried at NCSU averaged 100%-dry MC. Using the oven-dry weights determined for each sample charge, the green percent moisture content of the MSU sample charges averaged 91%-dry and for OSU 98%-dry. The lumber charges sent to Horizon Engineering, on the other hand, averaged 87%-dry moisture content.

MSU reported that their sample charges had oven-dry densities that ranged from 2.25 to 2.35 lb/BF. The oven-dried densities for the OSU sample charges ranged from 2.24 to 2.32 lb/BF. Horizon Engineering reported an average oven-dry density of 2.37 lb/BF for all of the three of the sample charges they received.

The lumber sampling method developed for Phase II extracted representative samples from each of the full-scale kiln test charges. The mill personnel at the direct-fired kiln provided the opportunity to collect green and kiln-dry weights for a portion of the lumber packets that made up the first three test charges. The process involved using a tared forklift to transport the lumber packets to and from the mill's truck scale. The packet weights shown in Table F.1, Appendix F include the weight of the stickers which may have added a slight positive bias. The average weight densities for test charges FSK DF1, FSK DF2, and FSK DF3 were 4.31 lb/BF, 4.33 lb/BF, and 4.45 lb/BF, respectively. The kiln dried weight densities for these three charges were 2.52, 2.69, and 2.51 lb/BF, respectively.

Table 6.4. Variability Study Lumber Sampling Data

Kiln Charge Designation	Charge Size (BF)	Green Charge Weight (lb)	Green Charge Weight per BF (lb/BF)	Kiln-dry Charge Weight (lb)	Kiln dry Charge Weight per BF (lb/BF)	Oven-dry Charge Weight (lb)	Oven dry Charge Weight per BF (lb/BF)	Green wood % MC-dry	End of Sample Event wood % MC-dry	Kiln-dry wood % MC-dry	Weight of water loss (lb)	Weight of water loss per BF (lb/BF)
Mississippi State University												
MSU 1	31.94	141	4.41	83	2.60	74	2.32	91%	15%	12%	58	1.82
MSU 2	31.94	143	4.48	85	2.66	75	2.35	91%	15%	13%	58	1.82
MSU 3	31.94	140	4.38	80	2.50	72	2.25	94%	15%	11%	60	1.88
MSU 4	31.94	139	4.35	82	2.57	74	2.32	88%	15%	11%	57	1.78
	Average		4.41		2.58		2.31	91%	15%	12%		1.82
Oregon State University												
OSU 3	48.89	219.0	4.48	117.7	2.41	110.7	2.26	98%	15%	6%	101	2.07
OSU 4	48.89	221.7	4.53	120.7	2.47	113.4	2.32	96%	15%	6%	101	2.07
OSU 5	48.89	219.4	4.49	116.4	2.38	109.5	2.24	100%	15%	6%	103	2.11
	Average		4.50		2.42		2.27	98%	15%	6%		2.08
Horizon Engineering, Inc.												
HE 1	49.78	235.2	4.72	122.2	2.45	118.0	2.37	99%	15%	4%	113	2.27
HE 2	49.78	208.8	4.19	124.2	2.50	118.0	2.37	77%	15%	5%	85	1.70
HE 3	49.78	216.4	4.35	122.7	2.46	118.0	2.37	83%	15%	4%	94	1.88
	Average		4.42		2.47		2.37	87%	15%	4%		1.95

The weight densities for the sample charges sent to MSU and OSU from the direct-fired kiln are shown in Table 6.5. The green weight densities for the MSU sample charges ranged from 3.29 to 4.17 lb/BF, while for OSU the range was 3.30 to 3.87 lb/BF. The oven-dried densities for the MSU sample charges ranged from 1.91 to 2.37 lb/BF. The OSU sample charges ranged in oven-dried densities from 2.03 to 2.23 lb/BF.

Table 6.6 shows the weight densities determined for the steam kiln sample charges sent to MSU and OSU. The green weight densities for the MSU sample charges ranged from 3.85 to 4.73 lb/BF. The oven-dried densities for those same charges ranged from 1.78 to 2.44 lb/BF. The OSU sample charges had green densities that ranged from 3.94 to 4.18 lb/BF. The oven-dried densities determined for the OSU sample charges ranged from 2.00 to 2.19 lb/BF. The oven-dry and green densities of lumber in this project are within the range of densities for southern pine provided in the *Dry Kiln Operator's Manual* (U. S. Dept. of Agriculture 1991).

6.3 Phase II Testing Schedule and Duration of Sampling Events

In Phase II of this project 12 full-scale kiln and 24 small-scale kiln charges were continuously sampled for total VOCs. The full-scale kiln sampling effort was divided into six direct-fired kiln charges and six steam-heated kiln charges. For each full-scale kiln charge there was one corresponding small-scale kiln charge dried at MSU and OSU.

The direct-fired full-scale kiln was tested first. This kiln was tested on two separate occasions that were three months apart. Sampling of the steam kiln followed with all six kiln charges tested in a nine day period.

The termination point for each sampling event was based on the moisture content of the wood. An attempt was made to terminate each small-scale kiln sample charge at the same kiln-dry wood moisture content as the corresponding full-scale kiln charge. This project encountered problems, however, in establishing the exact kiln-dry moisture content of each full-scale kiln charge because the kiln operators used indirect methods for determining this parameter, such as the temperature drop across the load (TDAL) and moisture meters. The kiln operators did, however, report that their target percent moisture content was 15%-dry. The lumber packet data provided earlier in Section 6.2, however, showed that the estimated kiln-dried moisture contents for the first three direct-fired kiln charges ranged from 12% to 15%-dry (Table F.1, Appendix F). These values indicated that there was a possibility that the full-scale kiln charges were dried below the targeted 15%-dry wood moisture content. To account for this possibility, the VOC mass emission rate data from the small-scale kilns were terminated at the wood moisture content values shown in Table 6.7.

The emission rate data for MSU was terminated at an average wood moisture content of 12% and 13%-dry for the direct-fired and steam kiln sample charges, respectively. The termination points for the OSU direct-fired and steam sample data were 13% and 14%-dry, respectively.

The determination of the ending wood moisture content for each kiln charge thus established the duration of each sampling event. The duration of the sampling events at the full- and small-scale kilns is provided in Table 6.8. The duration of the sampling events at the direct-fired kiln averaged 17.2 hours. The average duration of the sampling events for the corresponding sample charges dried at MSU and OSU was 15.8 hours and 17.4 hours, respectively.

The duration of the sampling events at the steam-heated kiln averaged approximately 25.7 hours (Table 6.8). The corresponding corrected sampling events at MSU and OSU were 13.2 hours and 17.7 hours.

The dates and times of each sampling event are provided below for the Phase II portion of this project.

Table 6.5. Lumber Sampling Data from the Direct-fired Kiln

Kiln Charge Designation	Charge Size (BF)	Green Charge Weight (lb)	Green Charge Weight per BF (lb/BF)	Kiln-dry Charge Weight (lb)	Kiln dry Charge Weight per BF (lb/BF)	Oven-dry Charge Weight (lb)	Oven dry Charge Weight per BF (lb/BF)	Green wood % MC-dry	End of Sample Event wood % MC-dry	Kiln-dry wood % MC-dry	Weight of water loss (lb)	Weight of water loss per BF (lb/BF)
Mississippi State University												
MSU DF1A	28.75	117	4.07	76	2.64	68	2.37	72%	12%	12%	41	1.43
MSU DF1B	28.75	120	4.17	71	2.47	63.5	2.21	89%	12%	12%	49	1.70
MSU DF2	31.94	105	3.29	70	2.19	64	2.00	64%	13%	9%	35	1.10
MSU DF3A	28.75	105	3.65	69	2.40	64	2.23	64%	11%	8%	36	1.25
MSU DF3B	28.75	110	3.83	70	2.43	64	2.23	72%	12%	9%	40	1.39
MSU DF4	31.94	124	3.88	68	2.13	61	1.91	103%	12%	11%	56	1.75
MSU DF5	31.94	108	3.38	71	2.22	64	2.00	69%	13%	11%	37	1.16
MSU DF6	28.75	119	4.14	76	2.64	68	2.37	75%	12%	12%	43	1.50
	Average		3.80		2.39		2.16	76%	12%	11%		1.41
Oregon State University												
OSU DF1	73.33	283.6	3.87	180.7	2.46	162.0	2.21	75%	12%	12%	103	1.40
OSU DF2C	48.89	176.1	3.60	117.9	2.41	104.5	2.14	69%	13%	13%	58	1.19
OSU DF3	73.33	268.4	3.66	183.2	2.50	163.5	2.23	64%	12%	12%	85	1.16
OSU DF4	73.33	242.1	3.30	175.2	2.39	157.3	2.15	54%	12%	11%	67	0.91
OSU DF5	73.33	265.7	3.62	171.8	2.34	149.9	2.04	77%	15%	15%	94	1.28
OSU DF6	73.33	257.8	3.52	167.1	2.28	148.9	2.03	73%	13%	12%	91	1.24
	Average		3.60		2.40		2.13	69%	13%	12%		1.20

Table 6.6. Lumber Sampling Data from the Steam Heated Kiln

	Charge Size (BF)	Green Charge Weight (lb)	Green Charge Weight per BF (lb/BF)	Kiln-dry Charge Weight (lb)	Kiln dry Charge Weight per BF (lb/BF)	Oven-dry Charge Weight (lb)	Oven dry Charge Weight per BF (lb/BF)	Green wood % MC-dry	End of Sample Event wood % MC-dry	Kiln-dry wood % MC-dry	Weight of water loss (lb)	Weight of water loss per BF (lb/BF)
Mississippi State University												
MSU INDF1	31.94	131	4.10	75	2.35	71	2.22	85%	14%	6%	56	1.75
MSU INDF2	31.94	123	3.85	61	1.91	57	1.78	116%	14%	7%	62	1.94
MSU INDF3	31.94	129	4.04	64	2.00	61	1.91	111%	12%	5%	65	2.04
MSU INDF5	27.47	130	4.73	71	2.58	67	2.44	94%	13%	6%	59	2.15
MSU INDF6	31.94	127	3.98	70	2.19	66	2.07	92%	15%	6%	57	1.78
MSU INDF7	31.94	121	3.79	65	2.04	61	1.91	98%	13%	7%	56	1.75
	Average		4.08		2.18		2.06	99%	13%	6%		1.90
Oregon State University												
OSU INDF1	73.33	306.3	4.18	169.9	2.32	154.9	2.11	98%	14%	10%	136	1.86
OSU INDF2	73.33	292.8	3.99	168.9	2.30	155.8	2.12	88%	14%	8%	124	1.69
OSU INDF3	73.33	299.1	4.08	169.8	2.32	151.9	2.07	97%	14%	12%	129	1.76
OSU INDF5	70.28	276.8	3.94	162.8	2.32	153.6	2.19	80%	14%	6%	114	1.62
OSU INDF6	73.33	291.6	3.98	171.9	2.34	155.7	2.12	87%	13%	10%	120	1.63
OSU INDF7	73.33	295.5	4.03	166.1	2.27	146.5	2.00	102%	14%	13%	129	1.76
	Average		4.03		2.31		2.10	92%	14%	10%		1.72

Table 6.7. Lumber Moisture Content Results

Sample Event Code	Lumber Dimension	FSK	MSU		OSU
		Wood-Moisture Content (dry)			
		DIRECT-FIRED KILN LUMBER SAMPLES			
1	2 x 6	12%	12%	12%	12%
2	2 x 4	15%	13%		13%
3	2 x 6	13%	11%	12%	12%
4	2 x 4	12%-15%*	12%		12%
5	2 x 4	12%-15%*	13%		15%
6	2 x 6	12%-15%*	12%		13%
	Average	13%	12%		13%
		STEAM KILN LUMBER SAMPLES			
1	2 x 4		14%		14%
2	2 x 4		14%		14%
3	2 x 4		12%		14%
5	2 x 6		13%		14%
6	2 x 4		15%		13%
7	2 x 4		13%		14%
	Average	12%-15%*	13%		14%

*Estimated moisture content

Table 6.8. Duration of Sampling Events

Sample Event Code	Lumber Dimension	FSK	MSU		OSU
		Duration of Sample Events (hours)			
		DIRECT-FIRED KILN LUMBER SAMPLES			
1	2 x 6	19.4	15.3	17.3	20.2
2	2 x 4	17.7	16.0		17.0
3	2 x 6	18.0	16.0	16.0	18.7
4	2 x 4	16.2	16.1		16.0
5	2 x 4	15.8	14.0		15.6
6	2 x 6	16.3	15.4		17.0
	Average	17.2	15.8		17.4
		STEAM KILN LUMBER SAMPLES			
1	2 x 4	25.1	12.0		17.0
2	2 x 4	24.9	12.0		16.0
3	2 x 4	28.9	12.0		19.0
5	2 x 6	25.0	18.0		17.0
6	2 x 4	25.1	12.0		18.0
7	2 x 4	25.1	13.0		19.0
	Average	25.7	13.2		17.7

Stage I: Dates and Times for the Direct-fired Kiln Sampling Events

Kiln Charge	FSK Test Dates (1999) & Times	MSU Test Dates (1999) & Times	OSU Test Dates (1999) & Times
DF1	5/19 – 5/20 12:13 - 07:36	(DF1A) 5/31 07:32 - 22:50 (DF1B) 6/8 – 6/9 06:59 - 00:15	6/3 – 6/4 05:21 - 01:30
DF2	5/20 – 5/21 12:25 - 06:10	7/1 04:34 – 21:20	6/17 – 6/18 14:32 - 07:29
DF3	5/21 - 5/22 12:01 - 06:02	(DF3A) 6/3 – 6/4 07:22 - 00:14 (DF3B) 6/23 05:15 - 22:15	6/10 05:08 - 23:47

Stage II: Dates and Times for the Direct-fired Kiln Sampling Events

Kiln Charge	FSK Test Dates (1999) & Times	MSU Test Dates (1999) & Times	OSU Test Dates (1999) & Times
DF4	8/3 - 8/4 14:42 - 06:55	8/11 04:21 - 20:27	8/20 05:27 - 21:30
DF5	8/4 - 8/5 15:14 - 06:59	8/24 03:14 - 18:00	8/23 05:23 - 20:59
DF6	8/5 - 8/6 14:11 - 06:28	8/18 03:26 - 18:48	8/24 05:02 - 22:02

Stage III: Dates and Times for the Steam-Heated Kiln Sampling Events

Kiln Charge	FSK Test Dates (1999) & Times	MSU Test Dates (1999) & Times	OSU Test Dates (1999) & Times
INDF1	10/5 - 10/6 16:40 - 17:47	11/03 03:21 - 20:07	11/9 - 11/10 13:06 - 10:06
INDF2	10/6 - 10/7 21:43 - 22:38	11/09 03:08 - 19:09	11/3 - 11/4 09:52 - 06:25
INDF3	10/7 - 10/9 23:24 - 04:18	11/11 - 11/12 07:05 - 00:07	11/11 - 11/12 09:22 - 05:34
INDF5	10/11 - 10/12 15:18 - 16:16	10/26 - 10/27 03:07 - 00:27	10/28 - 10/29 03:14 - 04:38
INDF6	10/12 - 10/13 17:43 - 18:42	11/18 05:51 - 21:18	11/18 - 11/19 04:56 - 00:59
INDF7	10/13 - 10/14 19:30 - 20:36	11/16 04:12 - 20:10	12/2 - 12/3 04:58 - 00:28

Appendices P and Q provide further information on lumber moisture contents and sampling times on a per sample run basis for the direct-fired and steam kiln drying cycles, respectively, at the full- and small-scale kilns.

6.4 Phase II VOC Mass Emission Rate Results

The direct-fired, full-scale kiln VOC mass emission rates presented in Table 6.9 ranged from 2.9 lb of VOC as C/MBF to 4.7 lb VOC as C/MBF. The average value was 3.8 lb VOC as C/MBF.

The steam-heated, full-scale kiln VOC mass emission rates (Table 6.9) ranged from 3.0 lb VOC as C/MBF to 4.7 lb VOC as C/MBF. The average value was 3.5 lb VOC as C/MBF.

The corresponding direct-fired sample charges at MSU yielded an average VOC mass emission rate of 2.4 lb VOC as C/MBF. This average was based on six charges and two duplicates shown in Table 6.9. VOC mass emission rates ranged from 1.9 lb VOC as C/MBF to 3.2 lb VOC as C/MBF.

The corresponding direct-fired sample charges at OSU yielded an average VOC mass emission rate of 3.0 lb VOC as C/MBF. The emission rates ranged from 2.0 lb VOC as C/MBF to 3.9 lb VOC as C/MBF. The results for each charge are shown in Table 6.9.

Appendices P and Q also provide further information on the measurement system "up-time," calibration times, and emission rates per sample run for the direct-fired and steam kiln drying cycles, respectively, at the full- and small-scale kilns.

Table 6.9. VOC Mass Emission Rate Results

Sample Event Code	Lumber Dimension	FSK	MSU	OSU
		(lb VOC as Carbon/MBF)		
		DIRECT-FIRED KILN LUMBER SAMPLES		
1	2 x 6	4.2	3.2 2.7	3.1
2	2 x 4	4.7	2.5	3.9
3	2 x 6	4.2	2.6 2.2	3.8
4	2 x 4	2.9	1.9	3.0
5	2 x 4	3.4	1.9	2.0
6	2 x 6	3.6	2.6	2.4
	Average	3.8	2.4	3.0
		STEAM KILN LUMBER SAMPLES		
1	2 x 4	3.0	4.8	4.4
2	2 x 4	3.9	2.6	3.9
3	2 x 4	4.7	2.6	4.6
5	2 x 6	3.1	3.3	3.8
6	2 x 4	3.0	2.6	4.4
7	2 x 4	3.5	2.4	4.4
	Average	3.5	3.1	4.2
Overall Average		3.7	2.7	3.6

6.5 Phase II Formaldehyde and Methanol Mass Emission Rate Results

Four of the twelve lumber charges were sampled for formaldehyde and methanol at the full-scale kiln and small-scale kilns. Table 6.10 provides the results.

The formaldehyde results for the two direct-fired charges averaged 0.10, 0.02, and 0.009 lb formaldehyde/MBF for the full-scale kiln, MSU and OSU, respectively. Formaldehyde results for the two steam-heated charges averaged 0.02, 0.003, and 0.02 lb formaldehyde/MBF for the full-scale, MSU, and OSU kilns, respectively.

The methanol results for the two steam-heated sampled charges averaged 0.16, 0.11, and 0.12 lb methanol/MBF for the full-scale kiln, MSU and OSU, respectively. Methanol results for the two steam-heated sampled charges averaged 0.21, 0.17, and 0.23 lb methanol/MBF for the full-scale kiln, MSU and OSU, respectively.

MSU did not sample steam charge number three for formaldehyde and methanol as was done at the full-scale kiln and at OSU. MSU results provided in this section were for the second steam sample charge instead.

Further details about the individual 3-hour formaldehyde and methanol sample runs are provided in Appendix R. The information presented is for the sampling efforts conducted with the NCASI Chilled Impinger Train sampling method.

6.6 Speciated VOC Mass Emission Rate Results

One drying cycle at the full-scale steam-heated kiln, the NCSU kiln, and the OSU kiln was sampled for 16 different compounds. These compounds collectively may be referred to as "VOC species" and this type of sampling may be referred to as "VOC speciation." In this case, the VOC species were various compounds listed by EPA as "hazardous air pollutants" (HAPs) plus terpenes and acetone. The NCASI Impinger/Canister Method was used to collect and analyze the compounds. The list of compounds targeted by this study are provided in Table 6.11.

Of the sixteen compounds analyzed, six were present at levels above 0.01 lb/MBF. They were acetaldehyde, acetone, formaldehyde, methanol, alpha-pinene, and beta-pinene. Mass emission rates for the 16 compounds are summarized in Table 6.11. Detailed information about each sampling effort and sample run has been provided in Appendix S.

Table 6.10. Formaldehyde and Methanol Mass Emission Rate Results

Sample Event Code	Lumber Dimension	FSK	MSU	OSU	FSK	MSU	OSU
		lb Formaldehyde/MBF			lb Methanol/MBF		
				DIRECT-FIRED KILN LUMBER SAMPLES			
2	2 x 4	0.091	0.020	0.009	0.171	0.101	0.142
5	2 x 4	0.114	0.020	0.008	0.151	0.112	0.089
	Average	0.103	0.020	0.009	0.161	0.107	0.116
				STEAM KILN LUMBER SAMPLES			
1	2 x 4	0.012	0.003	0.019	0.145	0.165	0.176
2	2 x 4		0.003			0.169	
3	2 x 4	0.019		0.023	0.265		0.274
	Average	0.016	0.003	0.021	0.205	0.167	0.225

Table 6.11. Speciated VOC Mass Emission Rate Results

	NCSU/DEECO	Steam FSK	OSU
	Phase I Charge 3	Phase II INDF3	Phase II INDF3
Ending Wood %Moisture Content:	22%	Assumed to be 12%-15%	14%
Duration of Drying Cycle (hr)	24.5	28.9	19.0
Charge Dimension (MBF)	1.54	156.10	0.07
VOC Compounds		lb/MBF	
ACETALDEHYDE	0.030	0.039	0.065
ACETONE	0.054	0.037	0.083
ACROLEIN	0.003	0.006	0.009
BENZENE	BDL	BDL	BDL
FORMALDEHYDE	0.013	0.019	0.023
M,P-XYLENE	BDL	BDL	BDL
METHANOL	0.182	0.265	0.274
METHYL ETHYL KETONE (MEK)	BDL	BDL	BDL
METHYL ISOBUTYL KETONE	BDL	0.001	0.001
O-XYLENE	BDL	0.0002	BDL
PHENOL	BDL	BDL	BDL
PROPIONALDEHYDE	0.001	0.001	0.003
STYRENE	BDL	BDL	BDL
TOLUENE	BDL	0.0001	0.0001
ALPHA-PINENE	1.320	0.291	0.361
BETA-PINENE	0.323	0.130	0.184

7.0 DISCUSSION

7.1 Small-Scale Variability Study

One of the primary objectives of the Variability Study was to assess variability among the small-scale kilns and among sampling events at individual small-scale kilns. The statistical parameters variance, standard deviation, and relative standard deviation provide measures of variability. For the small sample sizes available in this study, these parameters are perhaps best viewed as indicators of variability. Table 7.1 provides a statistical summary of the VOC results from the Variability Study. Figure 7.1 provides a graphical representation of VOC emission rate ranges overall and at each small-scale kiln.

Table 7.1. Statistical Analysis of the Variability Study VOC Data

	Average VOC (lb/MBF)	No. of Samples	Variance (w/in)	Stand. Dev. (lb/MBF)	Relative Stand. Dev. (%)
MSU	2.1	4	0.09	0.29	14.0
OSU	3.0	3	0.07	0.26	8.6
HDHE	1.5	3	0.25	0.50	33.6
NCSU and DEECO	2.0	3	0.22	0.47	23.3
All Small-Scale Kilns	2.2	13	0.40	0.63	28.6
MSU and OSU	2.5	7	0.30	0.55	22.0

These data indicate that MSU's and OSU's sample results were less variable than the other two facilities and, when combined, were less variable than the data set representing the results from all small-scale kilns. Difficulties in drying the lumber to a 15% endpoint appear to be responsible for much of the variability at NCSU. Difficulties in kiln operation and/or VOC measurement at the HDHE small-scale kiln are discussed later in this section.

The variability in the VOC results may have been affected by the kiln dry moisture contents reached by each small-scale kiln. MSU was the only small-scale kiln that ended its dry cycles close to the target 15%-dry wood moisture content value during the Variability Study. OSU and HDHE had kiln dry moisture contents that were considerably less than 15%-dry moisture content. NCSU, on the other hand, was considerably above the target wood moisture content value. The use of load cells could aid in estimating when small-scale kiln lumber charges have reached the target kiln dry wood moisture content.

The second objective of the Variability Study was to select two small-scale kilns to conduct the work efforts required in Phase II. The selection of the two small-scale kilns was based on a satisfactory assessment of the statistical data and the ability to meet the operating and sampling criteria specified by the project.

The VOC mass emission rate data were used to determine how well the measurement system and small-scale kiln performed at each facility. By plotting the lb VOC as C/MBF emitted for every sample interval over the duration of the sampling event, a VOC mass emission rate curve was produced for

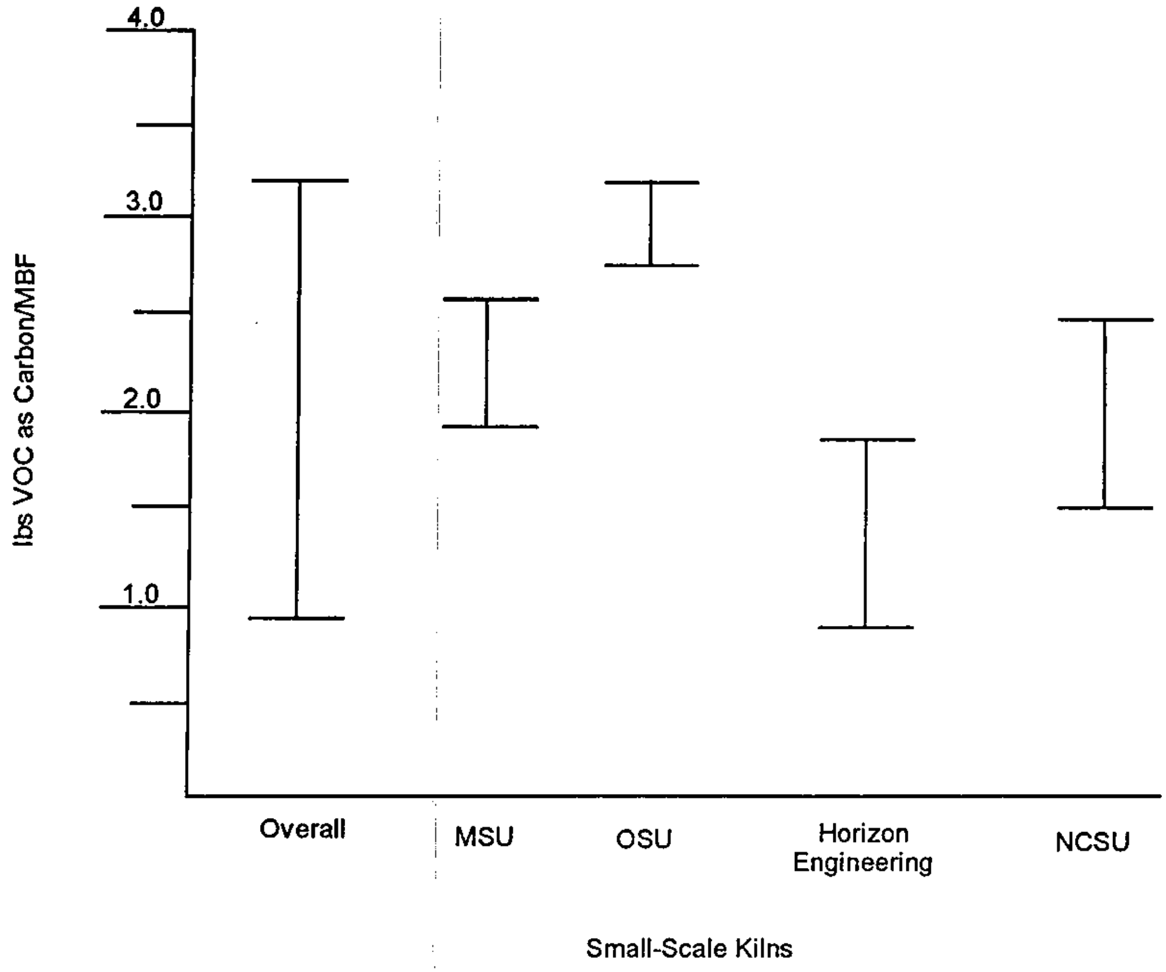

Figure 7.1. Variability Study VOC Mass Emission Rate Ranges

each drying cycle. The curves for the drying cycles at each facility were plotted on the same graph to evaluate the measured data and the performance of each small-scale kiln. These VOC mass emission rate curves are shown in Figures 7.2 through 7.5.

The mass emission rate curves for the MSU data (Figure 7.2) appear to have a different overall trend than the other three curves because MSU did not record emission rate data during the first three hours of the drying cycle. The beginning of the MSU VOC emission rate curves, at the 3-hour mark, appears to correspond to the backside of the peaks that are observed in the curves from the other three small-scale kilns. Although the initial peak is unavailable, the remainder of the four VOC mass emission rate curves tend to follow the same pattern. This indicates that MSU was able to operate their sample measurement system and kiln in a consistent manner.

Figure 7.3 shows that OSU was also able to operate their measurement system and kiln in a consistent manner. As can be seen, the VOC mass emission rate sharply increases to a peak at about hour three as the kiln is warming up to the set point temperatures. The emission rate then gradually decreases over the remainder of the drying cycle. This curve description matches the generic profile of the VOC mass emission rate curves reported at southern pine full-scale kilns.

The NCSU VOC mass emission rate curve shown in Figure 7.4 is different from the other small-scale kilns because the data were measured from two vents located on the roof of the NCSU kiln. The VOC emission rate during the first three hours is low because the roof vents were closed for the kiln's initial 3-hour warm-up period. At the 3-hour mark, the VOC curves show a significant jump in emission rate that corresponds to the opening of the exhaust roof vent. After the initial period of venting, the VOC curve follows the same gradual pattern of decreasing emission rate over the course of the remaining drying cycle. The profile of the three kiln charges at NCSU indicates that the measurement system and kiln were operated in a consistent manner. The spikes in the NCSU/DEECO data were caused by kiln fan reversals every three hours.

Results from the HDHE kiln (Figure 7.5) indicated inconsistency in kiln operation and/or VOC measurement. During the initial 3-hour warm-up period, the curve for two of the three drying cycles reached two emission peaks while the third charge followed a lower but steadily increasing trend. After the third hour of drying, the emission rate of one of the two fluctuating curves then decreased to a much lower emission rate and remained low for the remainder of the drying cycle. The other two curves followed a typical gradually decreasing emission rate trend after the 3-hour mark.

One reason for the inconsistent VOC emission rate data reported by HDHE may be explained by analyzing the exhaust flow rate patterns from the small-scale kilns. If the exhaust flow rate patterns shown in Figure 7.6 for HDHE are compared with patterns from the other kilns (Figures 7.7 through 7.9), it is evident that the HDHE kiln did not appear to operate as consistently as the other three small-scale kilns.

Another observation made from the exhaust flow rate data was that the data collected by MSU (Figure 7.7) had a vastly different pattern than the rest of the kilns. Although this venting rate pattern was different, the VOC mass emission rate results still indicate that MSU controlled their drying cycles in a consistent manner.

Figures 7.8 and 7.9 show very good duplication of exhaust flow rates at OSU and NCSU, respectively. When considered in conjunction with the VOC mass emission rate curves, the conclusion can be made that small-scale kilns have the capability of operating in a consistent manner.

The decision for choosing the small-scale kilns at MSU and OSU for the Phase II portion of this project was based on the VOC mass emission rate results, relatively low variability among sample

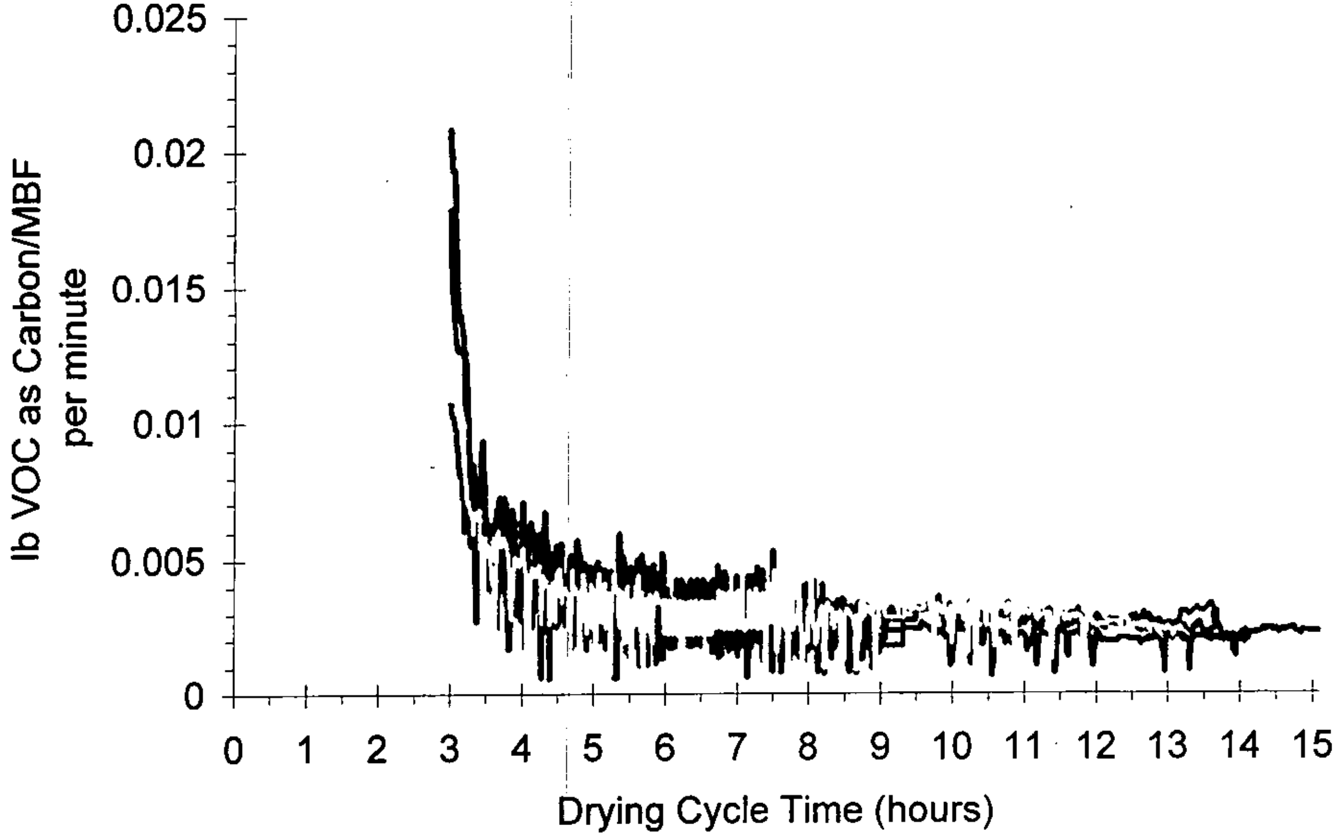

Figure 7.2. VOC Mass Emission Rates from a Generic High Temperature Drying Schedule (Variability Study Kiln Charges MSU 1 through 4)

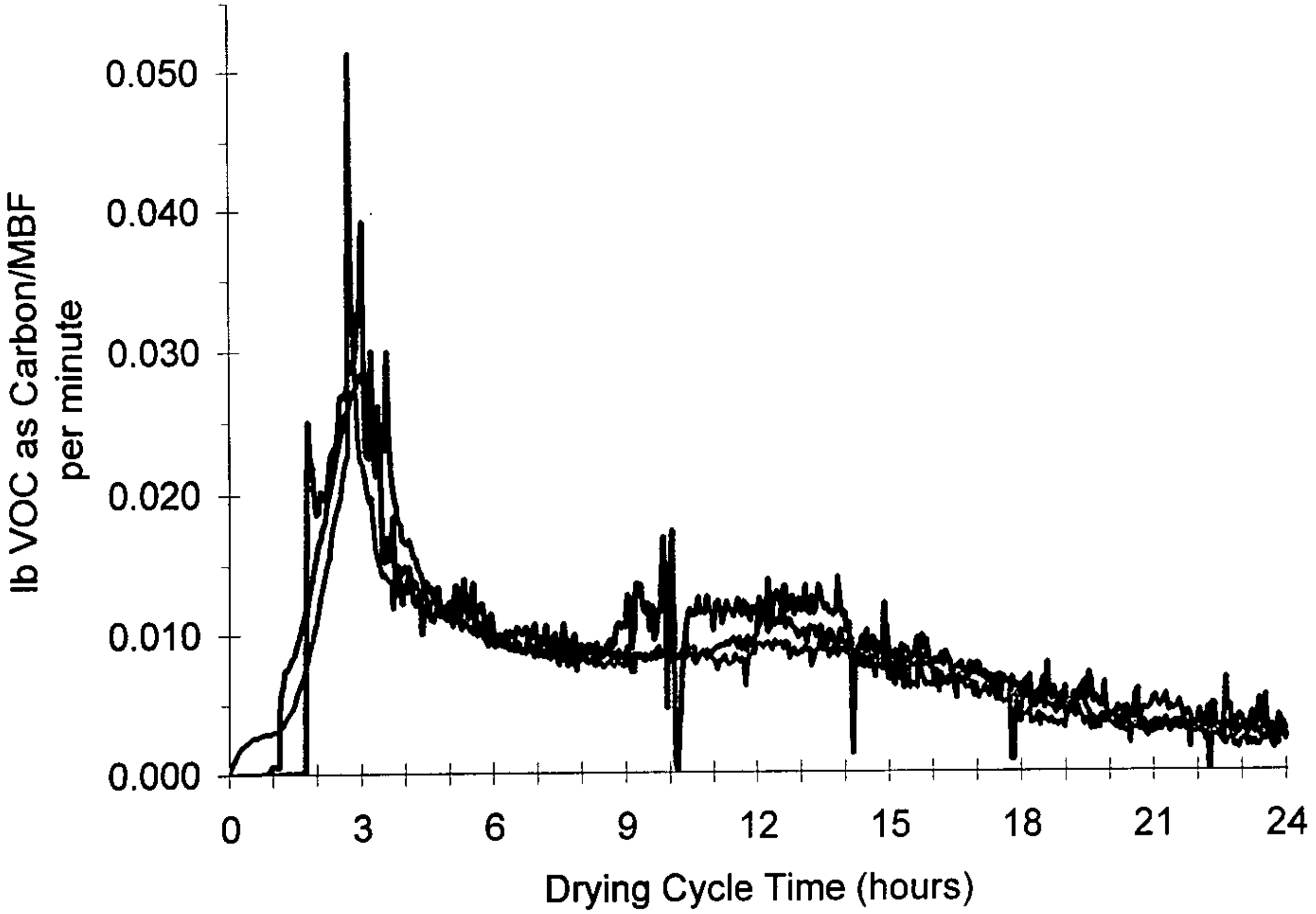

Figure 7.3. VOC Mass Emission Rates from a Generic High Temperature Drying Schedule (Variability Study Kiln Charges OSU 3 through 5)

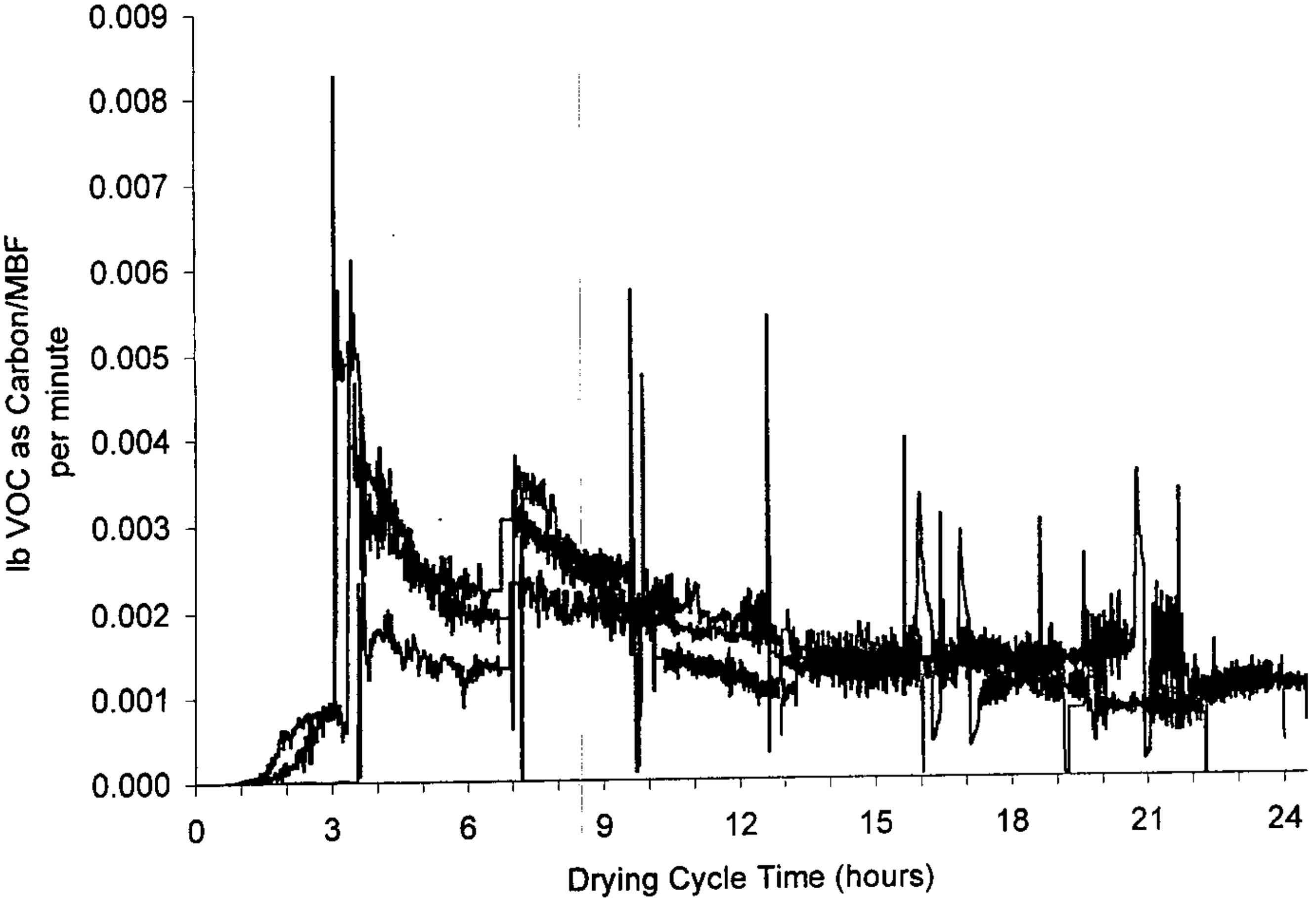

Figure 7.4. VOC Mass Emission Rates from a Generic High Temperature Drying Schedule (Variability Study Kiln Charges NCSU 2 through 4)

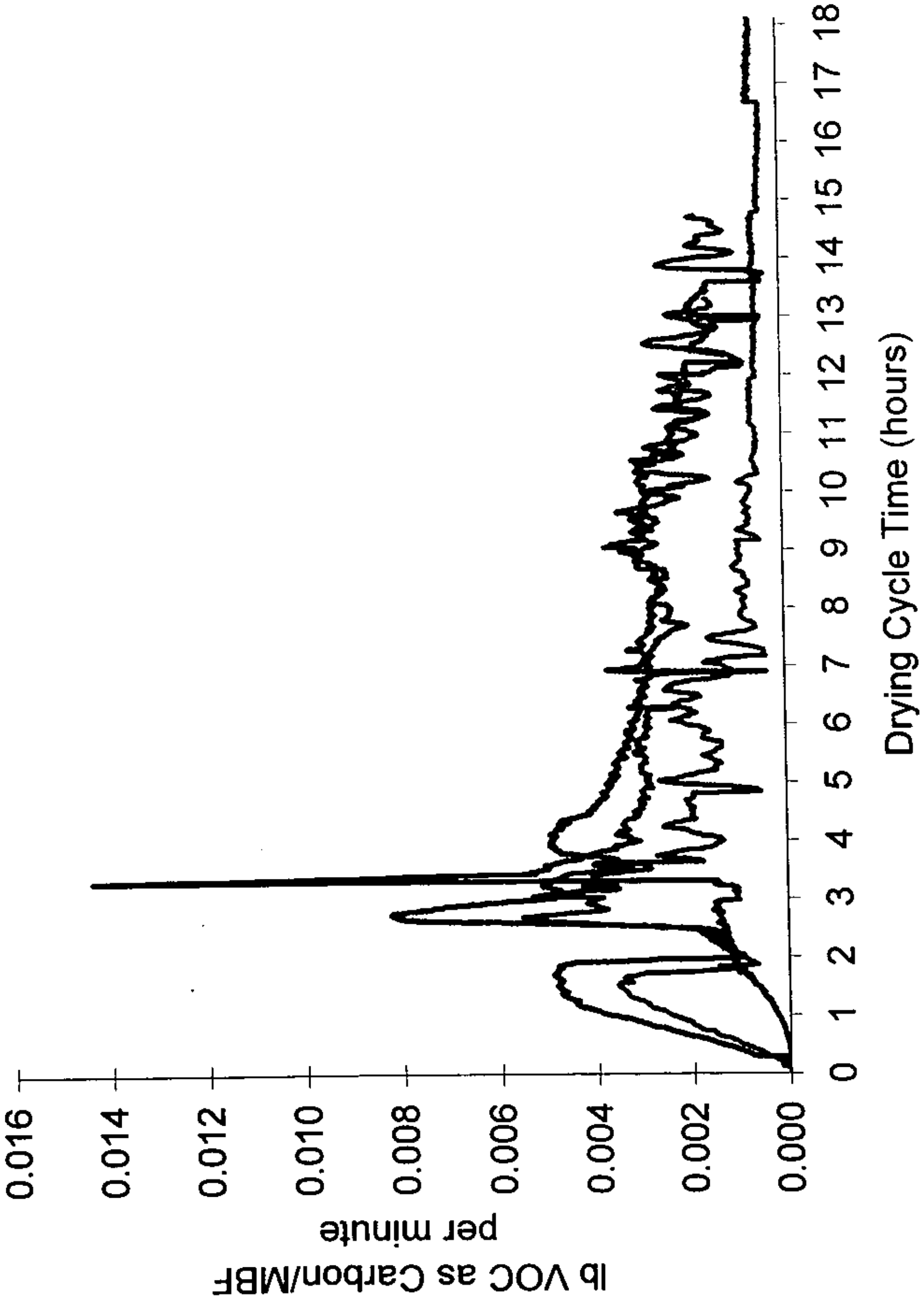

Figure 7.5. VOC Mass Emission Rates from a Generic High Temperature Drying Schedule (Variability Study Kiln Charges HDHE 1 thru 3)

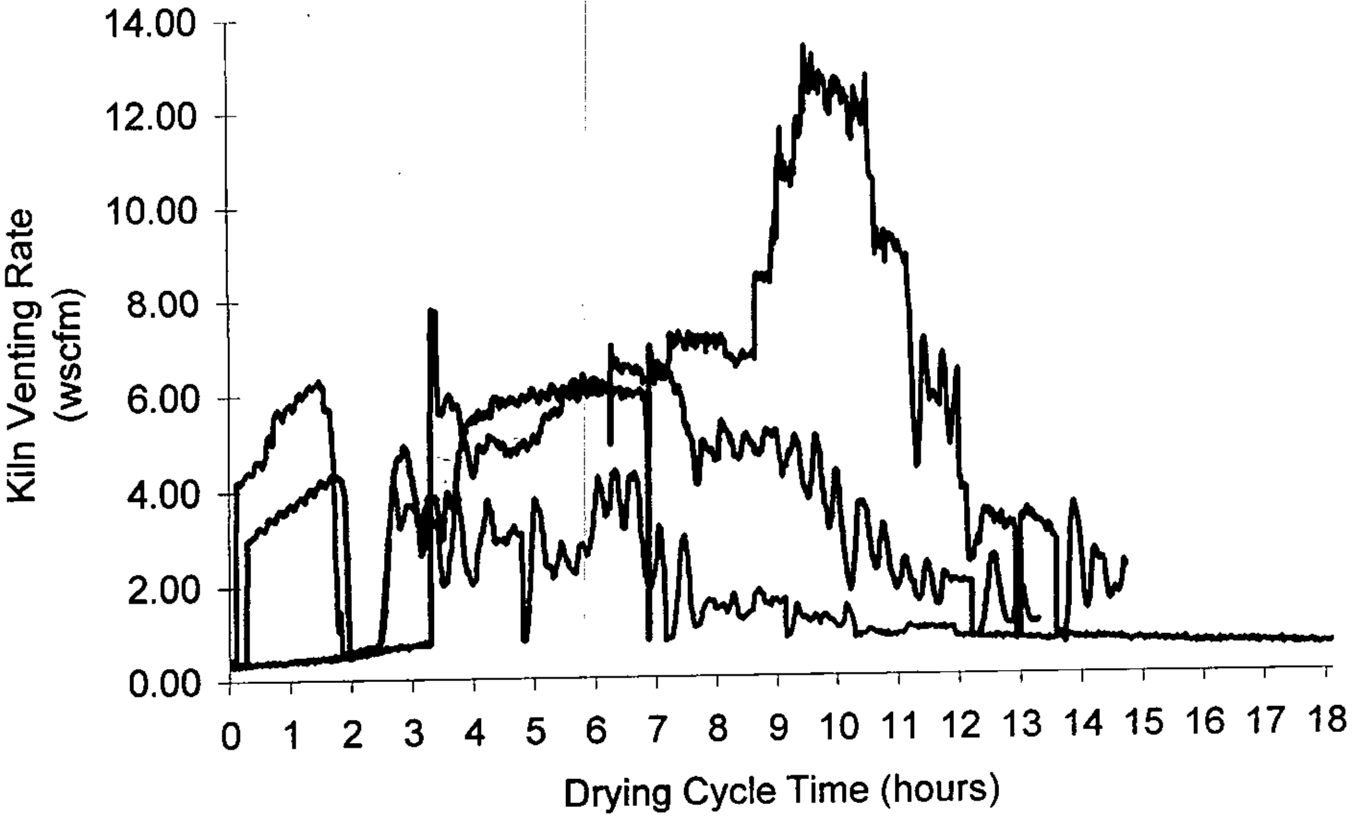

Figure 7.6. Comparison of Kiln Venting Rates (Variabilty Study Kiln Charges HDHE 1 thru 3)

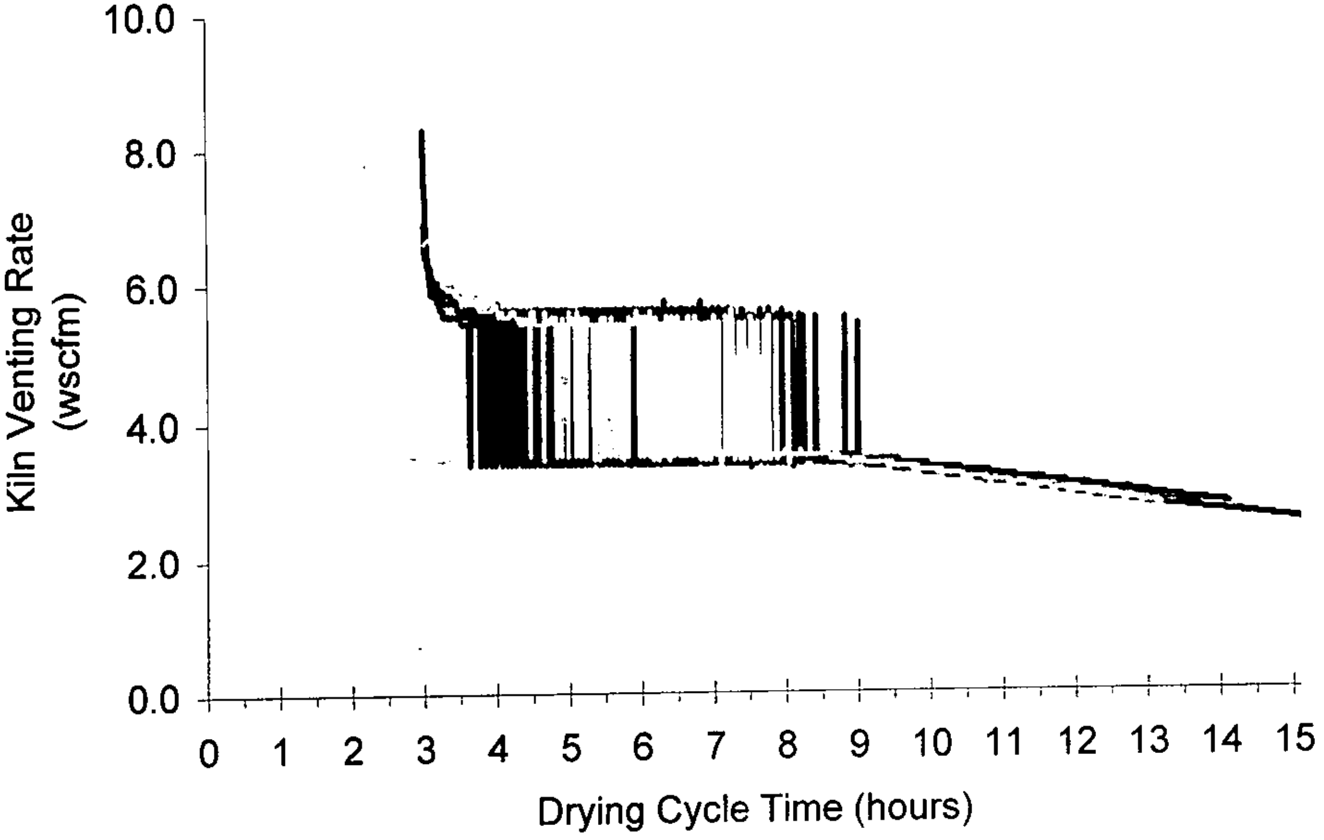

Figure 7.7. Comparison of Kiln Venting Rates (Variability Study Kiln Charges MSU 1 through 4)

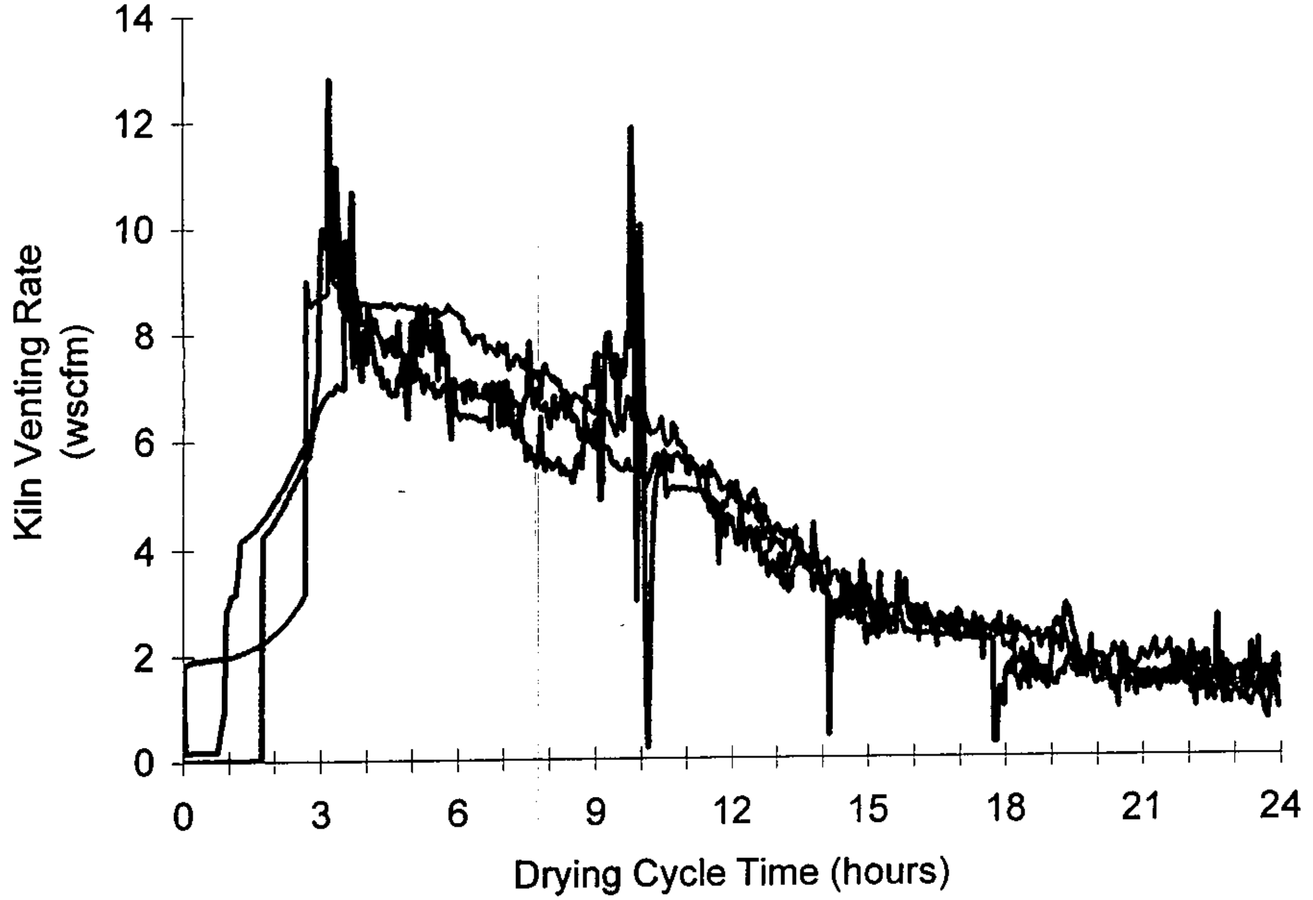

Figure 7.8. Comparison of Kiln Venting Rates (Variability Study Kiln Charges OSU 3 through 5)

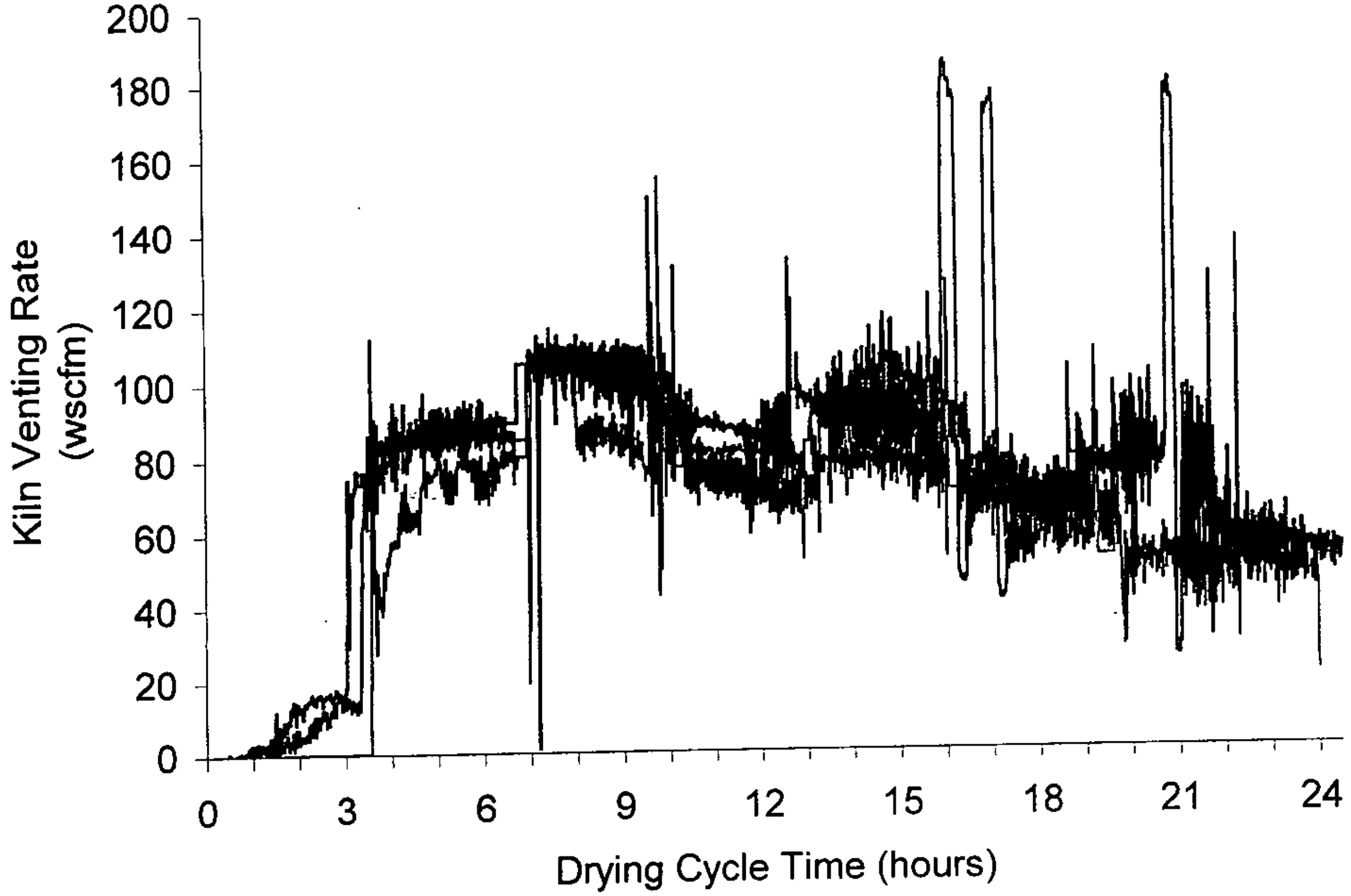

Figure 7.9. Comparison of Kiln Venting Rates (Variability Study Kiln Charges NCSU 2 through 4)

runs, the ability to control drying cycles in a consistent manner, and the willingness to allocate the required resources for the Phase II sampling effort. As previously mentioned, MSU, OSU, and NCSU were all able to control their drying cycles in a consistent manner as indicated by the VOC mass emission rate and exhaust flow rate curves. NCSU, however, did not express an interest in continuing into Phase II.

7.2 Lumber Sampling Methods

One of the objectives of this project was to develop a method to sample, store and ship the lumber obtained from the saw mills for the Variability Study and Phase II portions of this project. The lumber sampling methods developed for this project did not attempt to segregate individual boards by differences such as the number of knots or grain structure; instead, the methods focused on the importance of obtaining random lumber samples from each source sampled. Once the lumber samples were collected, the lumber was stored and shipped in refrigerated environments that were maintained below 35°F.

A limited assessment of the effect that refrigerated storage and transport had on the Variability Study lumber samples was made by determining the difference in weight loss between the sample's weight prior to shipment and upon delivery. The average weight loss from each sample board in the test was determined to be 0.35 lb, approximately 1%. The difference in weight, however, could be attributed to the fact the there were two different scales used to weigh the original and delivered sample boards. The accuracy of the scale used to weigh the original sample boards was considered to be within ±0.125 lb. Thus, the weights in Table 6.3 were reported to the nearest quarter pound.

The ability of the variability lumber sampling method to generate equivalent lumber samples for the Phase I participants was assessed by comparing the green densities, oven-dry densities, and wood moisture contents of the lumber samples sent to each small-scale kiln. The green lumber density at MSU and OSU compared favorably with the results being 4.41 and 4.50 lb/BF, respectively. The percent moisture content of the green lumber sent to MSU and OSU averaged 91%-dry and 98%-dry, respectively, while the moisture sections analyzed by NCSU averaged 100%-dry wood moisture content.

Although the average green wood density of the Horizon Engineering (HE) sample charges was equivalent to the value determined for MSU, the green densities for the individual charges varied significantly. The standard deviation for the green densities of the HE charges was 0.27 lb/BF compared to 0.05 lb/BF for the MSU samples. The average oven dried densities, however, were similar at 2.37 and 2.31 lb/BF, respectively. The were no oven-dried densities reported for the individual HE sample charges, so the differences in the standard deviations of oven dried densities could not be assessed.

Based on green lumber moisture contents, and green and oven-dry lumber densities, it appears that the Variability Study participants received equivalent lumber samples and that the lumber sampling method was successful.

The sample charges sent to MSU and OSU from both the direct-fired and steam kilns compared favorably in terms of green and oven-dry wood densities. The variability within the two groups of sample charges was somewhat different, however. The standard deviation of the green sample densities sent to MSU from both full-scale kilns was 0.34 lb/BF, while for OSU they were 0.18 and 0.08 lb/BF for the direct-fired and steam kilns, respectively. Since the relative standard deviations for the lumber charges sent to MSU and OSU were below 9%, the Phase II lumber sampling method appeared to extract equivalent samples for the small-scale kilns.

The wood density data collected from the first three direct-fired kiln charges did not compare favorably with the data determined from the sample charges sent to MSU and OSU. The green wood density range of 4.31 to 4.45 lb/BF at the full-scale kiln differed significantly from the 3.29 to 4.17 lb/BF that was determined for the corresponding small-scale kiln sample charges.

The discrepancy in the full- and small-scale kiln green weight densities may be attributed to the inaccuracy of the measured weights at the saw mill or moisture loss due to storage and shipment. The scale at the saw mill was normally used to weigh full and empty log trucks. Since the forklift and lumber pack would weigh much less than the log trucks, an error could have been introduced due to the scale's inability to discriminate between smaller weight values. Another possibility for the discrepancy in the green weight densities could be from the moisture loss due to refrigerated storage. However, with the amount of the discrepancy being as much as 1.16 lb/BF, the OSU sample charges (at 73 BF), for example, would have lost 10 gallons of water. Since shrink-wrap was used to reduce the air flow through the sample charges, this amount of water loss due to evaporation seems unlikely. Additionally, significantly moisture loss did not occur under similar shipping conditions in the Variability Study.

Overall the green and dry wood density information indicates that the lumber sent to MSU and OSU was similar in dry weight and moisture content. These parameters are not a direct measure of the VOC emissions potential or content but they do indicate that the samples were reasonably equivalent.

7.3 Phase II Mass Emission Rates

7.3.1 *Phase II Mass Emission Rate Curves*

The temperature schedules for the direct-fired and steam-heated full-scale kilns differed significantly from the generic drying schedule defined for the Variability Study. In order to match the temperature schedules of the full-scale kilns in Phase II, the small-scale kilns had to reach multiple set point temperatures during the course of each drying cycle. After some kiln modifications, both MSU and OSU were able to reasonably match the demanding temperature schedules of the full-scale kilns.

The effect of the two different temperature schedules is reflected in the VOC mass emission rate curves generated for the direct-fired (Figure 7.10) and steam-heated (Figure 7.11) full-scale kilns. The direct-fired VOC curve has two peaks that are approximately the same magnitude. The first peak occurred within the first three hours as the kiln was warming up, and the second peak occurred at the end of the drying cycle. In contrast, the temperature schedule for the steam kiln produced only one VOC emission peak (Figure 7.11). Although each graph shows periods of variability, the graphs clearly show the direct-fired kiln VOC mass emission rate curve to be different from the steam-heated kiln VOC curve.

As mentioned earlier, MSU and OSU were able to match the temperature schedules of the full-scale kilns. The resulting direct-fired VOC profiles for MSU and OSU are shown in Figures 7.12 and Figure 7.13, respectively. These two figures show the two VOC emission peaks associated with the direct-fired temperature profile were also demonstrated at each of the small-scale kilns. Similarly, Figures 7.14 and 7.15 show profiles with only the one VOC emission peak for the small-scale kilns when they dried lumber according to the steam-heated kiln temperature schedule.

The fact that small-scale kilns can emulate temperature schedules and VOC emission rate curves for the full-scale kilns is encouraging. Additional evidence of this is provided by the figures in Appendix T where the VOC mass emission curves for each kiln are compared on a charge-by-charge basis. Matched curves are indicators of similar lumber drying conditions.

The straight lines that appear in the VOC mass emission rate curves are a result of data that have been interpolated. As mentioned in Section 6 of this report, the VOC data were collected over extended

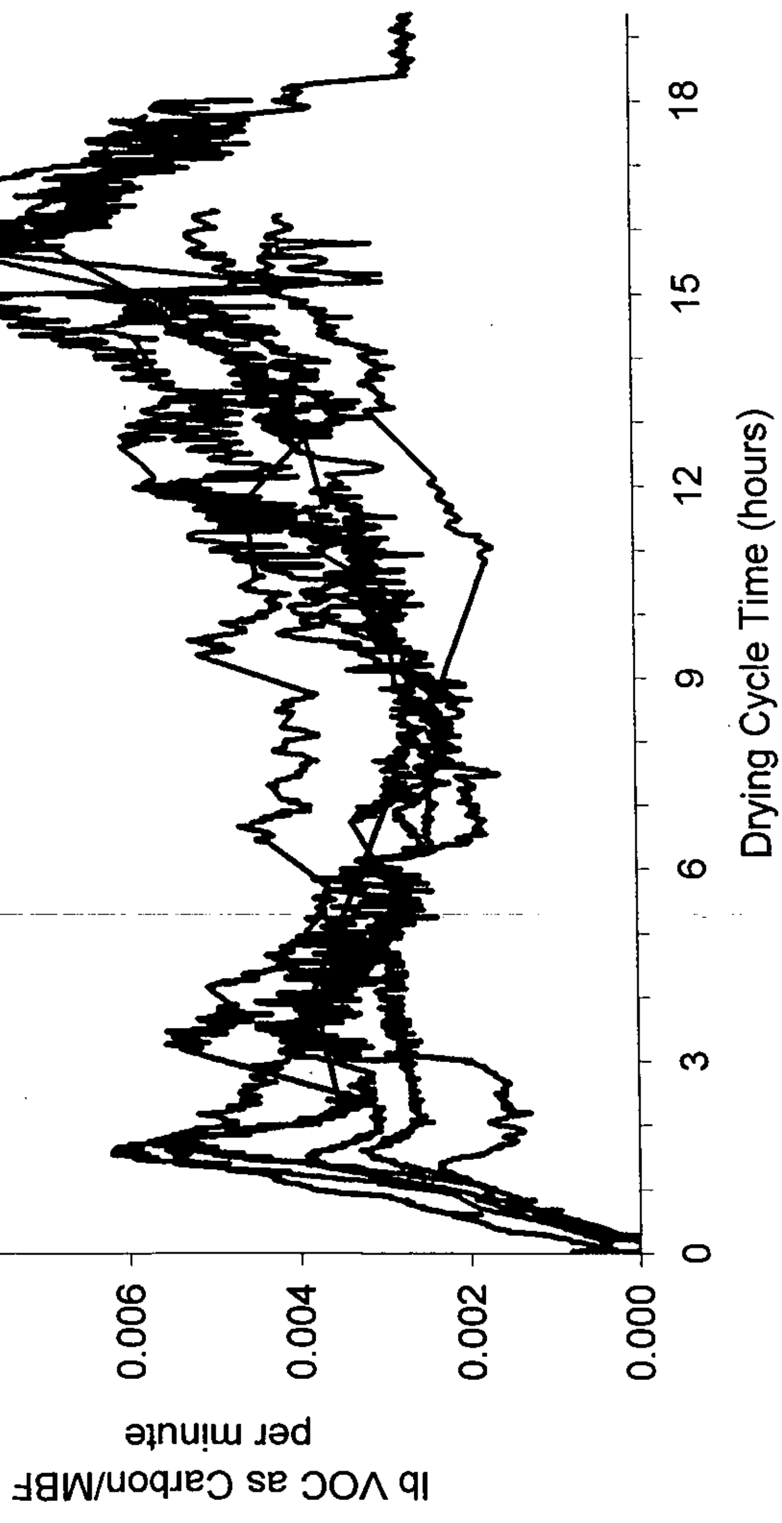

Figure 7.10. VOC Mass Emission Rates for the Direct-Fired Kiln (Kiln Charges FSK DF1 through DF6)

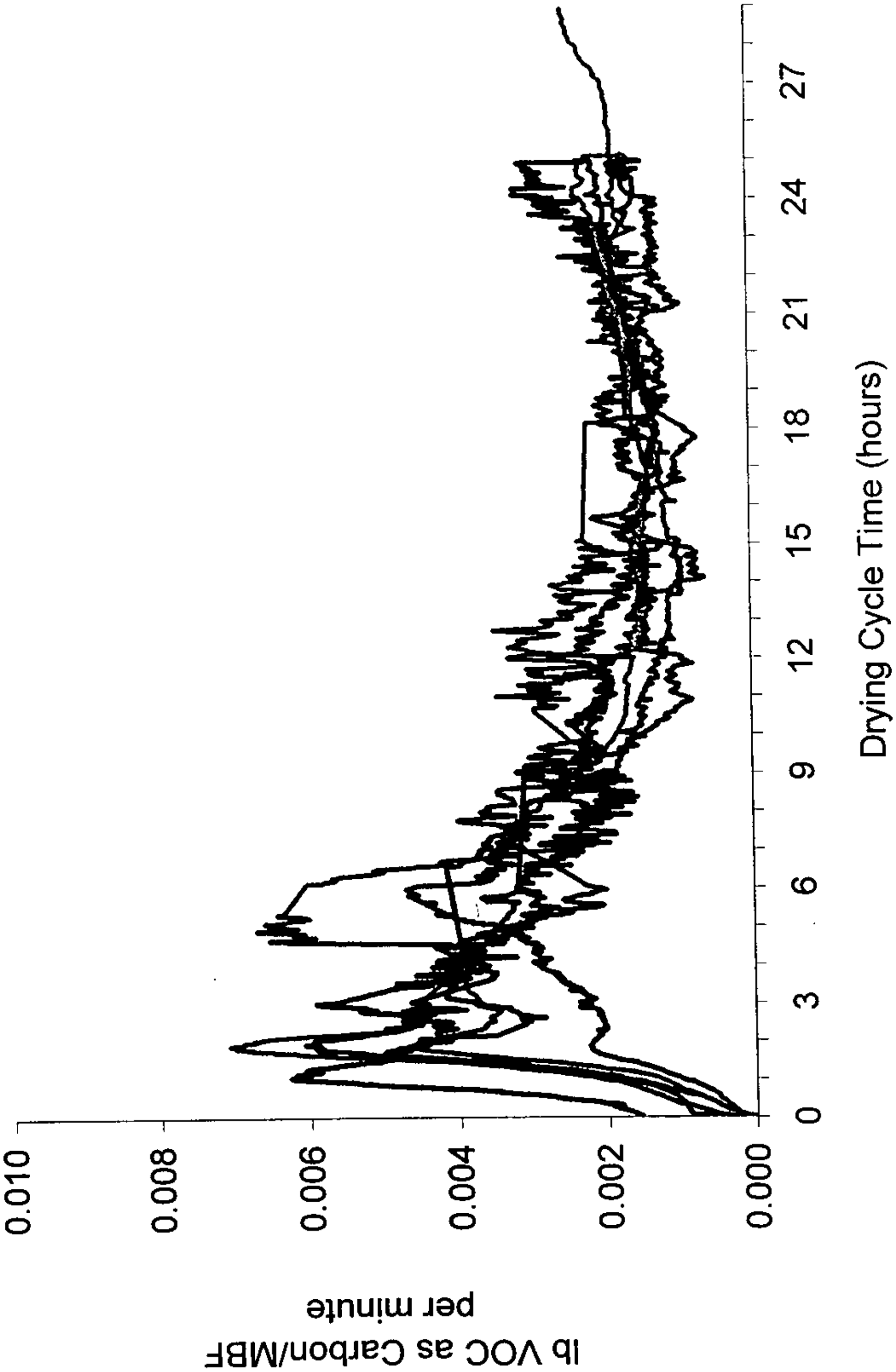

Figure 7.11. VOC Mass Emission Rates for the Steam-Heated Kiln (Kiln Charges FSK INDF1-3 and INDF 5-7)

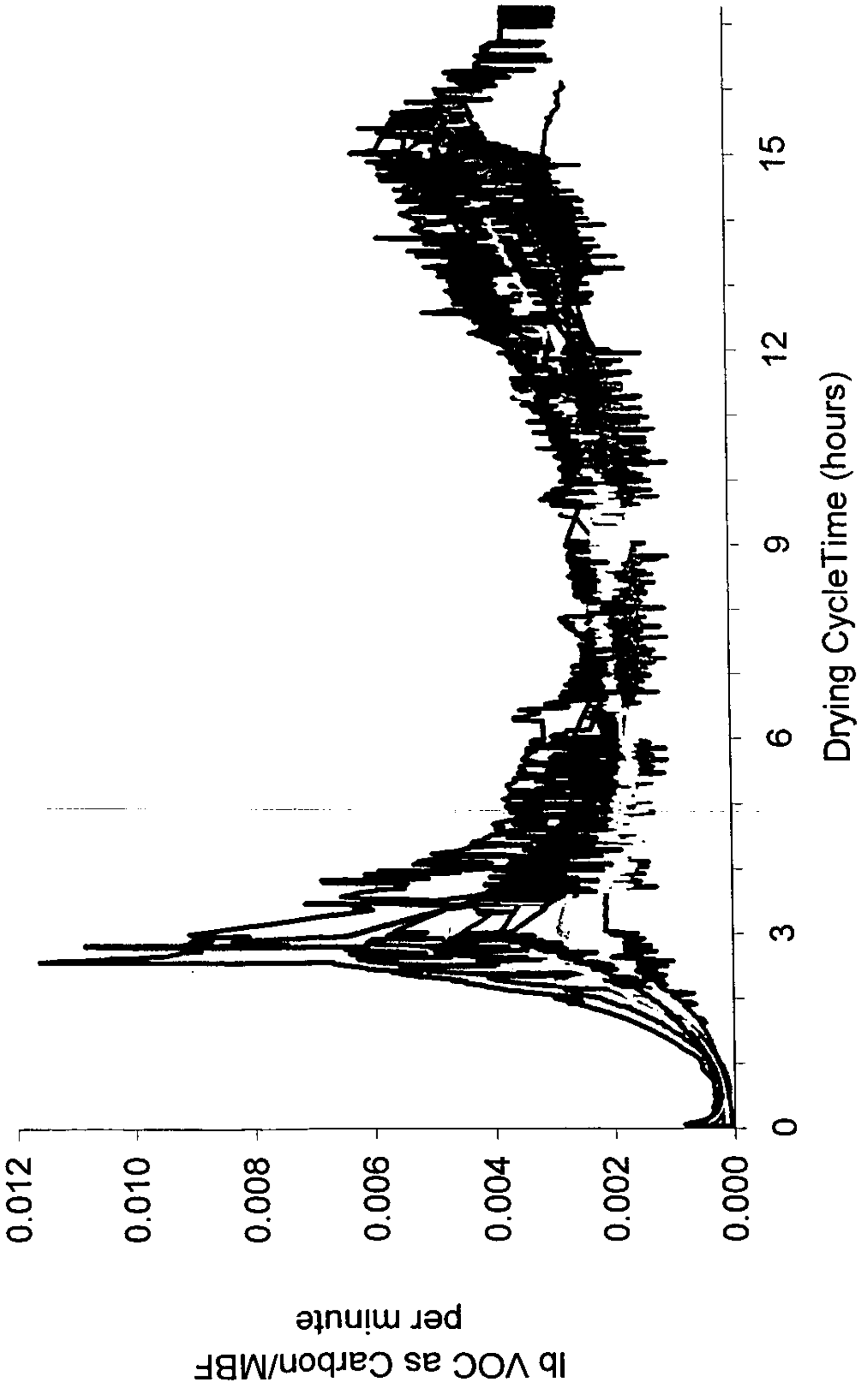

Figure 7.12. VOC Mass Emission Rates for the Direct-Fired Drying Schedule at MSU (Kiln Charges MSU DF1 through DF6)

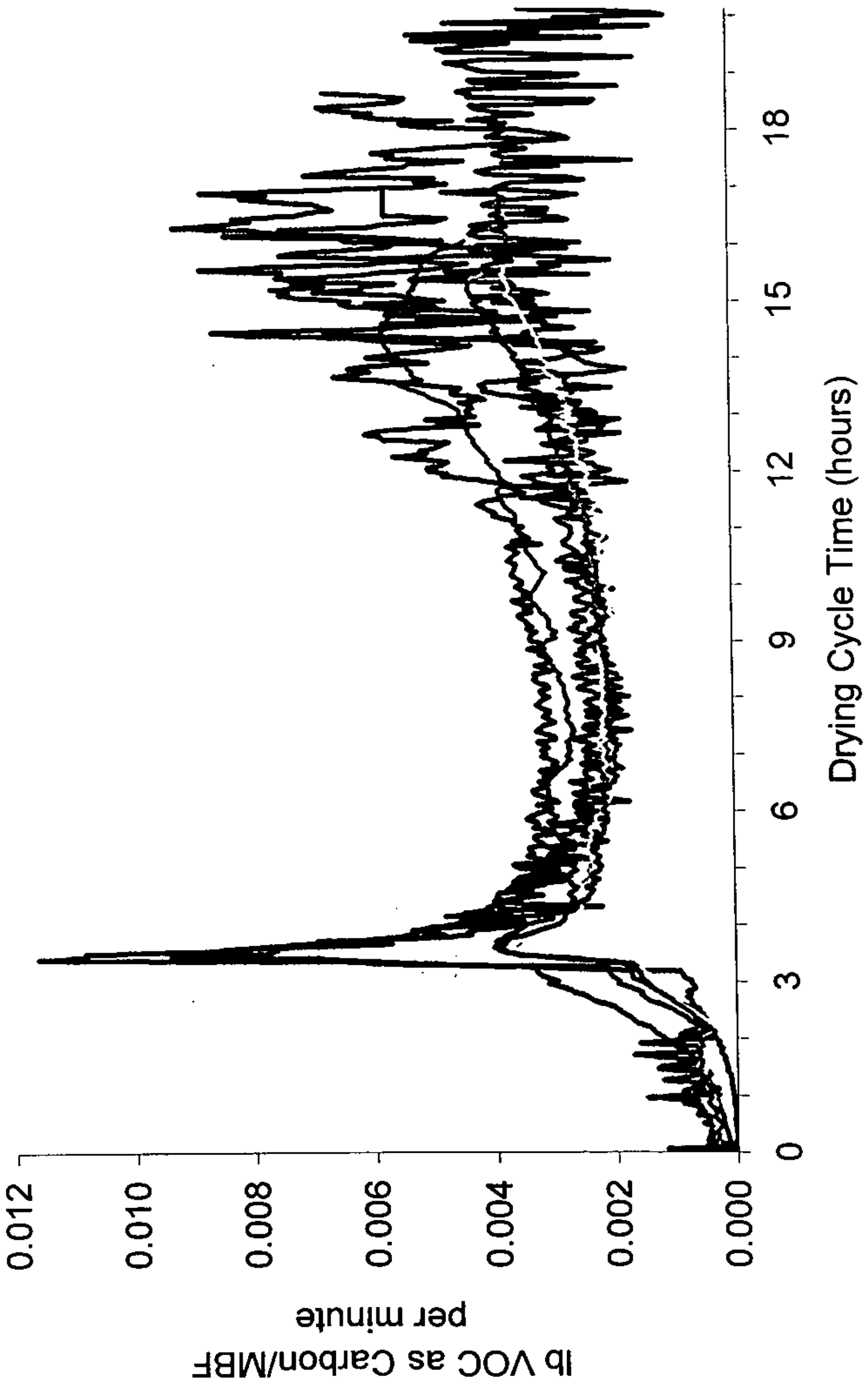

Figure 7.13. VOC Mass Emission Rates for the Direct-Fired Drying Schedule at OSU (Kiln Charges OSU DF1 through DF6)

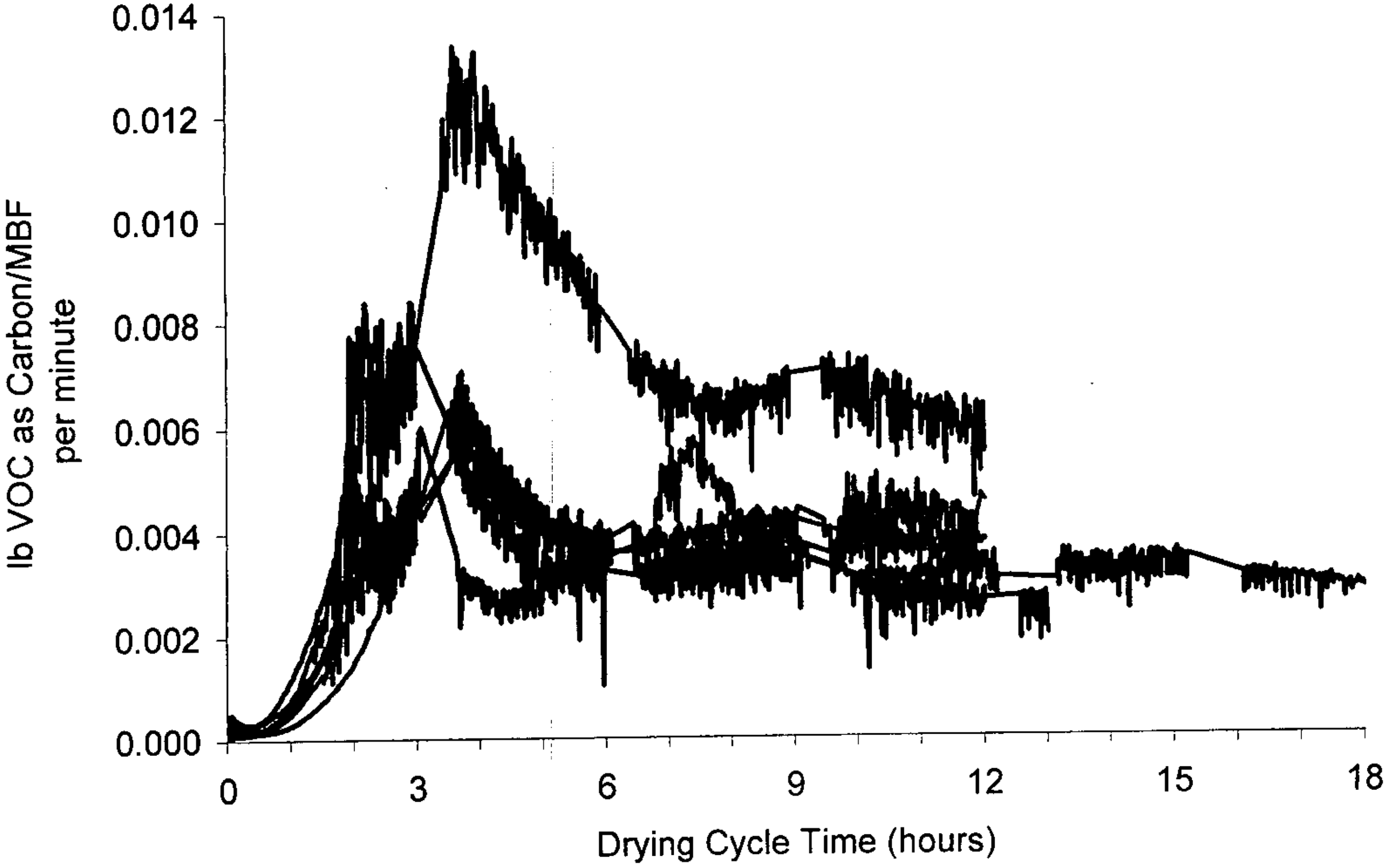

Figure 7.14. VOC Mass Emission Rates for the Steam-Heated Drying Schedule at MSU (Kiln Charges MSU INDF1-3 and INDF4-7)

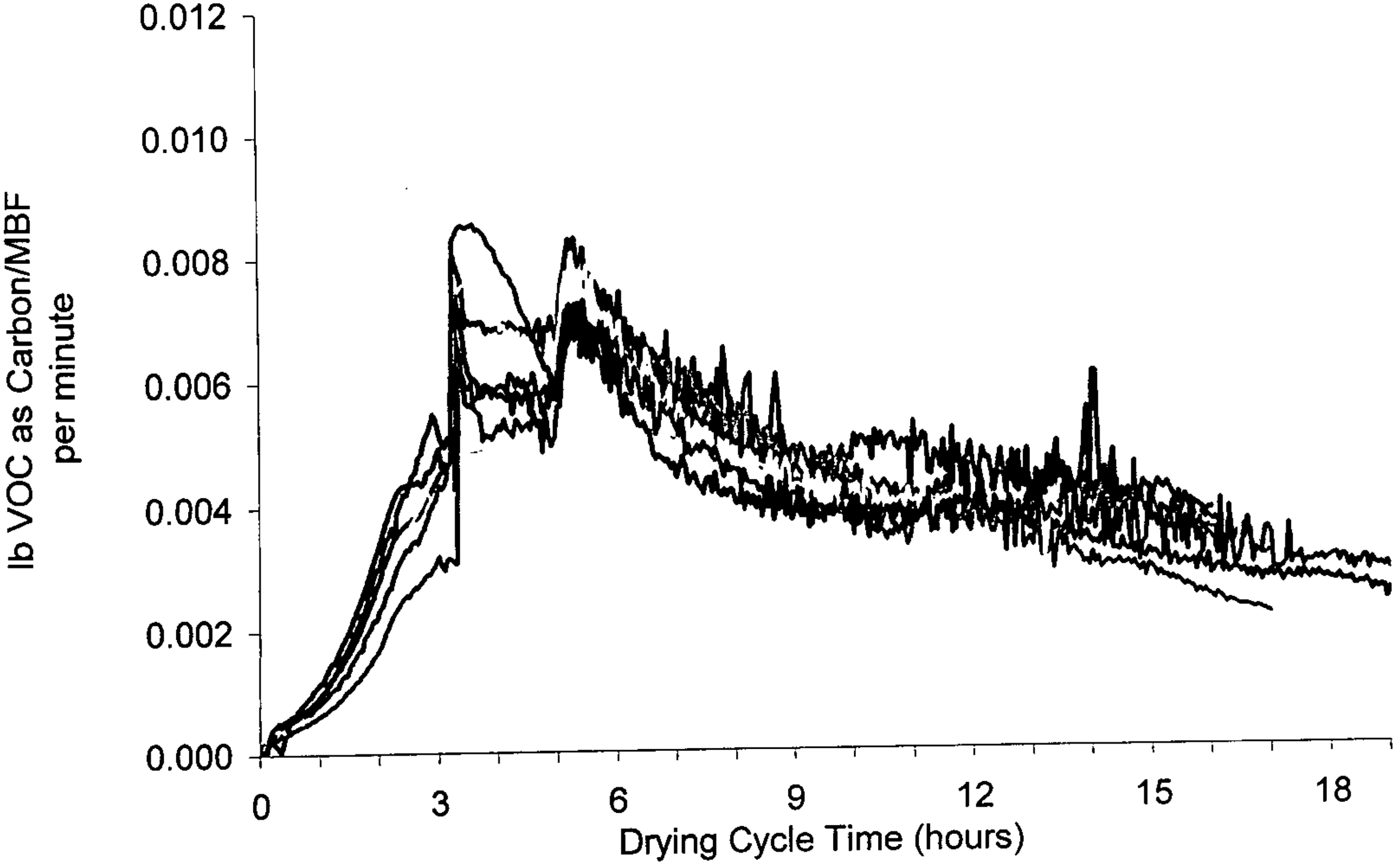

Figure 7.15. VOC Mass Emission Rates for the Steam-Heated Drying Schedule at OSU (Kiln Charges OSU INDF1-3 and INDF 5-7)

periods of time. To maintain the integrity of the measured data, each of the kiln sampling events was divided into sample runs so that no continuous period of data collection extended beyond three hours in duration. This allowed the measurement systems to be calibrated or serviced at least once every three hours. The drawback for instituting these quality assurance measures was the occasional gap in the measured data. All data gaps and other measured anomalies were interpolated to create the continuous VOC emission rate curves presented.

7.3.2 *Phase II VOC Mass Emission Rate Bar Graphs*

Graphical representations of VOC mass emission rate results from the kilns tested in Phase II of this study are shown in Figures 7.16 through 7.19. The vertical bars represent the calculated VOC mass emission rate results for each sampling event. Figure 7.16, for example, shows that there were six sampling events at the direct-fired kiln and OSU. For the MSU data in Figure 7.16, there are eight sampling events shown. The first two bars represent the results for the first sampling event MSU DF1A and for the duplicate charge, MSU DF1B. Likewise, the fourth and fifth bars show the results for MSU DF3A and DF3B.

Figure 7.16 shows that the VOC mass emission rates for the first three direct-fired full-scale kiln charges (FSK DF1, DF2, DF3) were higher than the last three kiln charges tested (FSK DF4, DF5, DF6). The difference in emissions between these two groups of measurements may be due to seasonal effects and/or air drying times. The first three test charges were conducted in May, while the last three tests were conducted in August. Furthermore, the lumber packets that made up the last three kiln charges (DF4, DF5, DF6) had been stored in the green lumber yard and air dried for approximately two days longer than the first three kiln charges (DF1, DF2, DF3). Out of all six direct-fired test charges, the fourth charge was stored for the longest period of time in the green lumber yard. The lumber charges for the steam kiln tests, however, were exposed to open storage conditions for approximately the same amount of time because of the limited green wood storage capacity at that saw mill.

While fugitive emissions were minimal at the direct-fired kiln, the exhaust fan at the steam kiln did not completely vent the kiln out of the heat exchanger exhaust stack. To minimize fugitive emissions from the steam kiln, an extra fan was installed after the first drying cycle (FSK INDF1) to draw more exhaust out of the kiln through the heat exchanger stack. This may explain the relatively low VOC emission result calculated for FSK INDF1 as shown in Figure 7.17. The two small-scale kilns did not have lower VOC emissions for the first charge.

The variability in the VOC mass emission rates could also be attributed to the differences in the volume of gas exhausted from the full- and small-scale kilns during the drying cycles. The values shown in Table 7.2 for the total volume of kiln gas exhausted have been normalized to a wet and dry standard cubic feet per thousand boot feet (scf/MBF) basis. For the direct-fired drying schedule, the full-scale kiln exhausted a significantly higher volume of gas exhaust (178,000 wscf/MBF) than the small-scale kilns (89,800 wscf/MBF). The steam drying schedule, on the other hand, showed the opposite phenomenon whereby the full-scale kiln exhausted 34,900 wscf/MBF of kiln gas, while 89,000 wscf/MBF and 80,200 wscf/MBF were measured for MSU and OSU, respectively.

Another factor that may have contributed to the variability in the full-scale kiln data was the effect that high moisture conditions had on the sampling equipment. The sampling equipment performed well at the direct-fired kiln where the exhaust gas had an average moisture content of 40%. At the steam kiln, however, the exhaust gas unexpectedly had a much higher moisture content. Moisture contents of 70% were encountered because measures taken to seal the kiln (to prevent fugitive losses) caused an increase in the wet bulb temperature inside the kiln. Because of the high moisture level in the sampled gas

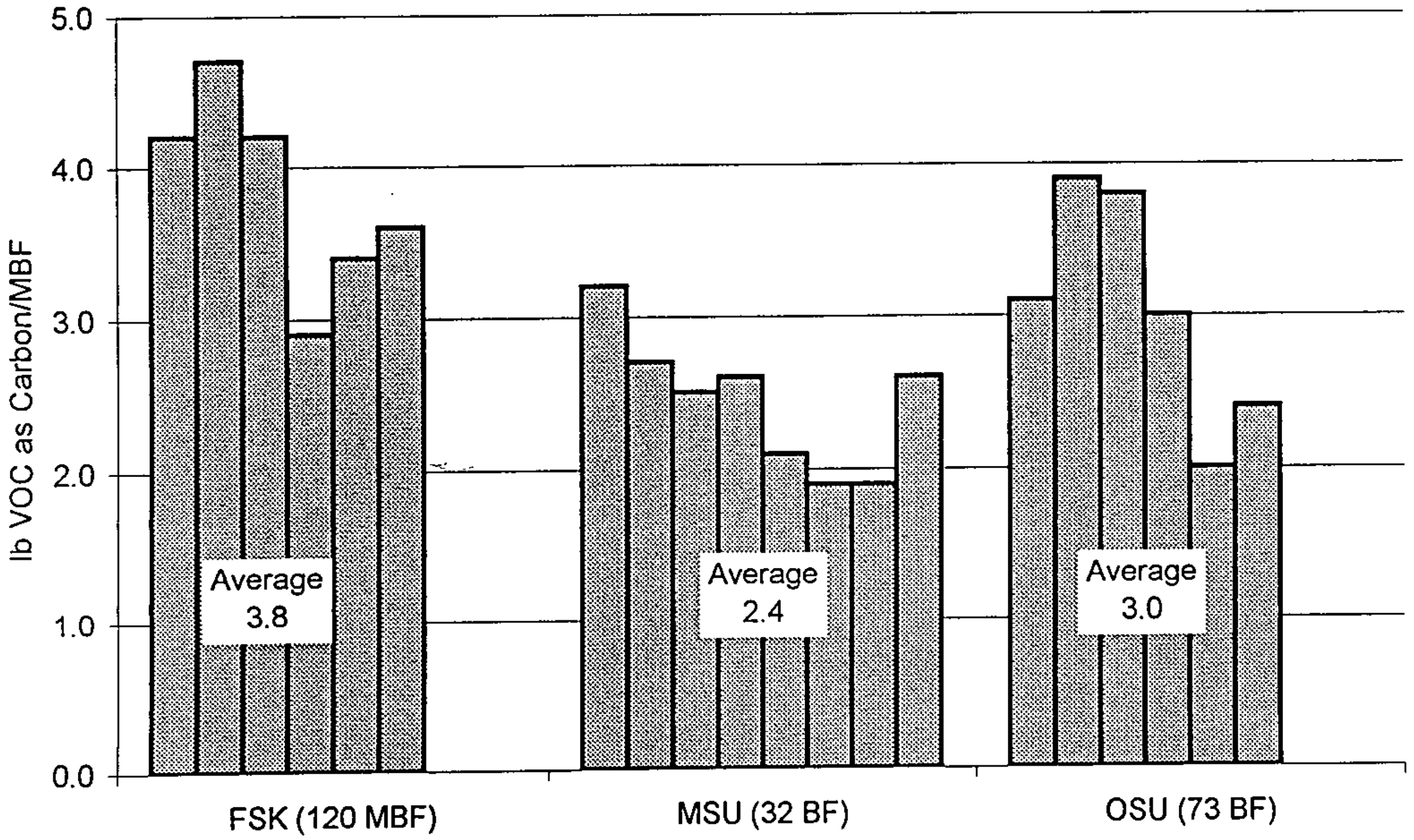

Figure 7.16. Comparison of VOC Mass Emission Rates for the Direct-Fired Drying Schedule

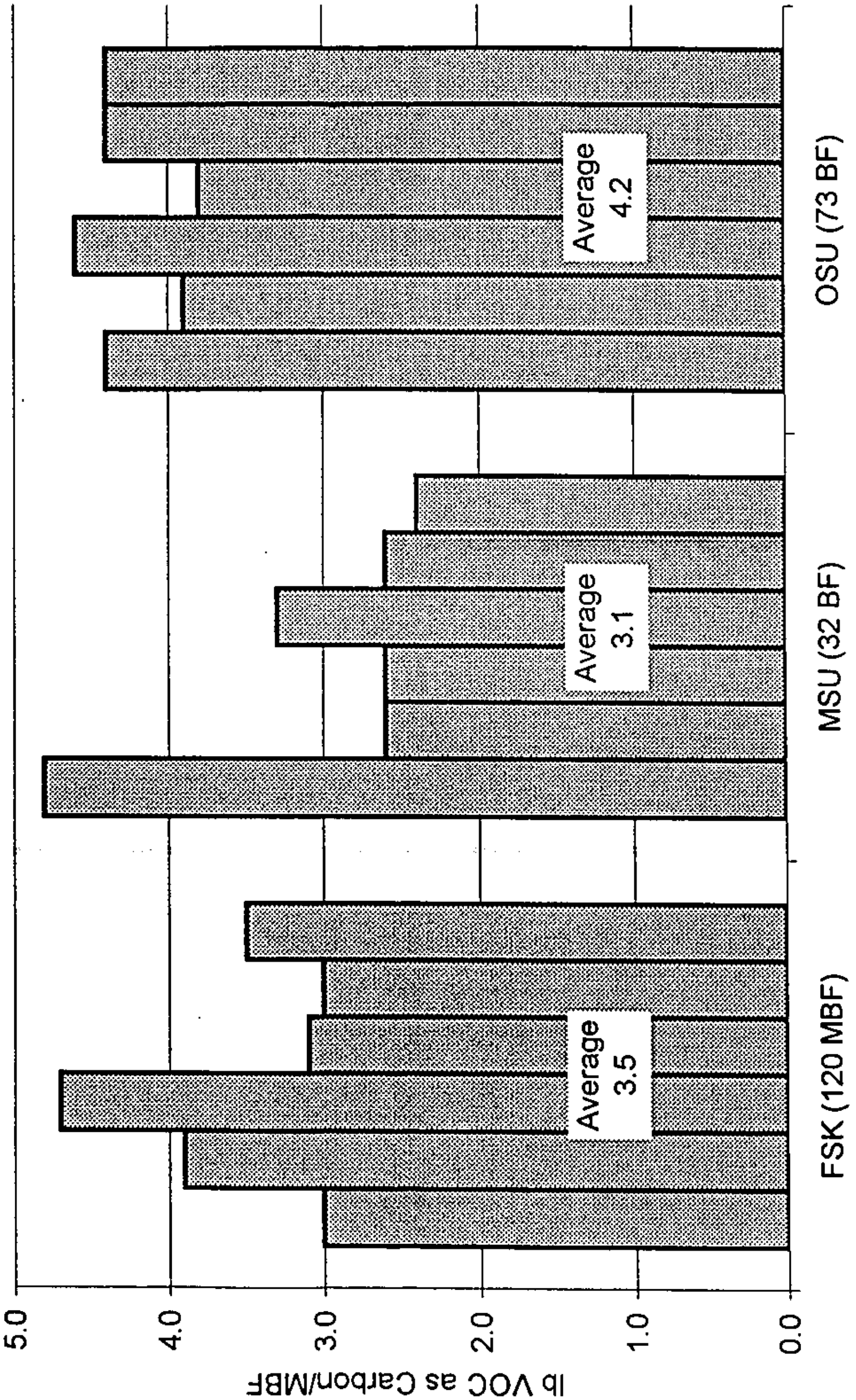

Figure 7.17. Comparison of VOC Mass Emission Rates for the Steam-Heated Drying Schedule

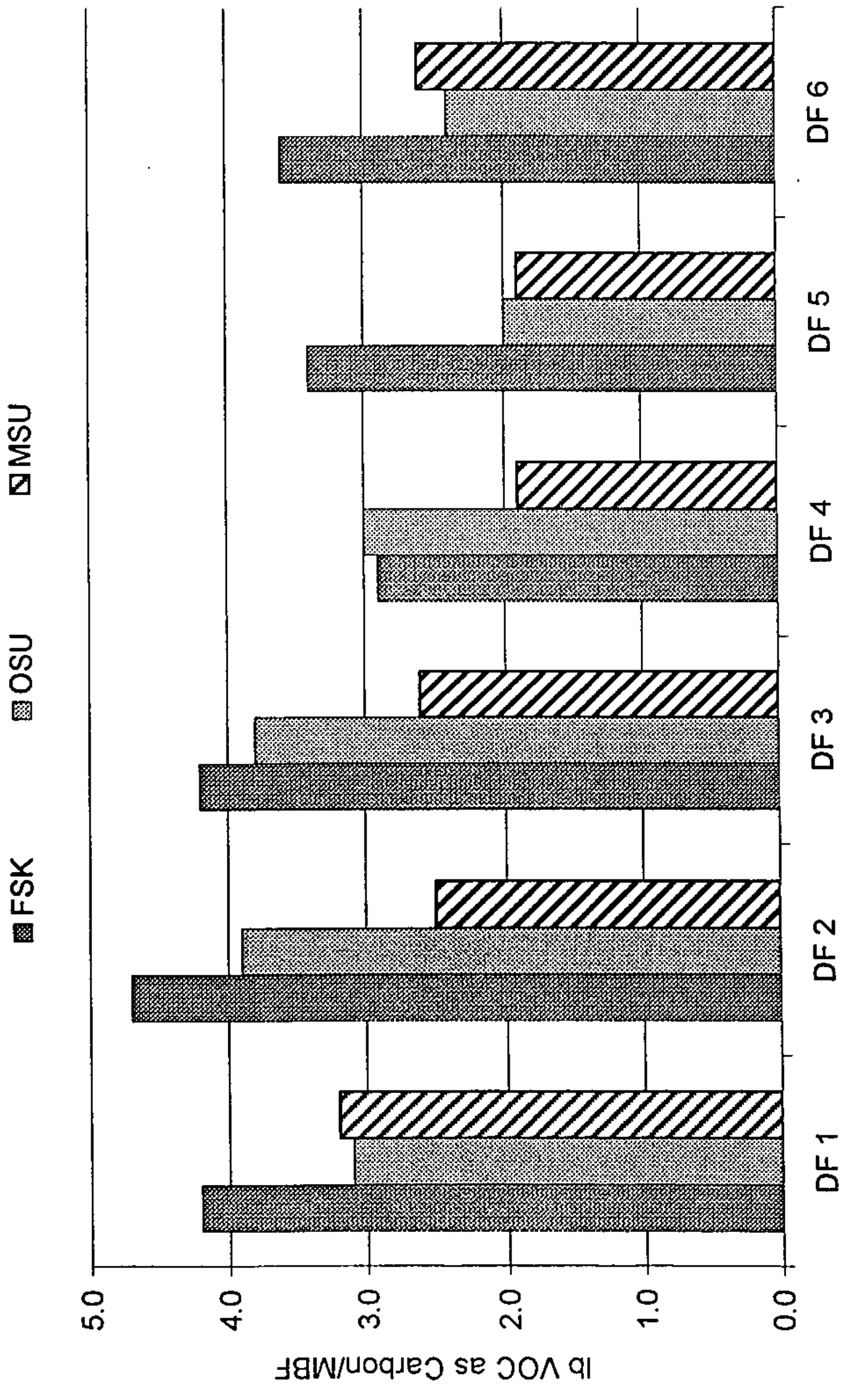

Figure 7.18. Per-Charge Comparison of VOC Mass Emission Rates for the Direct-Fired Drying Schedule

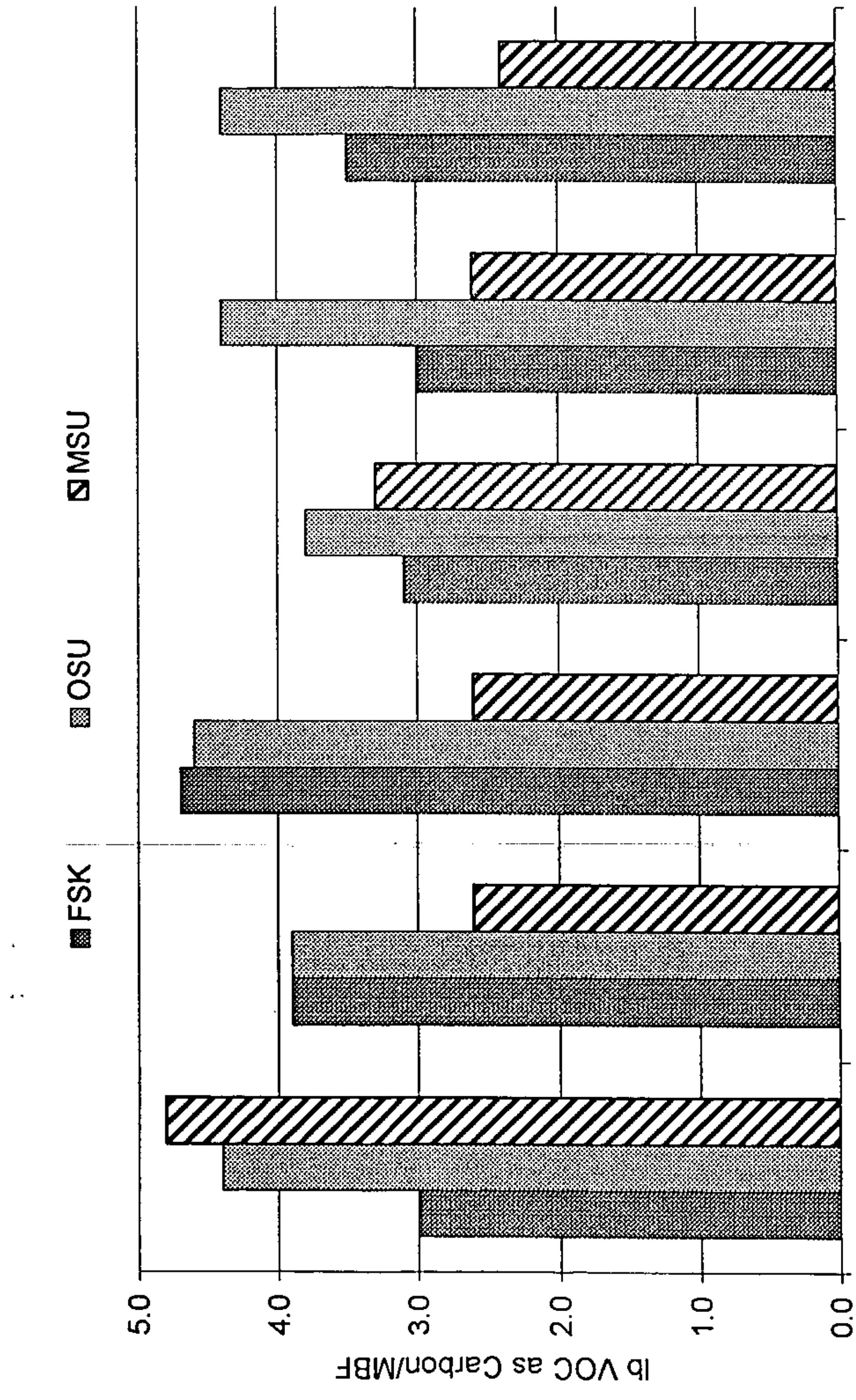

Figure 7.19. Per-Charge Comparison of VOC Mass Emission Rates for the Steam-Heated Drying Schedule

stream the heated probe and filter boxes for the VOC measurement systems were replaced after the third sampling event with units that had larger heaters. The higher moisture levels also required considerably more dilution gas to maintain the sampled gas stream at or below the 20% moisture content criteria specified by this project.

Table 7.2. Total Volume of Kiln Gas per MBF Exhausted for Phase II Drying Cycles

	FSK	MSU	OSU	FSK	MSU	OSU
	wscf x 10^4 per MBF			dscf x 10^4 per MBF		
DF1	18.80	8.36	9.49	13.90	5.67	6.16
DF1B		11.3			7.40	
DF2	18.10	8.72	9.04	12.90	5.85	6.13
DF3	17.30	8.74	9.11	11.90	6.00	6.23
DF3B		10.40			6.89	
DF4	18.10	7.67	6.61	12.60	5.56	4.53
DF5	17.50	7.73	9.75	11.90	5.61	6.84
DF6	17.00	8.90	9.85	12.20	6.67	7.07
Average	17.80	8.98	8.98	12.57	6.21	6.16
INDF1	2.69	8.62	8.99	0.93	4.85	4.02
INDF2	3.98	9.96	7.32	1.33	5.04	3.63
INDF3	3.75	9.95	8.50	1.25	4.75	4.00
INDF5	3.44	10.90	7.25	1.09	6.38	3.62
INDF6	3.38	6.68	7.56	1.09	3.52	3.67
INDF7	3.71	7.29	8.48	1.16	4.18	3.99
Average	3.49	8.90	8.02	1.14	4.79	3.82

Figures 7.18 and 7.19 provide charge-by-charge comparisons for all of the sampled charges. From a gross overview of these graphs, it appears that the two small-scale kilns are no more likely to match the results from each other than they are to match the results from the two full-scale kilns. This may be due to relatively high variability in the measurements made at all four kilns.

7.3.3 *Numerical Statistical Analysis of the Phase II VOC Mass Emission Rate Results*

Numerical statistical analyses were conducted on the VOC mass emission rate results from all four kilns. As with the Variability Study data, results from the analyses of variability conducted on the Phase II data might be better viewed as indicators rather than definitive results because of the small data set analyzed. The statistical comparisons that follow are also made on at least two invalid assumptions. These comparisons assume that emission rates obtained at the full-scale kilns are the "true" emission rates when, in fact, they include error. Secondly, the comparisons assume that the sample charges dried at the small-scale kilns were identical to the charges dried at the full-scale kilns. Although care was taken to obtain representative samples, exact matches were impossible.

Two different statistical methods were used to compare the small-scale kiln emission data to the full-scale kiln emission data. For each statistical test or method, the full-scale kiln VOC mass emission rates were compared to the emission rates obtained at each small-scale kiln. The Student-t test compared averages of data sets as they are shown in Figures 7.16 and 7.17. The paired difference test evaluated differences on a charge-by-charge basis, as they are shown in Figures 7.18 and 7.19.

The data were grouped in a number of ways for these analyses. First, all twelve drying cycles were evaluated as a group. Then the data were segregated into three sub-groups consisting of (1) the first three direct-fired drying cycles, (2) the second three direct-fired drying cycles, and (3) the six steam-heated drying cycles. The six direct-fired drying cycles were segregated due to reasons discussed previously in this section.

Analysis of MSU Emission Rate Data

Results from the Student-t test of all twelve drying cycles, shown in Table 7.3, indicate that the mean VOC mass emission rate from the entire MSU data set differs significantly from the mean emission rate from the entire full-scale kiln data set (95% confidence interval). Analysis by the paired difference method (Table 7.3) also shows that emission rates from the MSU kiln were statistically different than emission rates from the full-scale kiln.

A statistical evaluation of the three sub-groups is provided in Appendix U. The conclusion of these analyses was that the emission rates from the MSU direct-fired sample charges were significantly different from the corresponding full-scale emission rates (Table U.1 and Table U.2, Appendix U). The emission rates from the steam-heated kiln charges at MSU, however, were not found to be significantly different from the full-scale steam kiln emission rates (Table U.3, Appendix U). Therefore, emission rates from six of the 12 charges at MSU "pass" this statistical comparison.

Analysis of OSU Emission Rate Data

The OSU VOC mass emission rate data were compared to the full-scale kiln data as discussed previously for the MSU statistical analyses. The data comparison of the full twelve drying cycles indicates that the OSU emission rate data did not differ significantly from the full-scale kiln emission rate data (Table 7.2). For the sub-group evaluations, the OSU mass emission rate data were shown not to differ significantly from either of the two direct-fired sub-groups but did differ significantly for the steam-heated full scale emission rate data.

7.4 Phase II Formaldehyde and Methanol Mass Emission Rates

The formaldehyde and methanol sampling method provides results over discrete time intervals rather than continuously. Samples were collected over time intervals of approximately one hour and three hours at the full-and small-scale kilns, respectively. The resulting average mass emission rate from the formaldehyde and methanol sampling events are shown in Figures 7.20 and 7.21, respectively. These data were not evaluated by statistical methods due to the small sample size.

Figure 7.20 shows a significant difference in the formaldehyde emission rate at the full-scale direct-fired and steam kilns. This difference in emission rate results was not replicated in the emission rate results from the direct-fired and steam sample charges measured at MSU and OSU. The most likely explanation for this discrepancy is that the small-scale kilns used in this project were either electrically or steam heated. At the direct-fired full-scale kiln, however, the kiln air is re-heated by 1600°F air from the burner in a blend box that is connected to the side of the kiln. Kiln air containing volatile organic compounds enters the blend box at around 250°F and is mixed with the hot burner gases. The organic compounds in the blend box are therefore subjected to a wide range of temperatures and oxygen conditions, some of which appear to be favorable for the formation of formaldehyde.

Figure 7.20 also shows that the formaldehyde mass emission rates from the small-scale kilns were variable. These results may be due to the difficulty in measuring and analyzing formaldehyde at low concentrations.

Table 7.3. Statistical Analysis of the Phase II VOC Mass Emission Rate Results

FSK to MSU Comparison
All Data Combined (direct-fired & steam)

	FSK	MSU	Difference
DF1	4.2	2.95	1.3
DF2	4.7	2.5	2.2
DF3	4.2	2.4	1.8
DF4	2.9	1.9	1.0
DF5	3.4	1.9	1.5
DF6	3.6	2.6	1.0
INDF1	3.0	4.8	-1.8
INDF2	3.9	2.6	1.3
INDF3	4.7	2.6	2.1
INDF5	3.1	3.3	-0.2
INDF6	3.0	2.6	0.4
INDF7	3.5	2.4	1.1
mean	3.683	2.713	0.971
std dev	0.651	0.761	
var	0.423	0.579	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	3.683	2.713
Variance	0.423	0.579
Observations	12	12
Pearson Correlation	0	
Hypo. Mean Difference	21.000	
t Stat	3.359	<===
P(T<=t) two-tail	0.003	
t Critical two-tail	2.080	<===

CONCLUSION: Means differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	3.683	2.713
Variance	0.423	0.579
Observations	12	12
Pearson Correlation	-0.212	
Hypo. Mean Difference	0	
df	11	
t Stat	3.055	<===
P(T<=t) two-tail	0.011	
t Critical two-tail	2.201	<===

CONCLUSION: The VOC mass emission rate from the MSU kiln was significantly less than the DF & steam kilns.

FSK to OSU Comparison
All Data Combined (direct-fired & steam)

	FSK	OSU	Difference
DF1	4.2	3.1	1.1
DF2	4.7	3.9	0.8
DF3	4.2	3.8	0.4
DF4	2.9	3.0	-0.1
DF5	3.4	2.0	1.4
DF6	3.6	2.4	1.2
INDF1	3.0	4.4	-1.4
INDF2	3.9	3.9	0
INDF3	4.7	4.6	0.1
INDF5	3.1	3.8	-0.7
INDF6	3.0	4.4	-1.4
INDF7	3.5	4.4	-0.9
mean	3.683	3.642	0.042
std dev	0.651	0.840	
var	0.423	0.706	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	3.683	3.642
Variance	0.423	0.706
Observations	12	12
Pearson Correlation	0.000	
Hypo. Mean Difference	21.000	
t Stat	0.136	<===
P(T<=t) two-tail	0.893	
t Critical two-tail	2.080	<===

CONCLUSION: Means do not differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	3.683	3.642
Variance	0.423	0.706
Observations	12	12
Pearson Correlation	0.149	
Hypo. Mean Difference	0.000	
df	11	
t Stat	0.147	<===
P(T<=t) two-tail	0.886	
t Critical two-tail	2.201	<===

CONCLUSION: The VOC mass emission rate from the OSU kiln was not significantly different than the DF & Steam kilns.

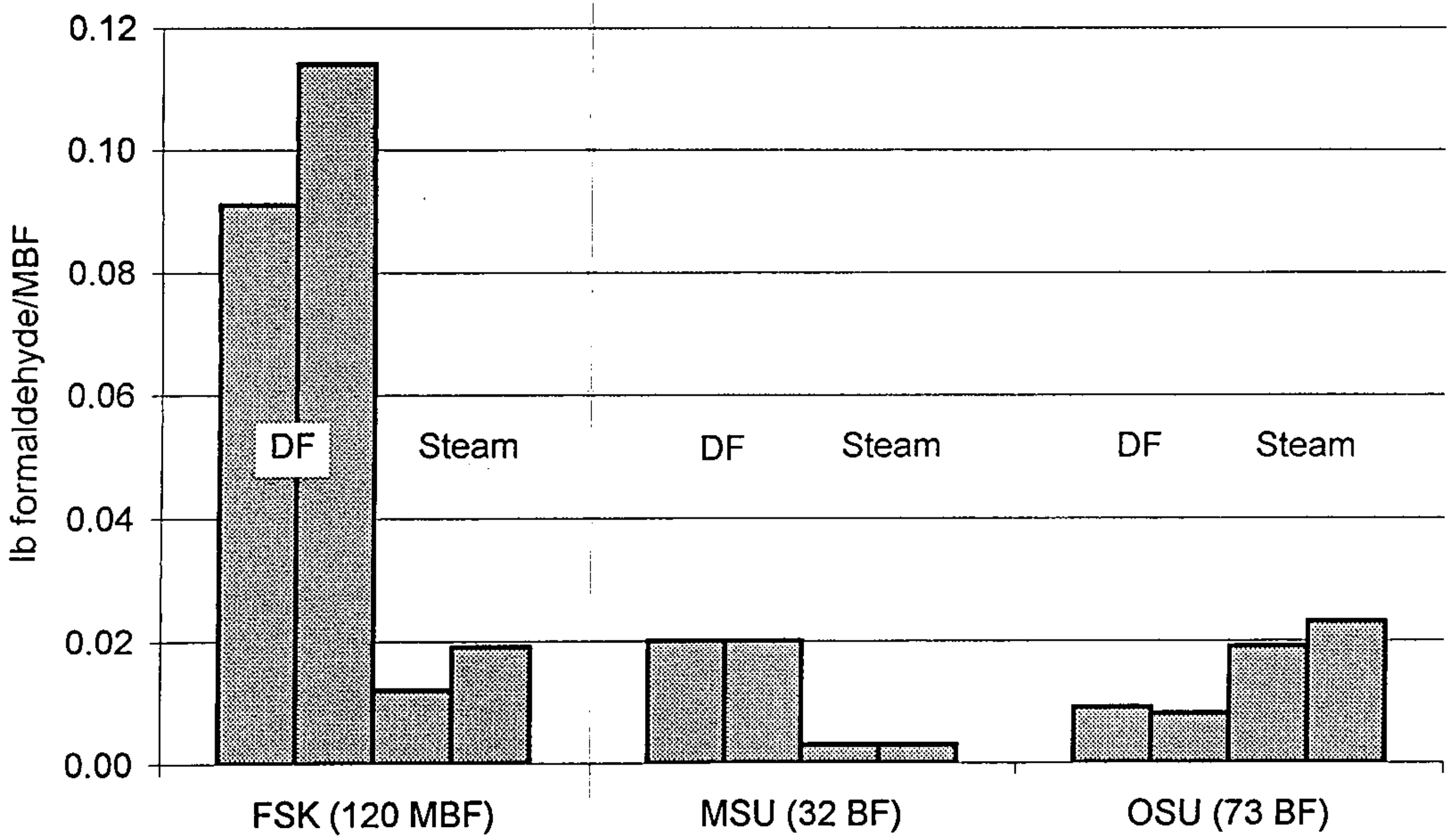

Figure 7.20. Comparison of Formaldehyde Mass Emission Rates for the Direct-Fired and Steam-Heated Drying Schedules

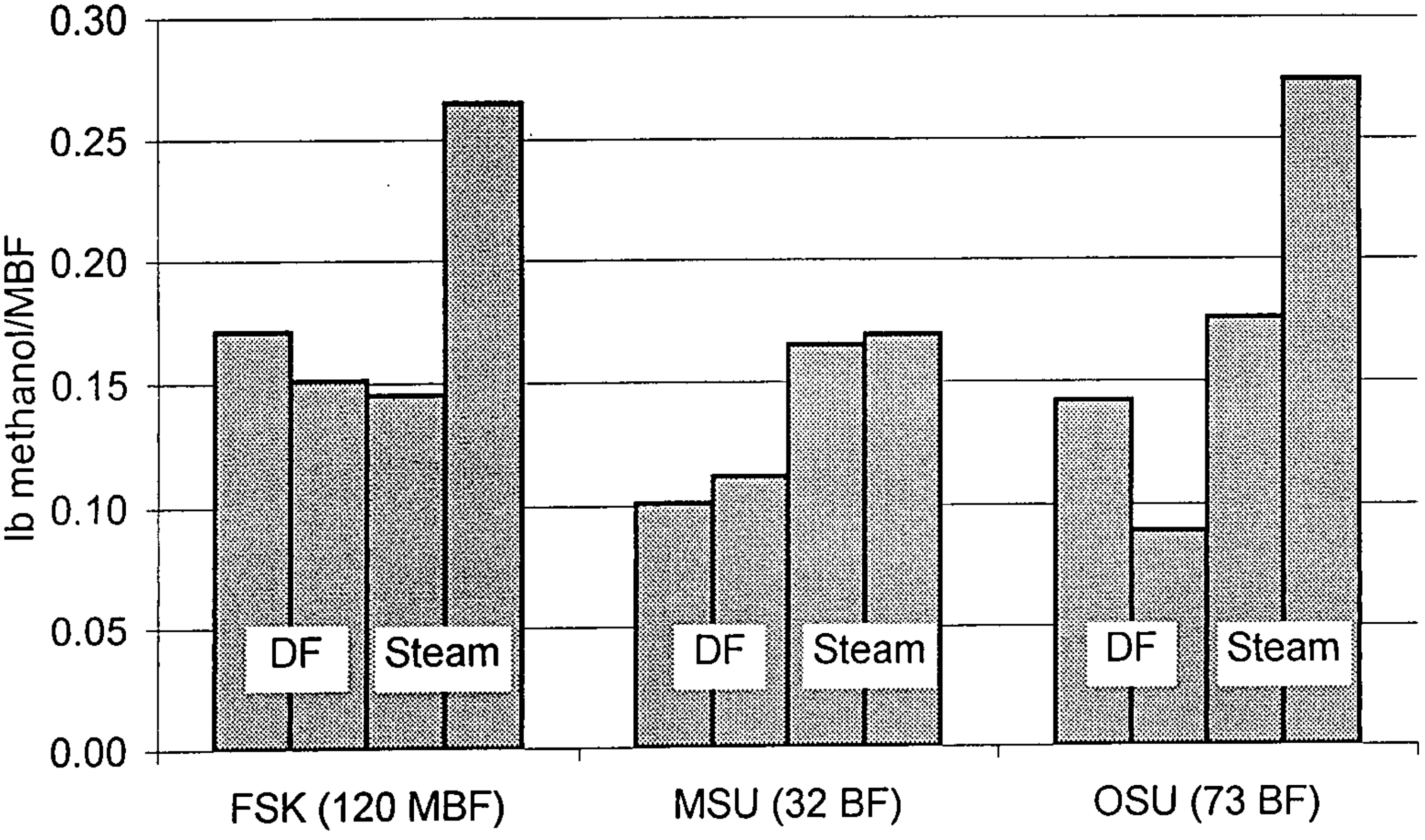

Figure 7.21. Comparison of Methanol Mass Emission Rates for the Direct-Fired and Steam-Heated Drying Schedules

Figure 7.21 shows a graph of the methanol mass emission rates that resulted from the full- and small-scale kiln tests. The small-scale kiln data appear to indicate that the high humidity steam kiln temperature schedule creates more methanol than the relatively low humidity direct-fired temperature schedule.

The mass emission rate curves for the formaldehyde and methanol data for each of the drying cycles at the full- and small-scale kilns have been included in Appendix V. As mentioned earlier, the sampling method provides results for discrete time intervals. The data presented by gray shading in each of the figures represent the average formaldehyde or methanol emission rates for each discrete interval. The continuous solid line connecting the discrete results represents the interpolated mass emission rate curve used to calculate the overall mass emission rate for the sampling event.

The formaldehyde mass emission rate curves for the two direct-fired, full-scale kiln test charges are shown in Figure V.1, Appendix V. These curves are somewhat similar in shape to the VOC mass emission rate curves presented earlier for these test charges. The similarity in mass emission rate curves may support the theory that formaldehyde is formed in the blend box of the direct-fired kiln. In contrast, the formaldehyde emission curves for the corresponding MSU and OSU sample charges do not have the two emission peaks that characterize the VOC emission curve. Figures V.2 and V.3 show a relatively steady increase in formaldehyde emissions throughout the MSU and OSU sampling events.

Figures V.4 through V.6 show the formaldehyde emission rate curves for the steam-heated kiln test charges and the corresponding sampling events at MSU and OSU. There appears to be no significant relationship between these curves. The full-scale kiln curves show increases in methanol emissions over the drying cycle. This pattern is not reflected in the curves from MSU and OSU since the resulting mass emission rate curves tended to be relatively flat during the second half of both sampling events.

Figures V.7 through V.12 show the methanol emission rate graphs for the full- and small-scale kilns. In general, these graphs show an increase in methanol throughout the drying cycle. Since the kiln wet/dry bulb temperatures were relatively steady-state over most of the kiln cycle, the increasing methanol emissions may be due to increases in the lumber temperature. Note that these curves are not similar to the shape of the VOC curves. It is reasonable to assume that different mechanisms are responsible for VOC and methanol/formaldehyde formation in lumber kilns.

7.5 Speciated VOC Mass Emission Rates

A limited assessment for sixteen selected VOC compounds was conducted for this project. The intent of the VOC speciation was to identify compounds emitted from southern pine lumber during drying and to characterize the behavior of those compounds over the course of the high temperature drying cycle.

Alpha-pinene, beta-pinene, and methanol were emitted in the largest quantities. Figures W.1 through W.3, Appendix W, show that the emission rates of alpha-pinene and beta-pinene increased rapidly at the start of the drying cycle and then gradually decreased over the remainder of the drying cycle. Methanol steadily increased throughout the drying cycle and reaching a maximum at the end of the cycle.

The relationship between the compounds presented in Appendix W is similar to the findings of the Wood Products MACT Study. For southern pine dryers in that study, alpha-pinene and beta-pinene were typically the major compounds emitted. Methanol, formaldehyde, and acetaldehyde, in that order, were typically the predominant HAPs.

For all three kilns tested in this study, methanol, acetaldehyde, and formaldehyde, in that order, were predominant HAPs. Acetone, which is not a HAP, was emitted in higher quantities than acetaldehyde at two of the three kilns.

The relationship of alpha-pinene and beta-pinene to the HAPs for the NCSU/DEECO data is similar to the relationship seen at southern pine wood products dryers, where alpha-pinene and beta-pinene typically are 70% to 95% of the mass emissions. This was not the case for the data obtained from the OSU and full-scale steam kilns.

Since DEECO conducted the sampling and analysis for the samples collected at the NCSU kiln and NCASI conducted the sampling and analysis at the OSU and steam kilns, it appears that the values obtained by NCASI for these two compounds are low. Caution is advised in their use.

7.6 Emissions from the Direct-Fired Burner

The heat source for the direct-fired lumber kiln at Idabel, Oklahoma, is a sloped pile burner or gasifier. The fuel source is green sawdust produced from sawing operations at the front end of the mill. An assessment of the gas moisture content and the VOC, formaldehyde, and methanol mass emission rates from the burner was conducted at the same time as the VOC sampling events. The objective was to deduct those emission rate contributions from the kiln exhaust emission rate measurements to determine the mass emission rate contributions from the lumber drying process only. Thus, the direct-fired results could be compared to the results from the small-scale kilns without the data being biased from the gasifier.

The concentration measurements of the burner exhaust were obtained from the sample port that was installed prior to the blend box (Figure 4.20, Section 4.3.1). F-factor calculations were used to determine the flow rate from the burner.

One green sawdust sample was collected from the burner fuel hopper every hour during emissions testing for moisture and heat content analyses. The average moisture content of the green sawdust for the first three burner tests was 53%-wet basis. The average moisture content of the sawdust for the last three burner tests was 51%-wet basis. The heat content value of the sawdust was found to range from 8577 Btu/lb to 9224 Btu/lb (based on dry material).

The burner fuel feed rate was recorded in 15 minute increments during each direct-fired sampling event. The dry fuel feed rates for each sampling event are shown in Figures X.1 through X.3 in Appendix X.

The moisture content by volume of the burner exhaust was measured below 20% for all burner sampling events except for one sample run during the second direct-fired test charge. The moisture content measurements for each burner sampling event are shown in Figures X.4 through X.6. Since the moisture content was below 20%, the VOC sample gas stream did not require dilution.

The burner exhaust flow rate and VOC mass emission rate profiles for each sampling event are shown in Figures X.7 through X.9. The profiles show that the VOC emissions for the burner for every case were very low to none. The only burner test that measured enough VOCs to create an emission rate curve was the fourth sampling event.

Due to the low VOC concentration measurements, no adjustment was made to the kiln VOC emission data. Using the F-factors of 9280 dscf/MMBtu for O_2 and 1920 dscf/MMBtu for CO_2, the VOC mass emission rate results for each burner test are shown in Tables X.1 through X.6 in Appendix X (Code of Federal Regulations 1993). The data collected from the fourth and fifth burner tests yielded the only reportable mass emission rate values of 0.05 and 0.01 lb of VOC as C/MBF, respectively.

The burner exhaust was also sampled for formaldehyde and methanol over the second and fifth direct-fired kiln test charges. Formaldehyde was only detected in samples collected for the fifth burner test, and the resulting mass emission rate was calculated to be 0.003 lb formaldehyde/MBF (Table X.7, Appendix X). Since the mass emission rate of formaldehyde at the kiln exhaust stack was determined to be 0.103 lb/MBF for the fifth direct-fired test charge, the amount of formaldehyde measured in the burner exhaust was considered to be negligible. Tables X.8 and X.9 show that the formaldehyde and methanol concentrations collected during the second burner test were below the detection limit. Table X.10 shows that the methanol concentration for the fifth burner test was also measured below the detection limit.

8.0 CONCLUSIONS

Emissions from typical lumber kilns have historically been difficult to quantify because the kilns operate in a non-steady state batch process over extended periods of time. The sampling of a typical lumber kiln, therefore, is a costly and labor intensive undertaking. This project was designed to assess the feasibility of an alternative lumber kiln sampling method whereby small laboratory sized dry kilns are tested in place of the full-scale kilns. The objectives of this project were to (1) develop protocols or criteria for using small-scale kilns as surrogates for testing full-scale kilns, (2) obtain measurements of speciated and total VOC emissions at both large- and small-scale kilns, (3) compare the production-based emission rate measurements to determine the correlation of the small-scale to full-scale kiln emissions, and (4) compile the results into a database and issue a report on the findings.

The experimental approach to these objectives was to divide the project into two phases. The first phase of the project was to assess the variability of up to five small-scale kilns and to select two small-scale kilns for the Phase II work efforts. In Phase II, the feasibility of using the small-scale kilns as testing surrogates for full-scale kilns was assessed.

8.1 Small-Scale Variability Study

Although this project provided standard sampling procedures for VOCs, formaldehyde, and methanol and established the required standard kiln operating parameters, the results from the Variability Study indicated that all four kilns had different operational characteristics. This was evident from the VOC mass emission rate curves and the kiln venting rate curves presented in this report. NCASI decided that MSU and OSU were the best candidates for Phase II based on the consistency of their kiln operations and their willingness to modify their kilns to meet the criteria required by this project. The results from the Variability Study indicate, therefore, that there is significant variability in the operations of small-scale kilns and that caution is warranted in their use. Emissions testing should not be conducted without establishment of proper parameters and careful oversight.

8.2 Lumber Sampling Methods

The lumber sampling methods developed for this project were specific to the conditions required for the Variability Study and Phase II efforts. These stringent and labor-intensive methods should not be necessary for ordinary emissions testing. An "equivalent" batch of lumber was divided up amongst the Variability Study small-scale kilns so that each kiln received representative sample charges. The Phase II lumber sampling method required the sample charges to be representative of each full-scale kiln charge tested. Both methods appeared to configure equivalent sample charges amongst the small-scale kilns.

For samples sent by the industry to small-scale kilns, it is recommended that the original green weight of each small-scale kiln sample charge, or portion thereof, be recorded prior to shipment and then upon delivery to assess any moisture loss from the lumber. Furthermore, measures should be taken to prevent the loss of moisture and VOCs during shipment and storage, such as shrink-wrapping and refrigerating (35°F) sample charges.

8.3 Phase II VOC Mass Emission Rates

Although measures were taken after the Variability Study to further standardize the sampling and dry kiln operational procedures, the visual and numerical analyses of the VOC mass emission rate data still indicated a relatively wide variability at full-scale and small-scale kilns in this study. Industry VOC test data from full-scale southern pine kilns also exhibit high variability, however, with data ranging from 1.4 to 5.4 lb VOC as C/MBF (NCASI 2000). The variability in the industry data is due, in part, to the wide variety of measurement methods used and the difficulty involved in testing typical full-scale kilns. Other factors such as seasonal variability may also be significant.

The data obtained in this project indicate that small-scale kilns can emulate full-scale kiln operating conditions. By matching specific full-scale kiln temperature schedules, the small-scale kilns can model the VOC mass emission rate curves fairly well. Matching emission rate curves is not, however, a sure indicator of a successful correlation as indicated by the statistical analyses that were performed on the VOC mass emission rate results. When the whole data set was compared using the Student-t and the paired different tests, the OSU small-scale kiln results proved to be within the acceptable range of variability while the MSU data were not. When the direct-fired data and steam data were separated, the statistical analysis concluded that only 50% of the OSU and MSU data were found to be within the acceptable range of variability.

A statistical analysis of the MSU and OSU data also showed a significant difference between the two small-scale kilns. There was only one readily apparent difference between the two kilns that could have caused this discrepancy, the dimension of the kiln charges. The 32 board foot charge at MSU requires that the sample boards be 23 inches in length. The 73 board foot OSU kiln can accommodate 44 inch long lumber samples. Since neither kiln end-seals its lumber samples, the ratio of the area of the board ends to the length of the samples is greater for the MSU charge than for the OSU charge. MSU has, however, investigated the influence of "end effect" and concluded that sealing the board ends did not significantly alter the outcome of the VOC mass emission rate or drying time.

Thus, the results from this project indicate that under certain conditions small-scale kilns can emulate full-scale kilns. Those conditions include quality assurance measures (QA), use of a dilution system for sample gas streams with moisture contents greater than 20% by volume, and a standard mass emission rate calculation procedure. Quality assurance checks while the sampling effort is being conducted ensure that the measurement systems continue to function appropriately.

8.4 Formaldehyde and Methanol Mass Emission Rates

Formaldehyde and methanol were measured over four kiln charges at the full-scale and small-scale kilns. Because of the small number of samples, a statistical comparison of the data was not conducted. The data show high variability in the formaldehyde mass emission rates but reasonably consistent methanol mass emission rates. Similarly, the mass emission rate profiles or curves did not compare well between the full-scale and small-scale kilns for formaldehyde but compared reasonably well for methanol.

Clearly, formaldehyde emission rates were different at the full-scale direct-fired and steam-heated kilns. At the direct-fired kiln there is potential for formaldehyde formation in the blend box. One would not expect the small-scale kilns, which are steam or electrically heated, to match the direct-fired kiln formaldehyde mass emission rates.

8.5 Mass Emission Rate Calculations

All of the mass emission rate calculations for this project were standardized in order to make a valid comparison of the results amongst the different dry kilns. Although future sampling efforts may not be concerned with matching the results from multiple sources, the results reported from the Variability Study participants clearly indicated that there is more than one method for determining the mass emission rate results. Even though a consensus on a standard mass emission rate calculation procedure is not likely to occur, an effort should be made to present all the raw data with an accompanying explanation of all calculation methods. The explanation should indicate how the data were adjusted for calibration periods and measurement system anomalies. The method for determining the mass emission rate termination point should also be described.

8.6 Overview

Although future sampling efforts will most likely be conducted for emission factor development, experience obtained from this project indicates that the continuous mass emission rate and kiln exhaust venting rate curves are useful quality assurance tools. A relative comparison of the curves may help in evaluation of sample results that are outside of the expected range.

The future use of small-scale kilns as surrogates for testing full-scale kilns should be evaluated with due respect to the inherently high variability in normal full-scale kiln test results. The full-scale kilns tested in this report are idealized and among a very few in the country that have exhaust stacks. If typical difficult-to-test kilns, without stacks, had been tested, the full-scale kiln emission results would likely have been more variable and the statistical comparisons more favorable for both MSU and OSU. As expertise in operating and sampling small-scale kilns increases, data quality and consistency should improve.

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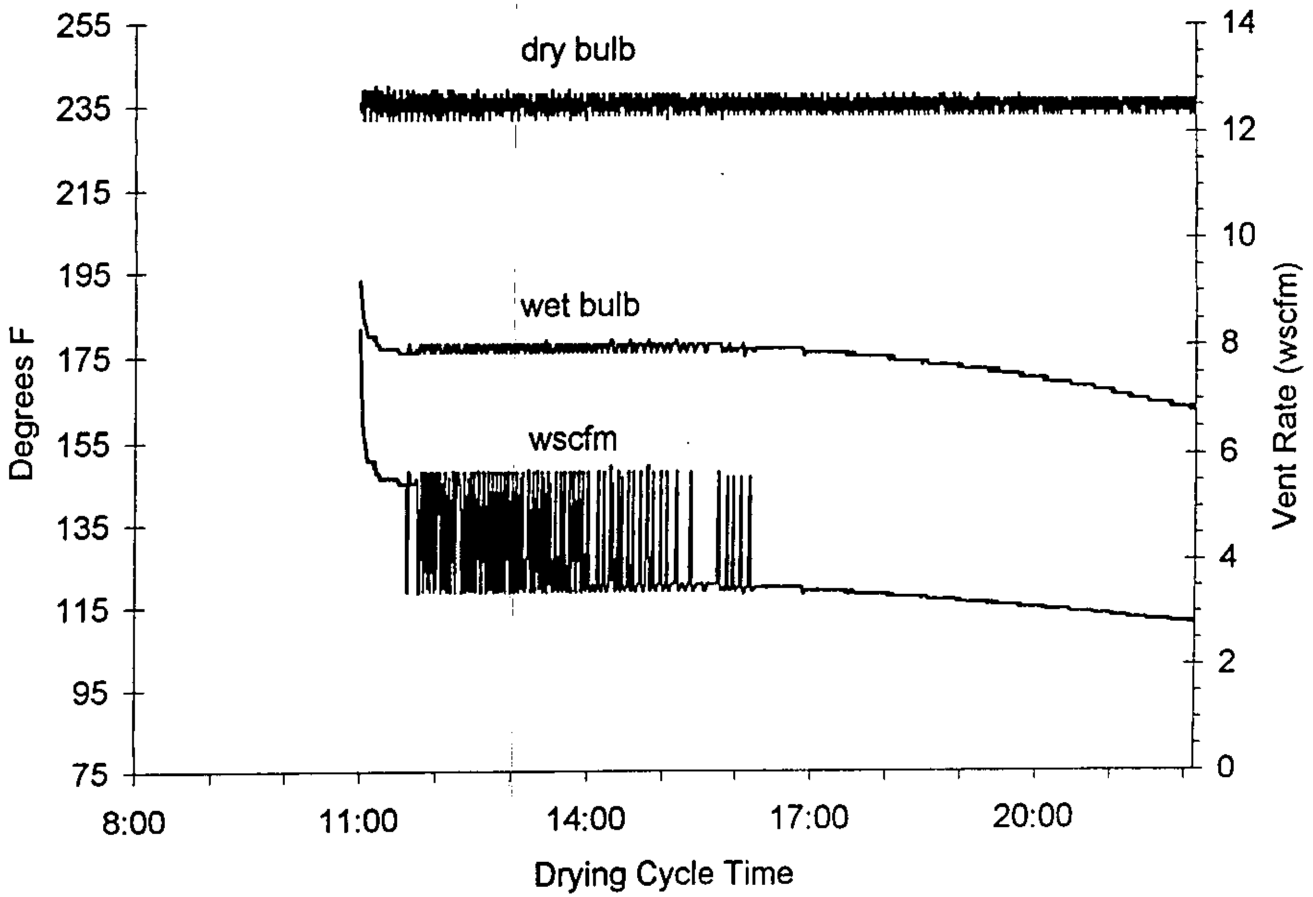
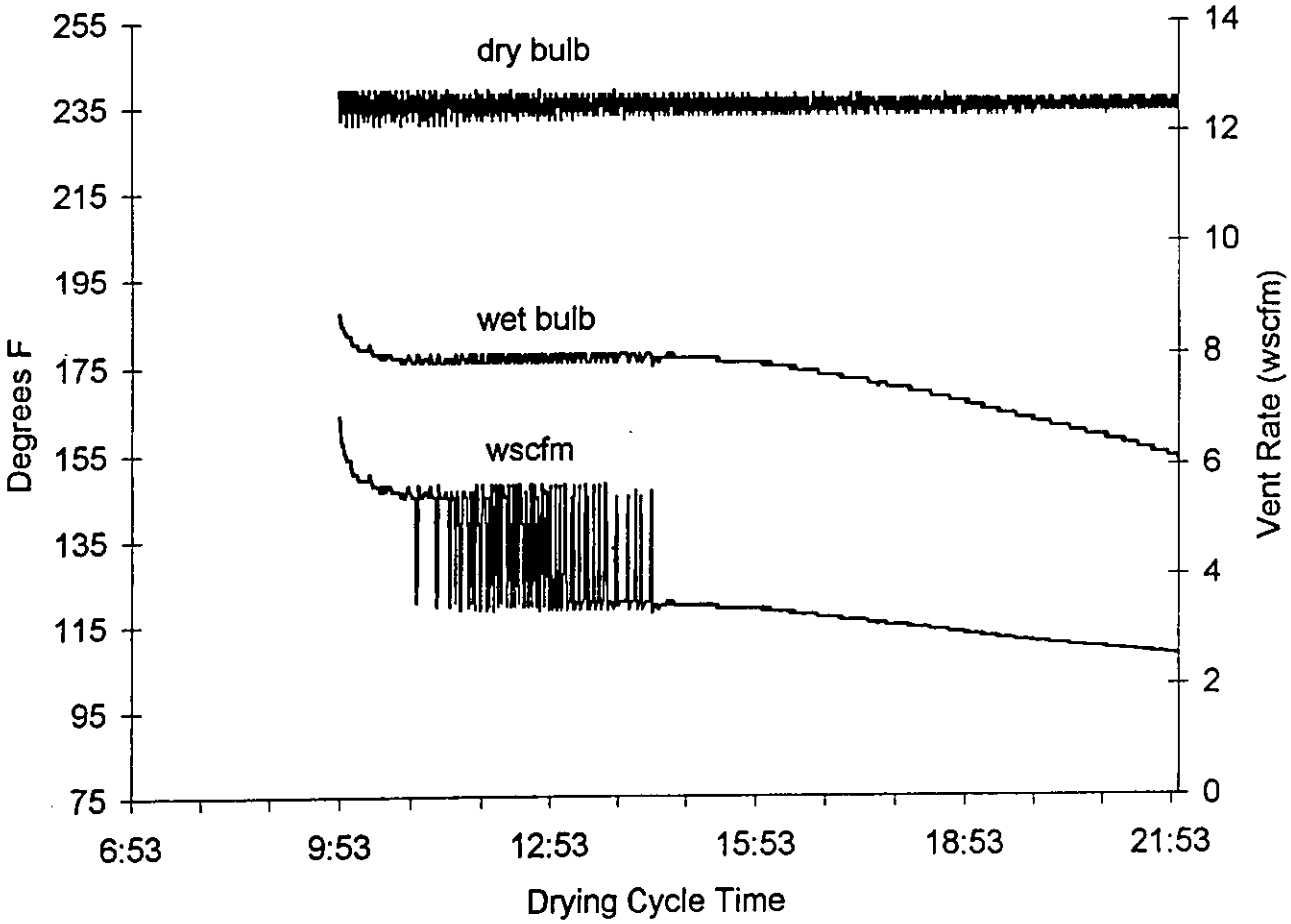
APPENDIX A

SMALL-SCALE KILN VARIABILITY STUDY WET/DRY BULB TEMPERATURE PROFILES

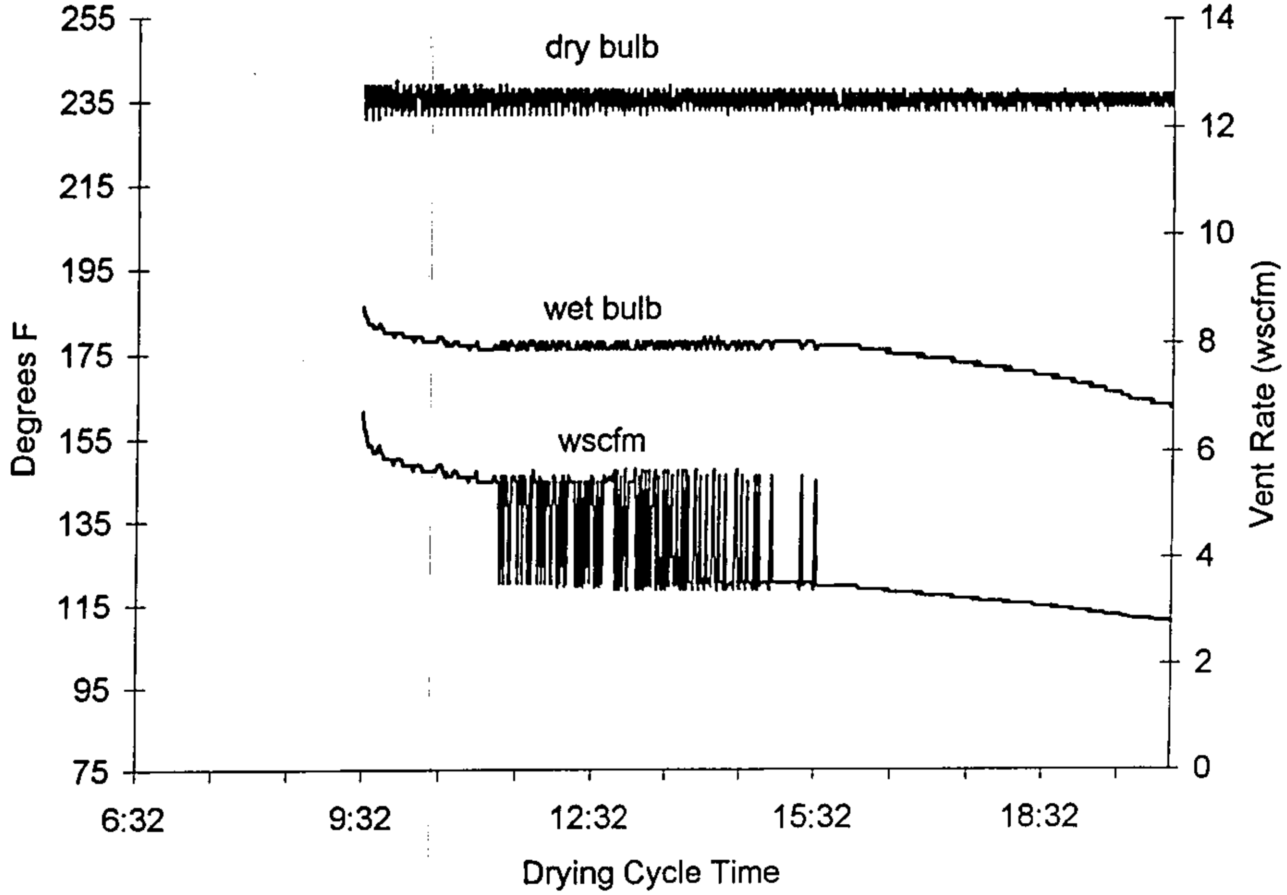
Variability Study Kiln Charge MSU 1
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



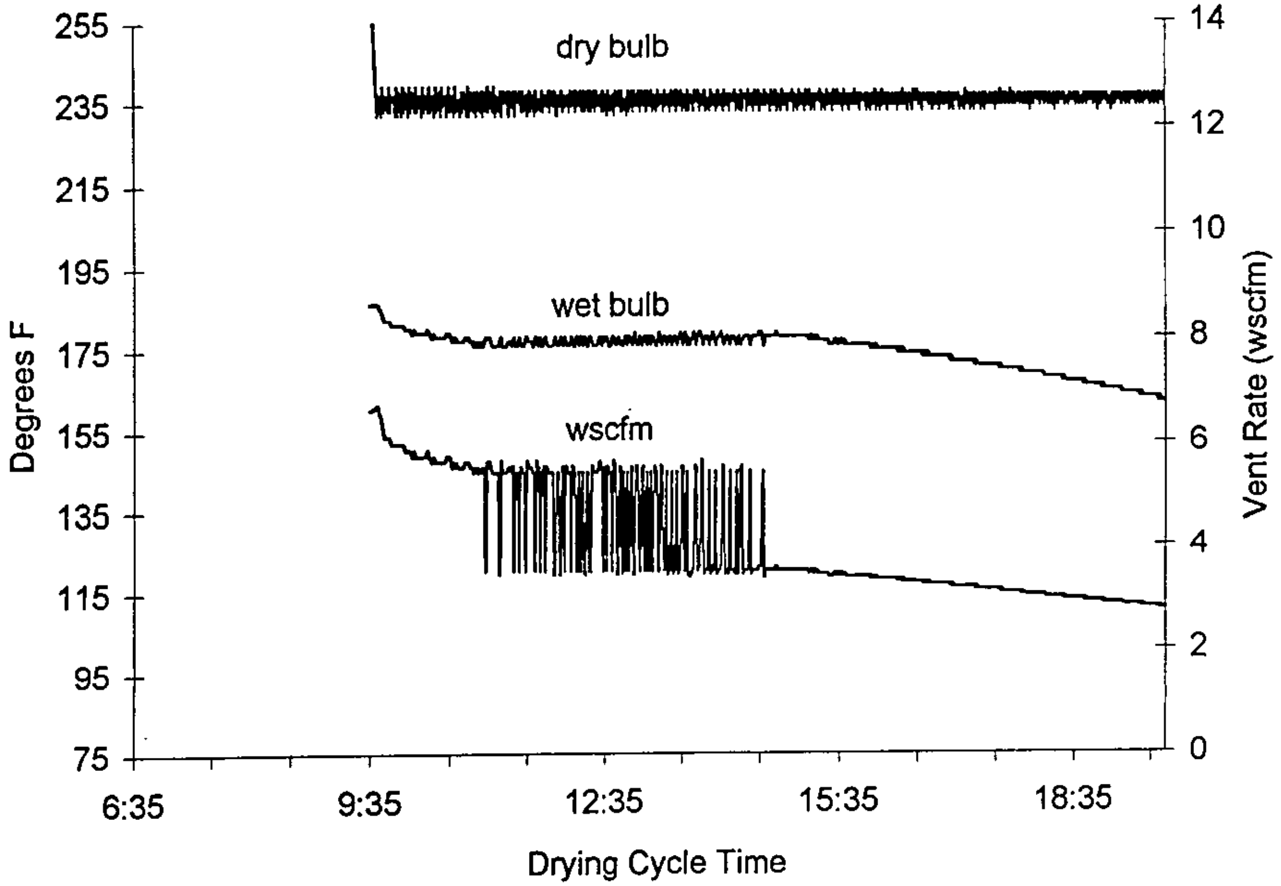
Variability Study Kiln Charge MSU 2
Comparison of WB/DB Temperatures to Venting Rate



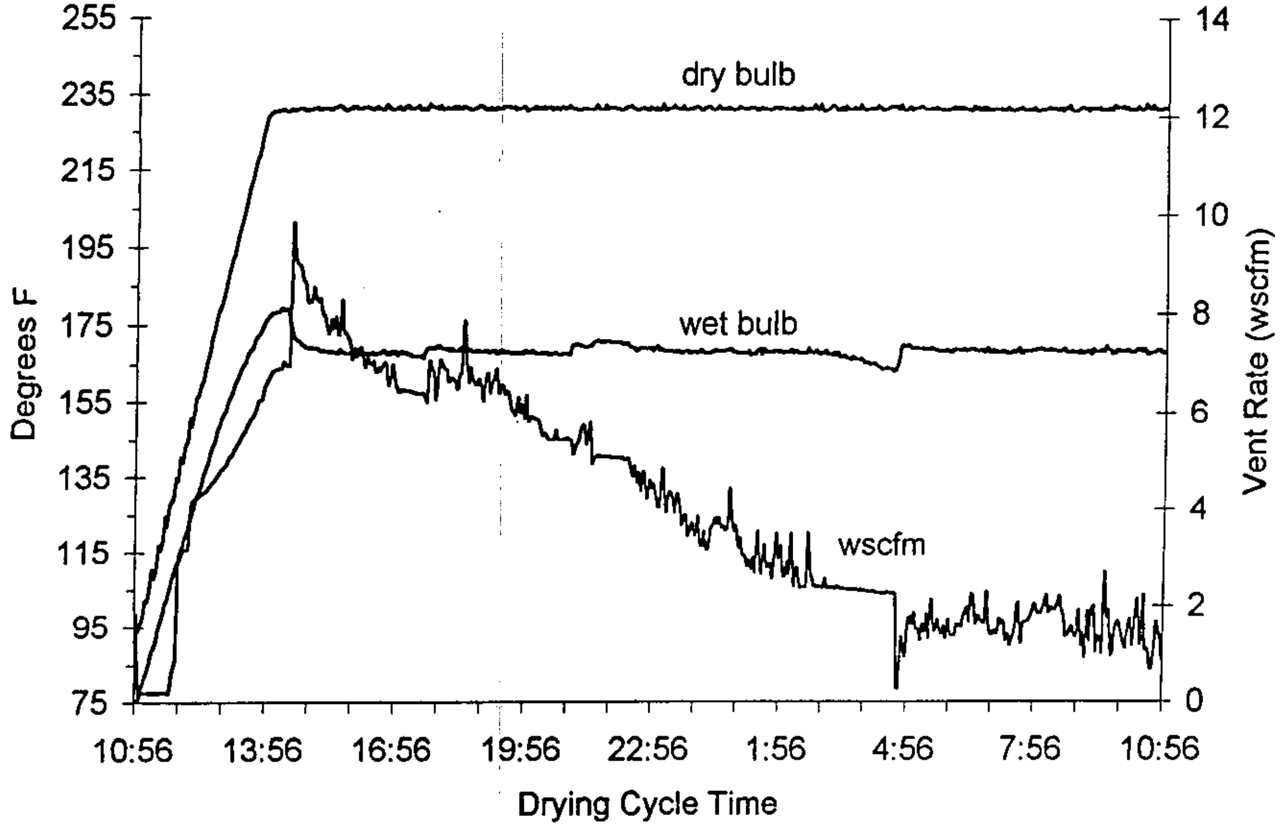
Variability Study Kiln Charge MSU 3
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



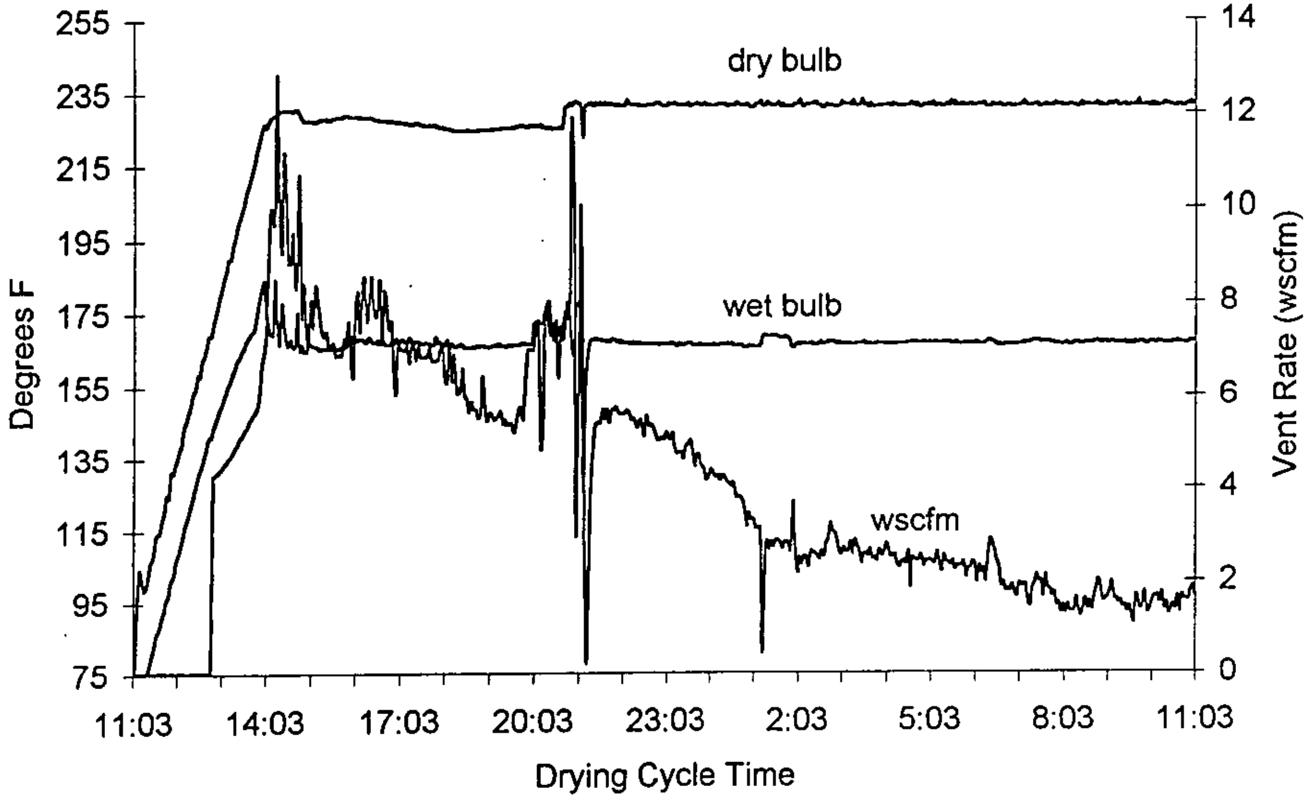
Variability Study Kiln Charge MSU 4
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



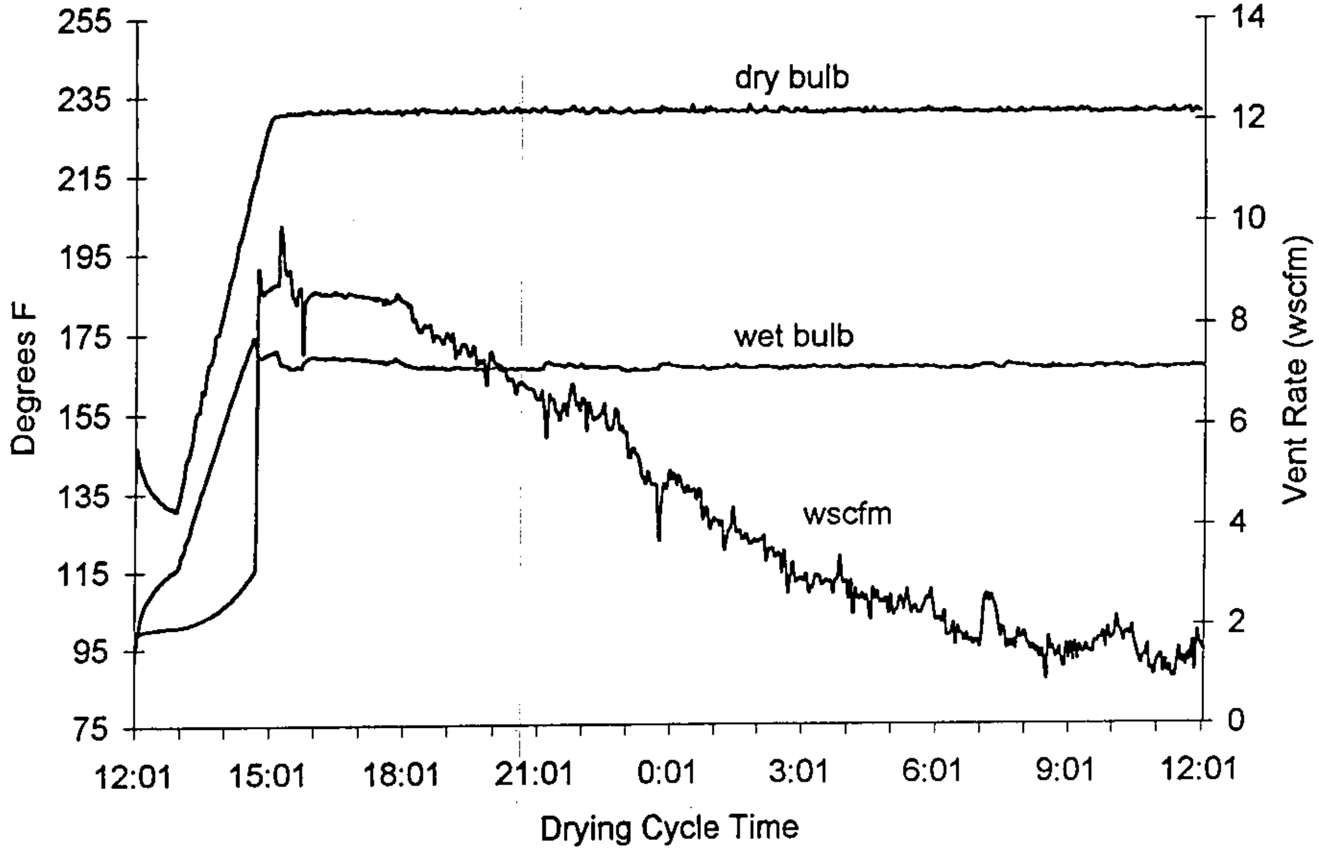
Variability Study Kiln Charge OSU 3
Comparison of WB/DB Temperatures to Venting Rate



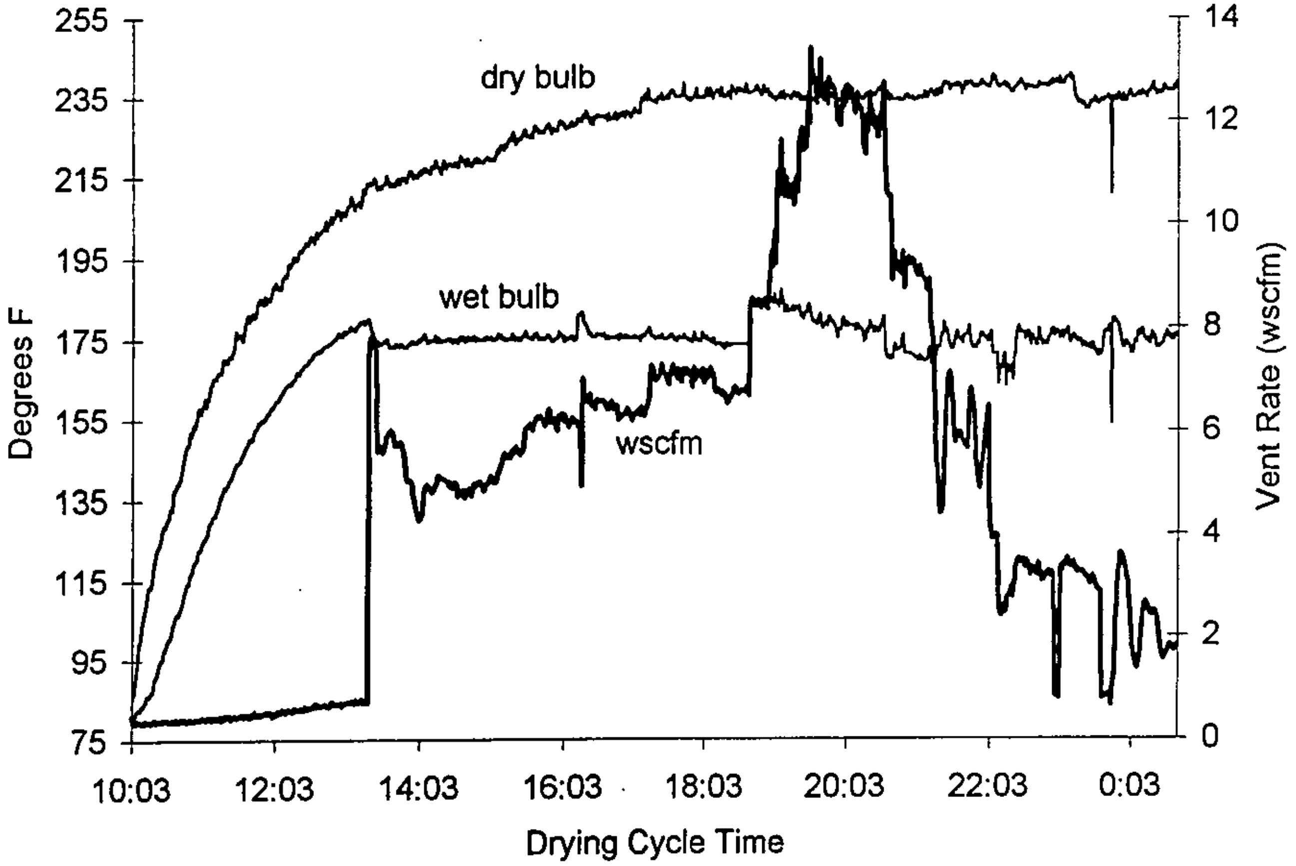
Variability Study Kiln Charge OSU 4
Comparison of Wet/Dry Bulb Temperature to Venting Rate



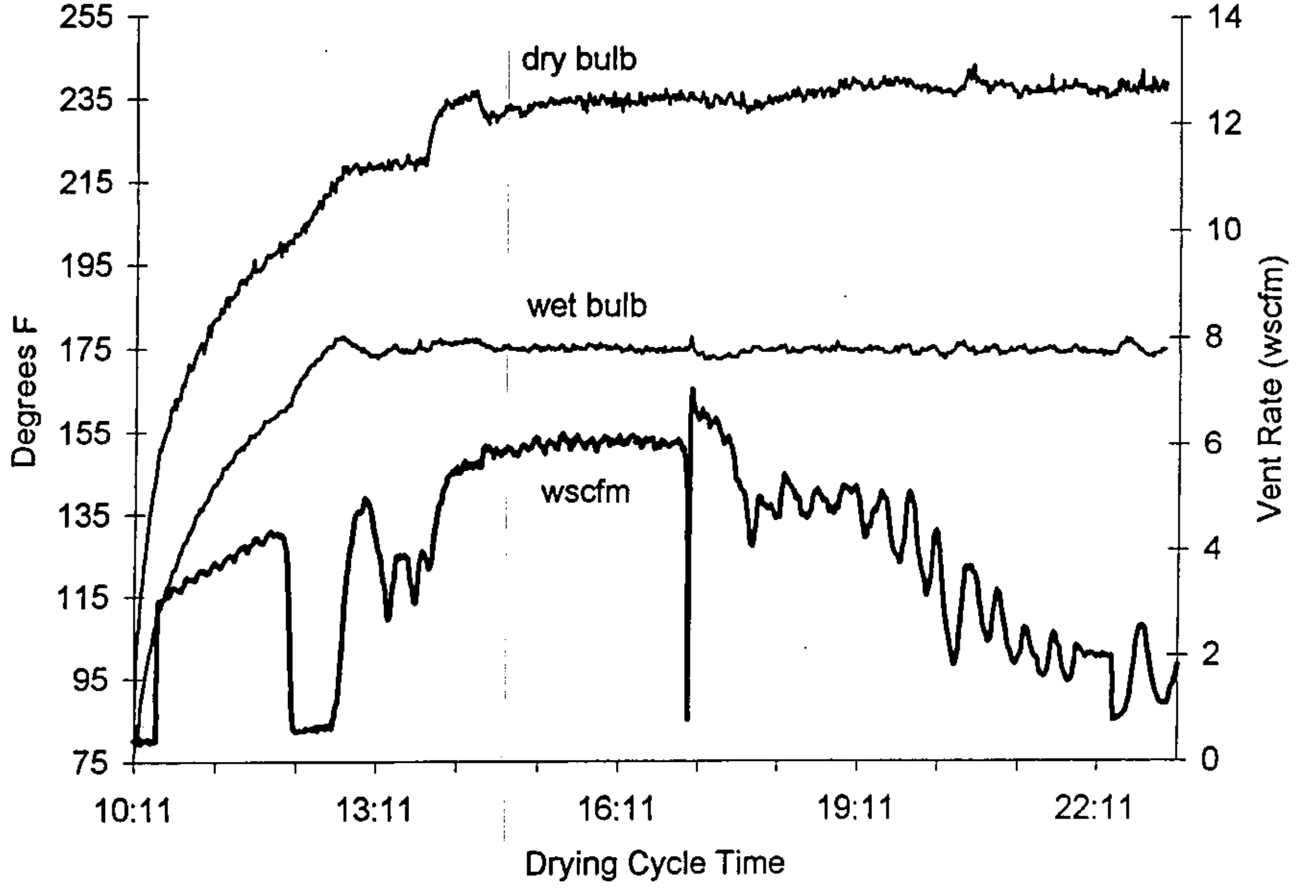
Variability Study Kiln Charge OSU 5
Comparison of Wet/Dry Bulb Temperature to Venting Rate



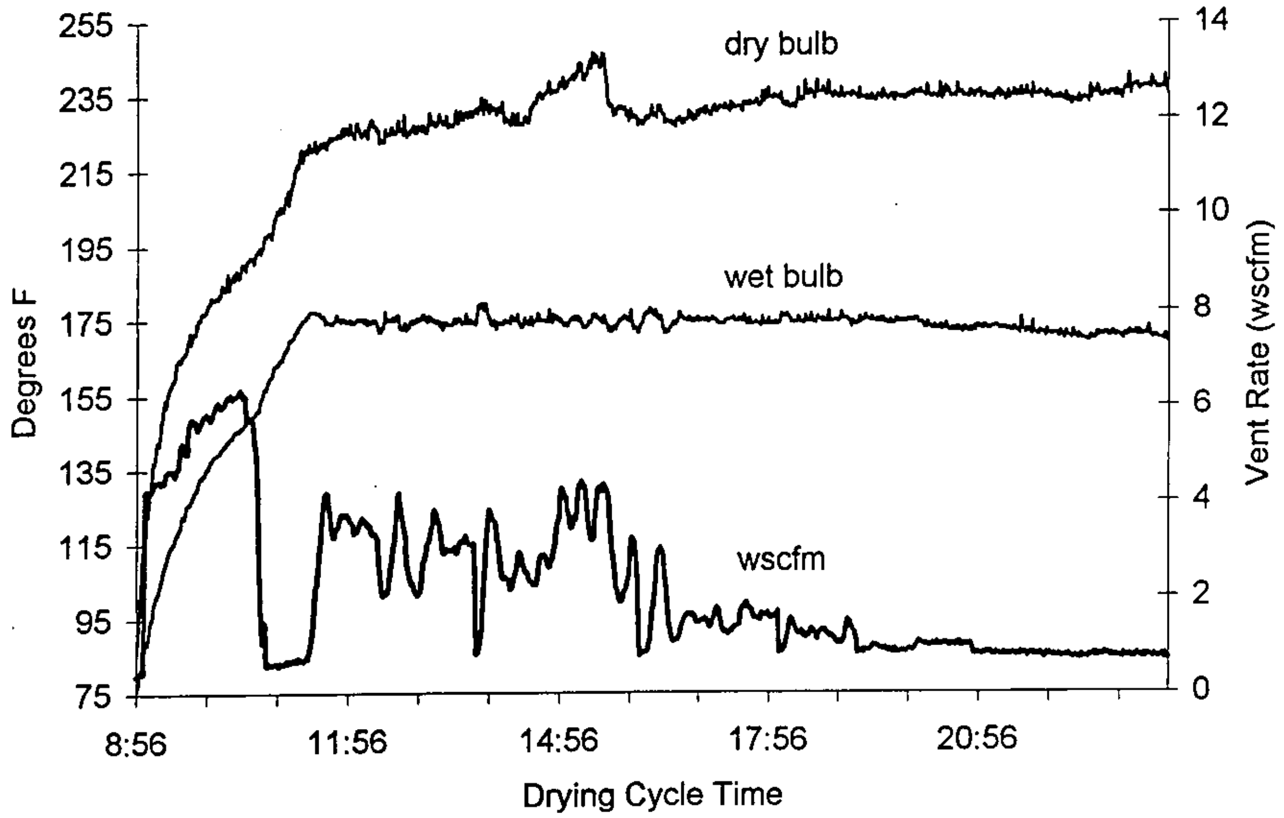
Variability Study Kiln Charge HE 1
Comparison of Wet/Dry Bulb Temperature to Venting Rate



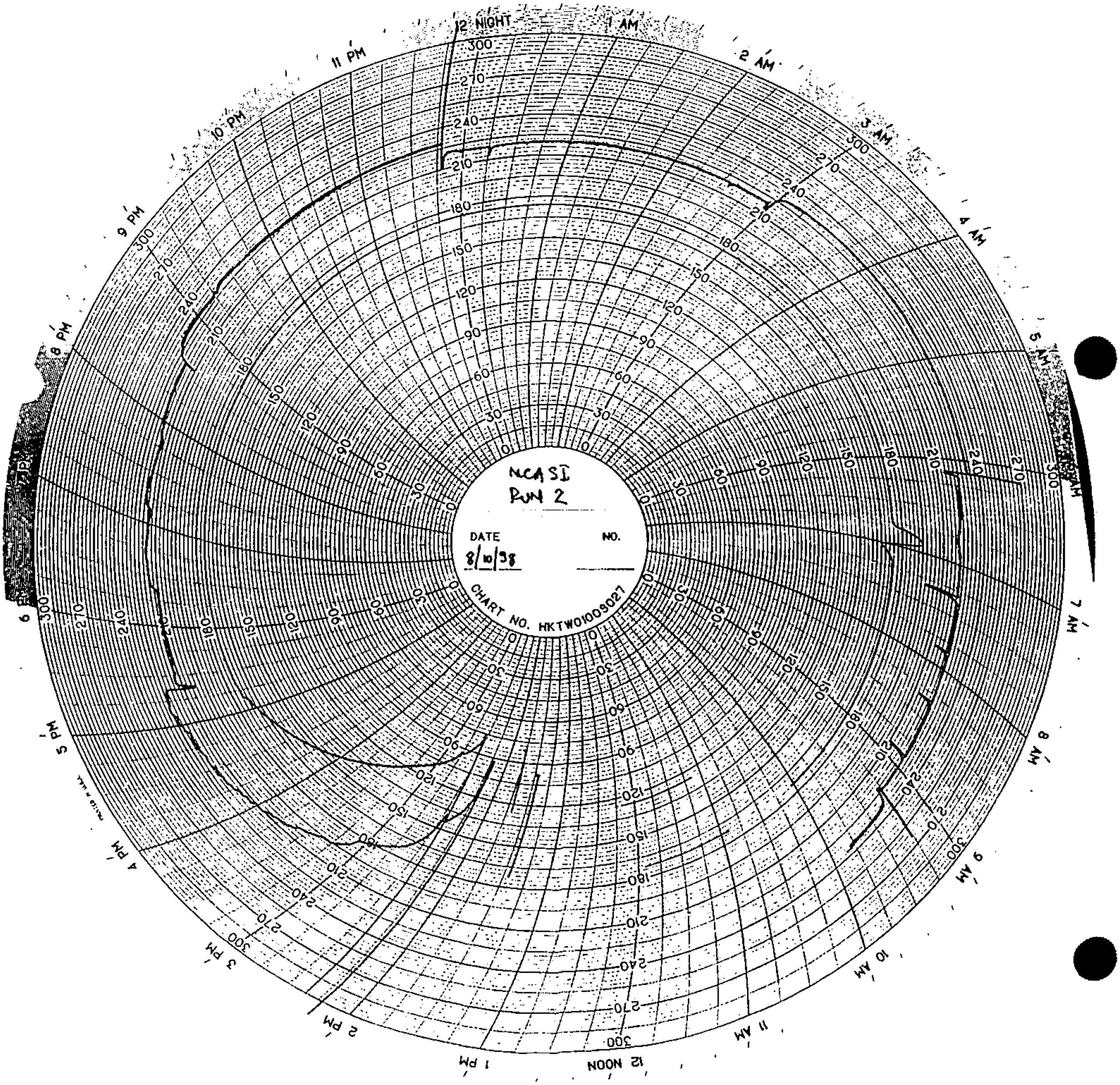
Variability Study Kiln Charge HE 2
Comparison of WB/DB Temperatures to Venting Rate



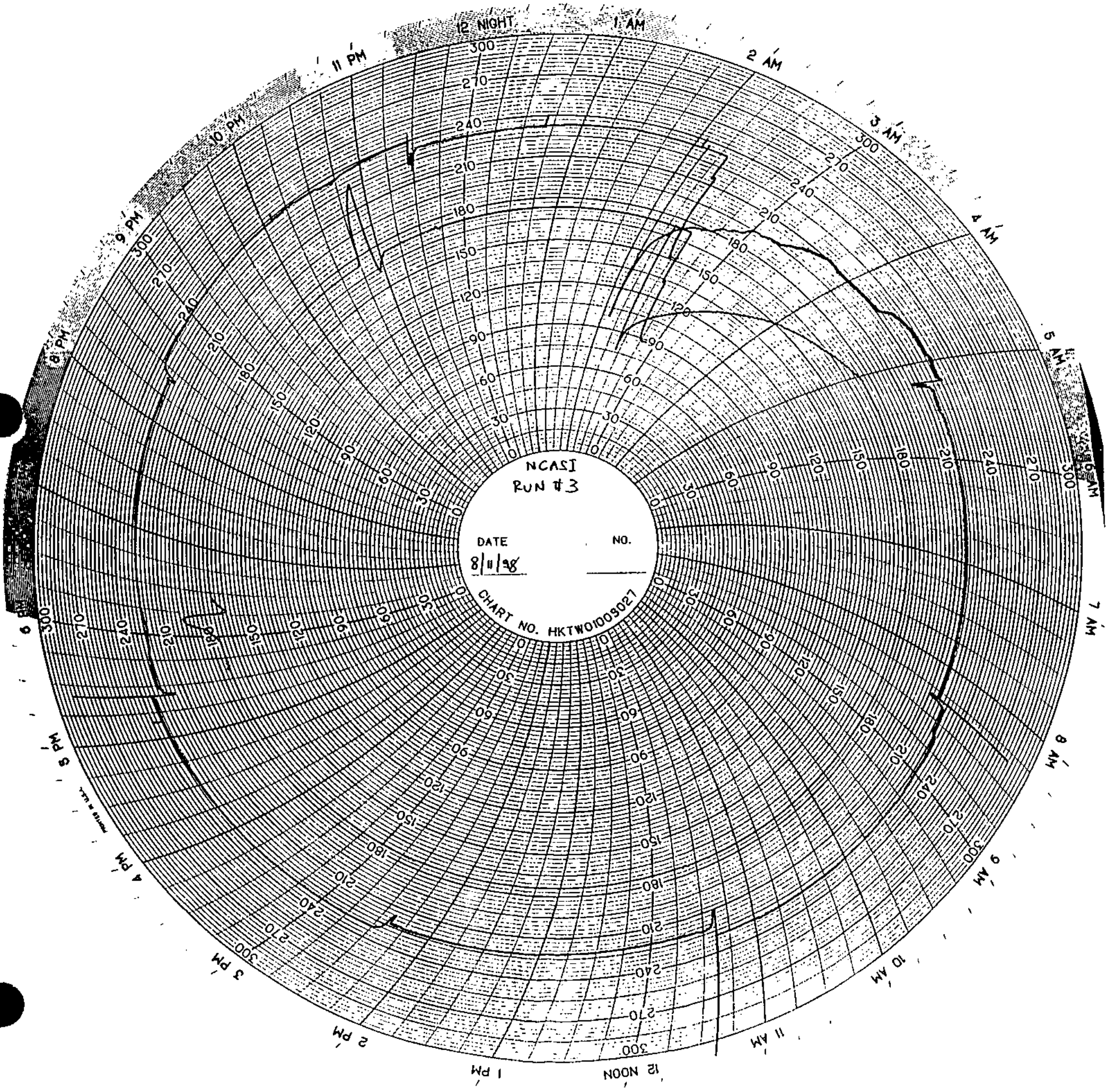
Variability Study Kiln Charge HDHE 3
Comparison of Wet/Dry Bulb Temperature to Venting Rate



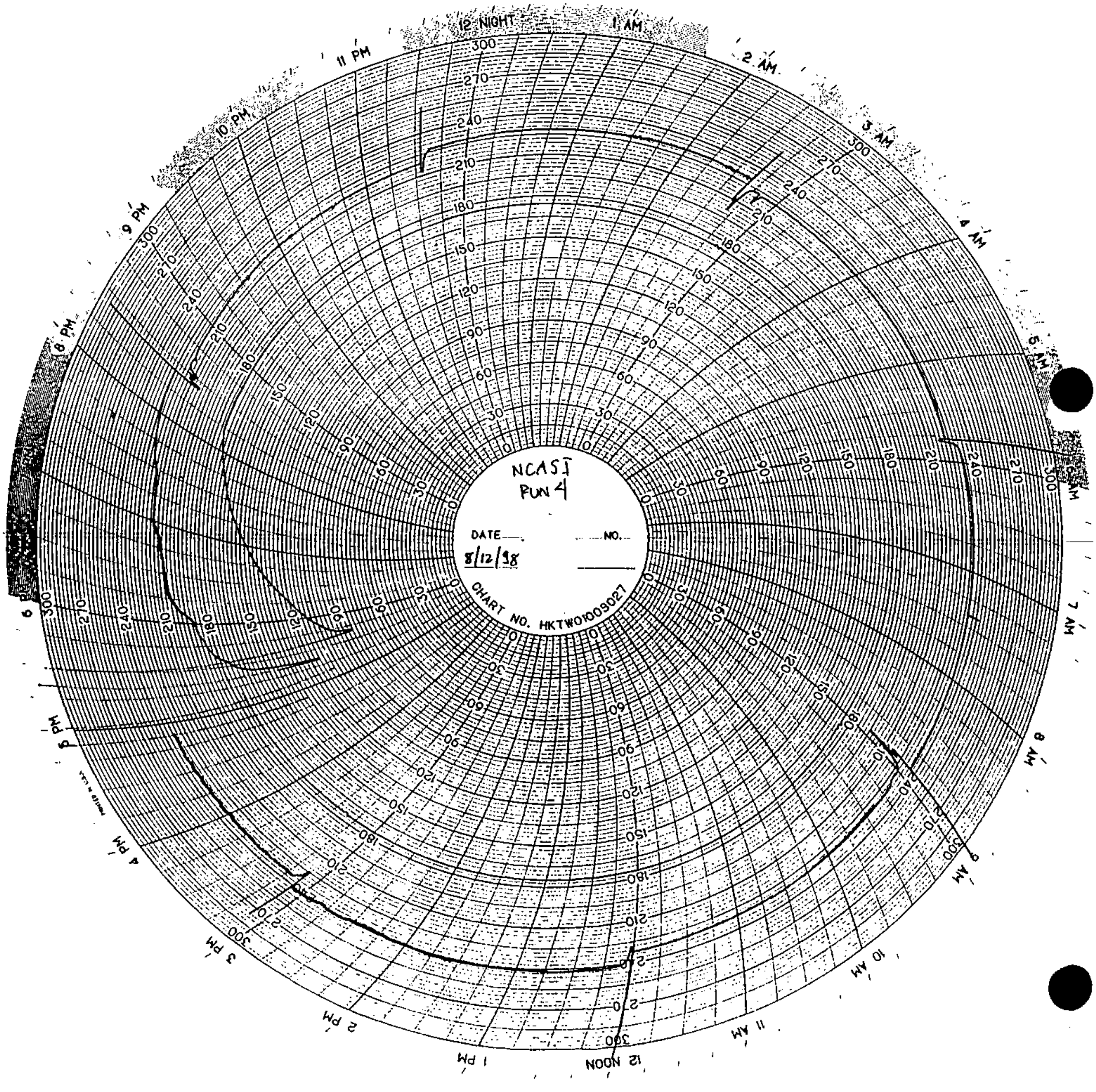
Variability Study Kiln Charge NCSU 2
Wet/Dry Bulb Temperature Schedule



Variability Study Kiln Charge NCSU 3
Wet/Dry Bulb Temperature Schedule



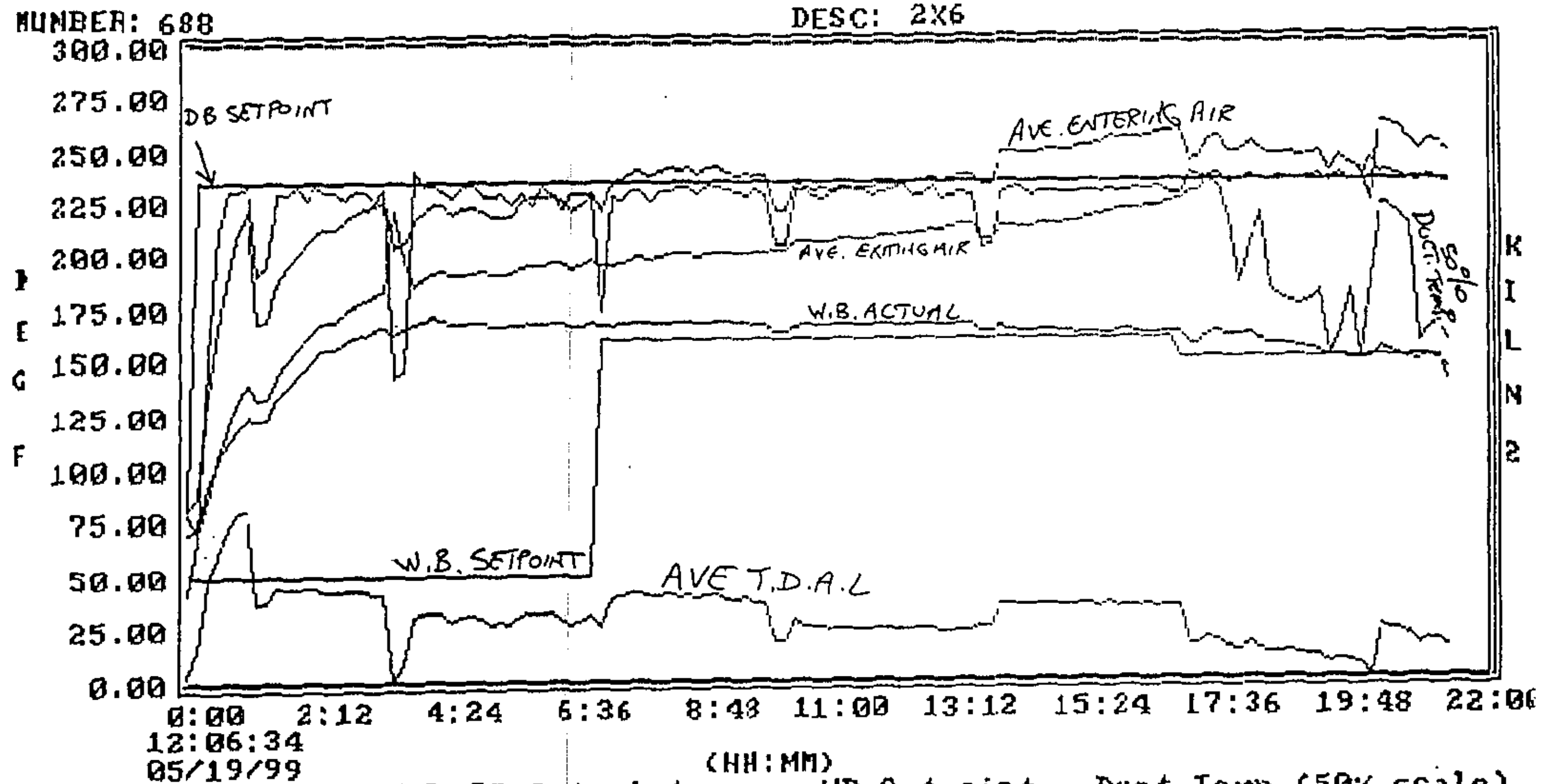
Variability Study Kiln Charge NCSU 4
Wet/Dry Bulb Temperature Schedule



APPENDIX B

DIRECT-FIRED FULL-SCALE KILN WET/DRY BULB TEMPERATURE PROFILES

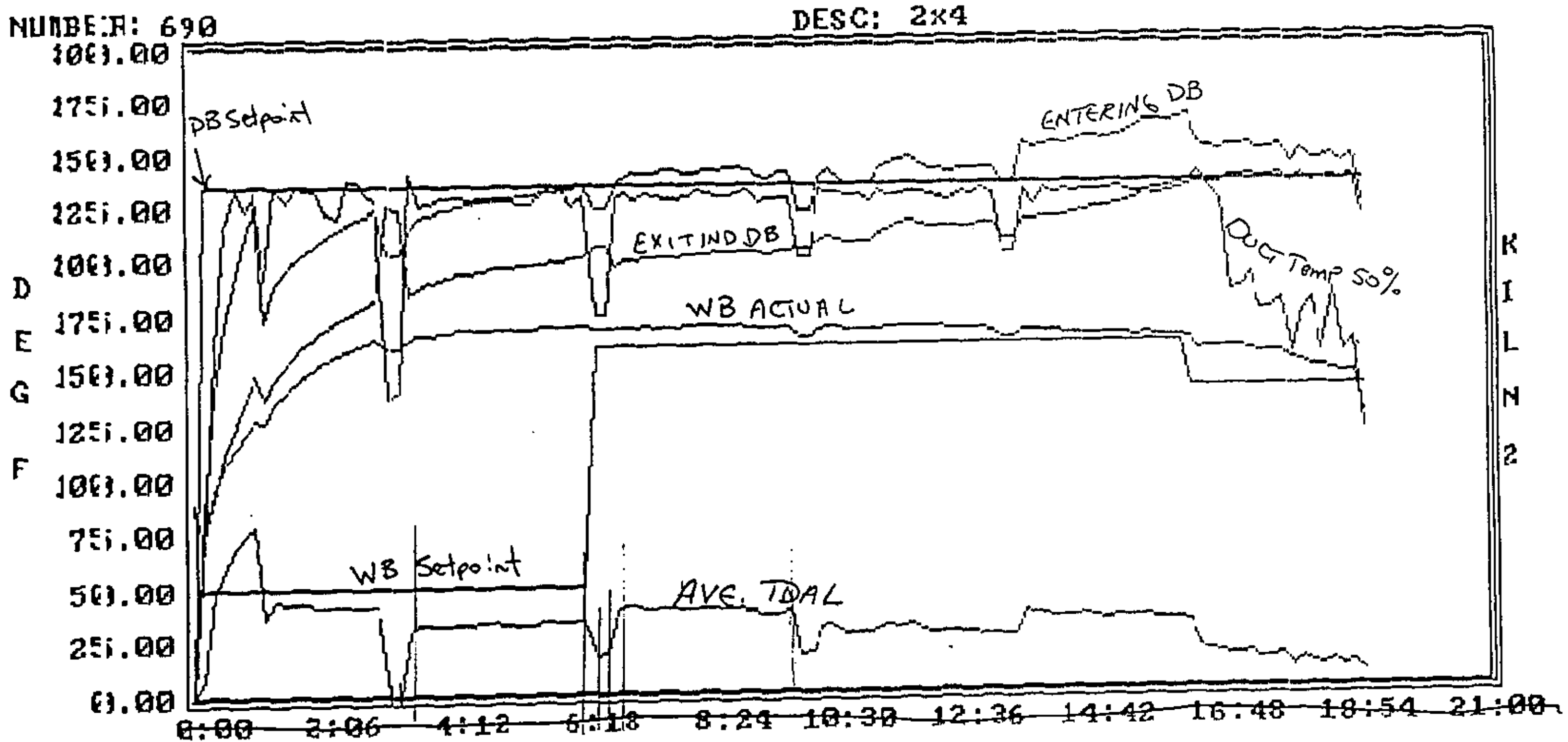
Kiln Charge FSK DF1



Average Entering DB DB Setpoint WB Setpoint Duct Temp (50% scale)
Average Exiting DB Average T.D.A.L. WB Actual

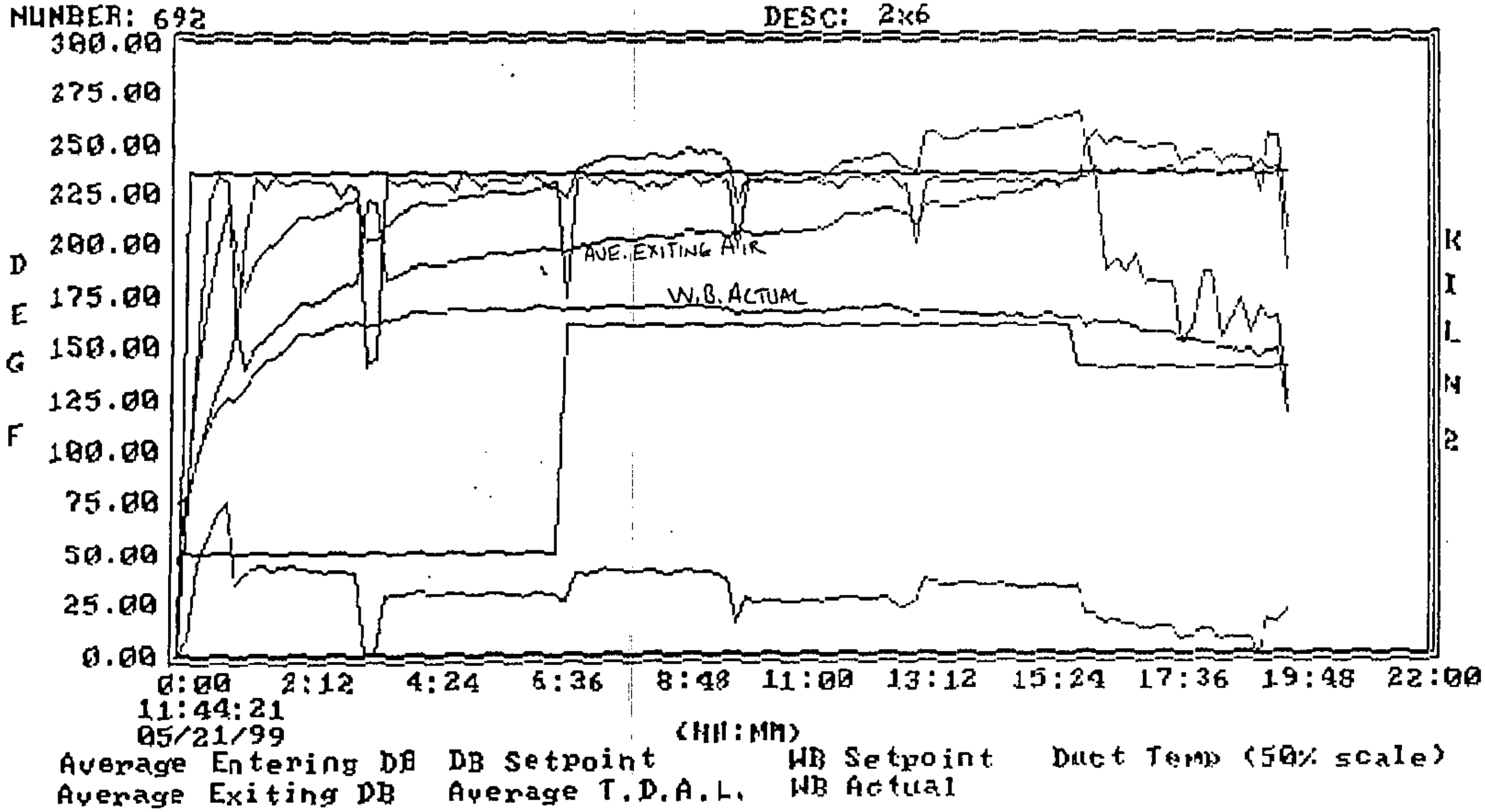
TIME:	VALUES:		
05/19/99		81.207	50.005
12:06:34		78.307	2.900
		81.207	42.304
		70.606	

Kiln Charge FSK DF2



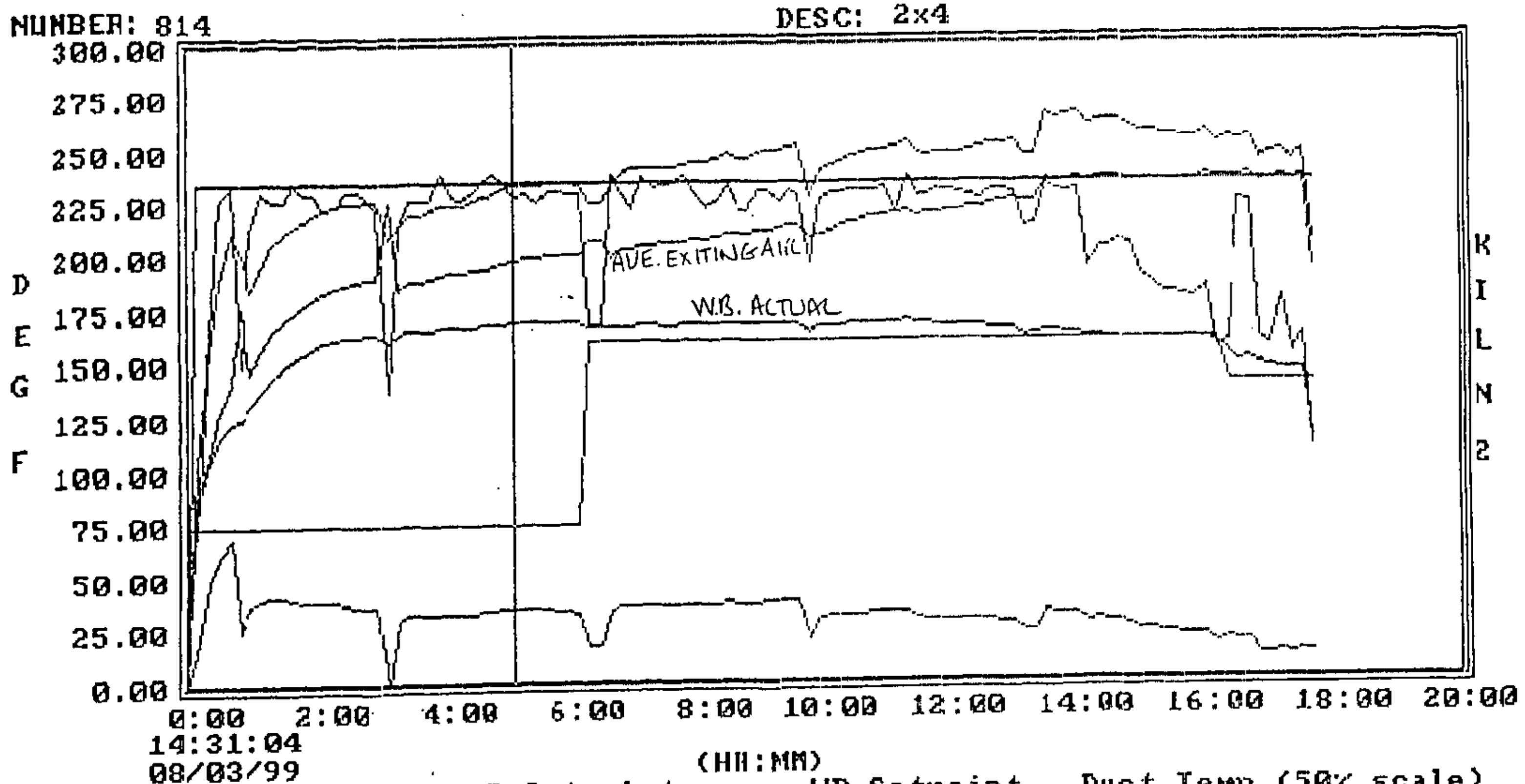
```
Average Entering DB  DB Setpoint           WB Setpoint   Duct Temp (50% scale)
Average Exiting DB   Average T.D.A.L.      WB Actual

TIME:        VALUES:     0.000          50.005
05/20/99                 0.000           0.000
12:12:13                 0.000          89.708
                        86.808
```

Kiln Charge FSK DF3



```
TIME:        VALUES:   0.000       50.005
05/21/99               0.000       0.000
11:44:21               0.000       44.704
                       74.107
```

Kiln Charge FSK DF4

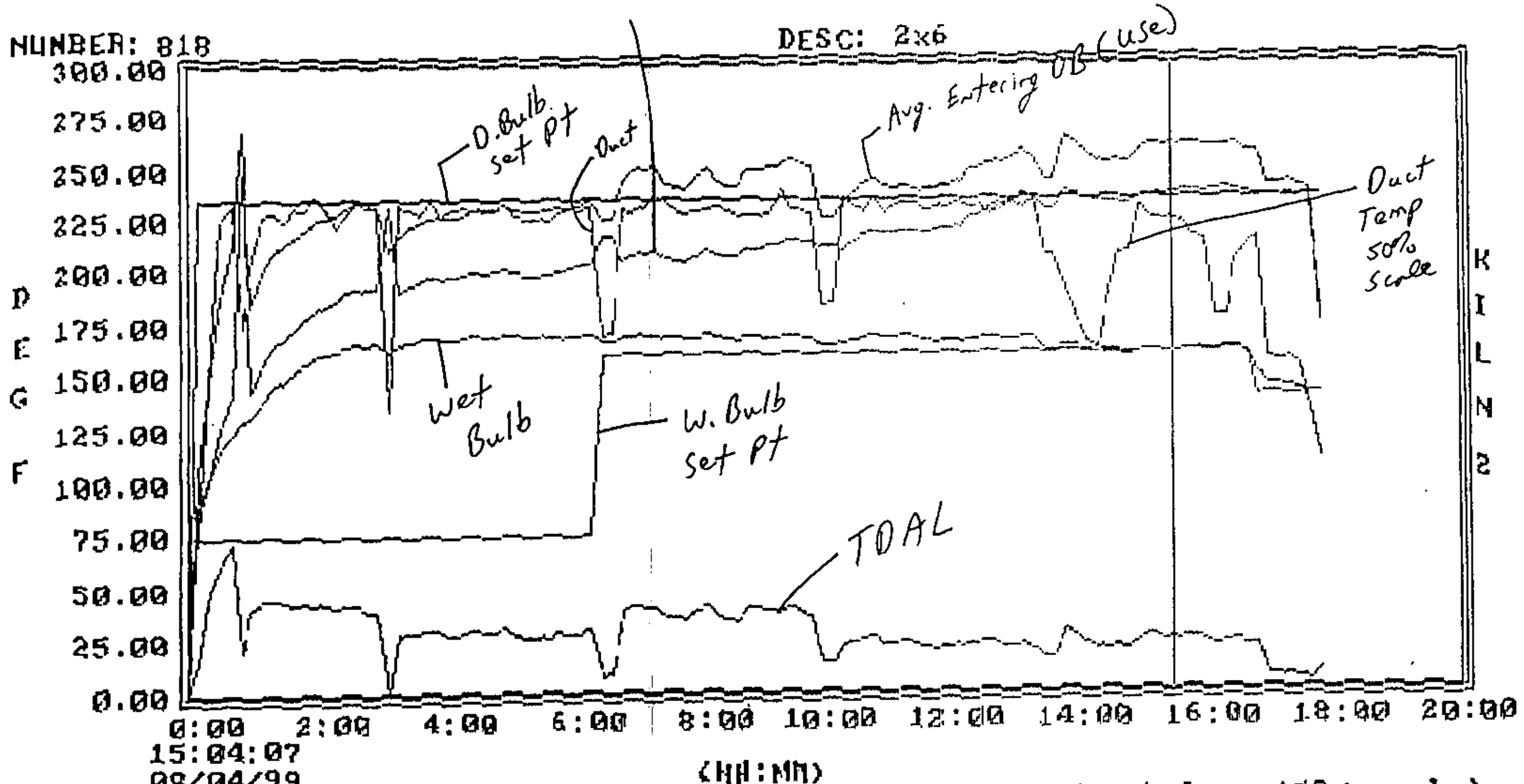


```
Average Entering DB  DB Setpoint       WB Setpoint   Duct Temp (50% scale)
Average Exiting DB   Average T.D.A.L.  WB Actual

TIME:        VALUES:  233.021      75.007
08/03/99              198.218      34.803
19:27:34              235.022      227.921
                      169.015
```

1st TEST

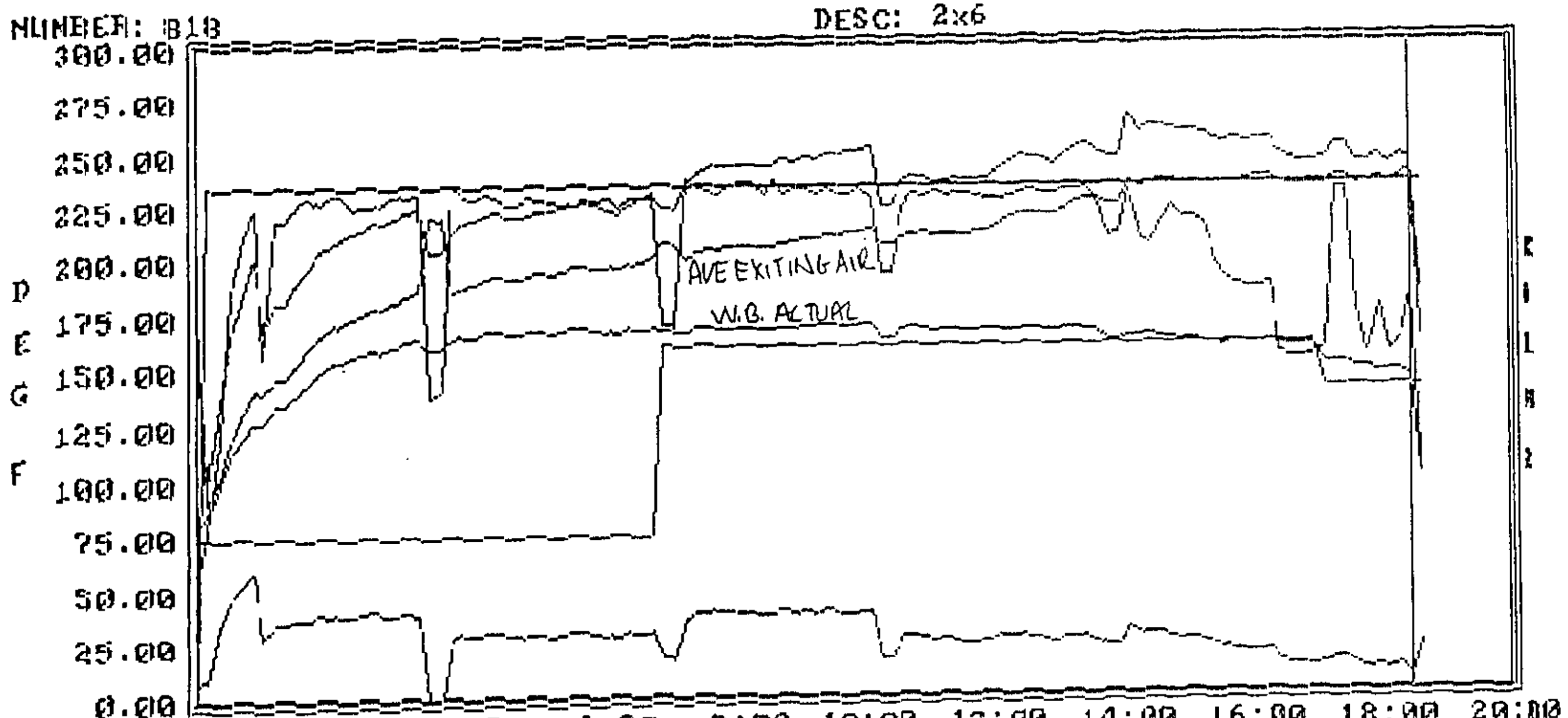
Kiln Charge FSK DF5

```
NUMBER: 818                          DESC: 2x6
```



```
15:04:07
08/04/99                               (HH:MM)
Average Entering DB   DB Setpoint         WB Setpoint    Duct Temp (50% scale)
Average Exiting DB    Average T.D.A.L.    WB Actual

TIME:         VALUES:     261.624         160.015
08/05/99                  236.822         24.802
04:59:35                  235.022         225.421
                          160.415
```

Kiln Charge FSK DF6

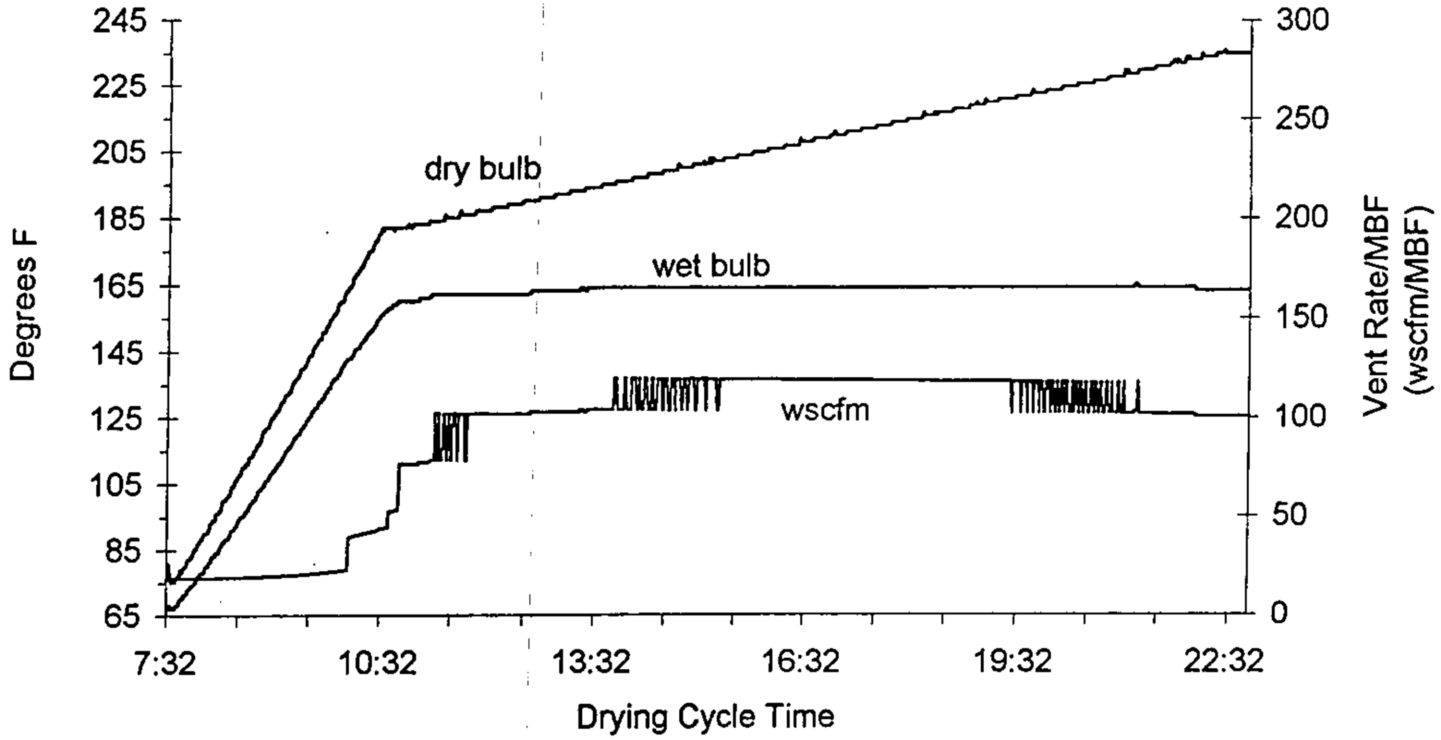


```
14:02:10
08/05/99                          (HH:MM)
Average Entering DB  DB Setpoint         WB Setpoint    Duct Temp (50% scale)
Average Exiting DB   Average T.D.A.L.    WB Actual

TIME:       VALUES:   245.622      140.013
08/06/99              240.722        4.900
16:20:36              235.022      181.417
                      143.013
```

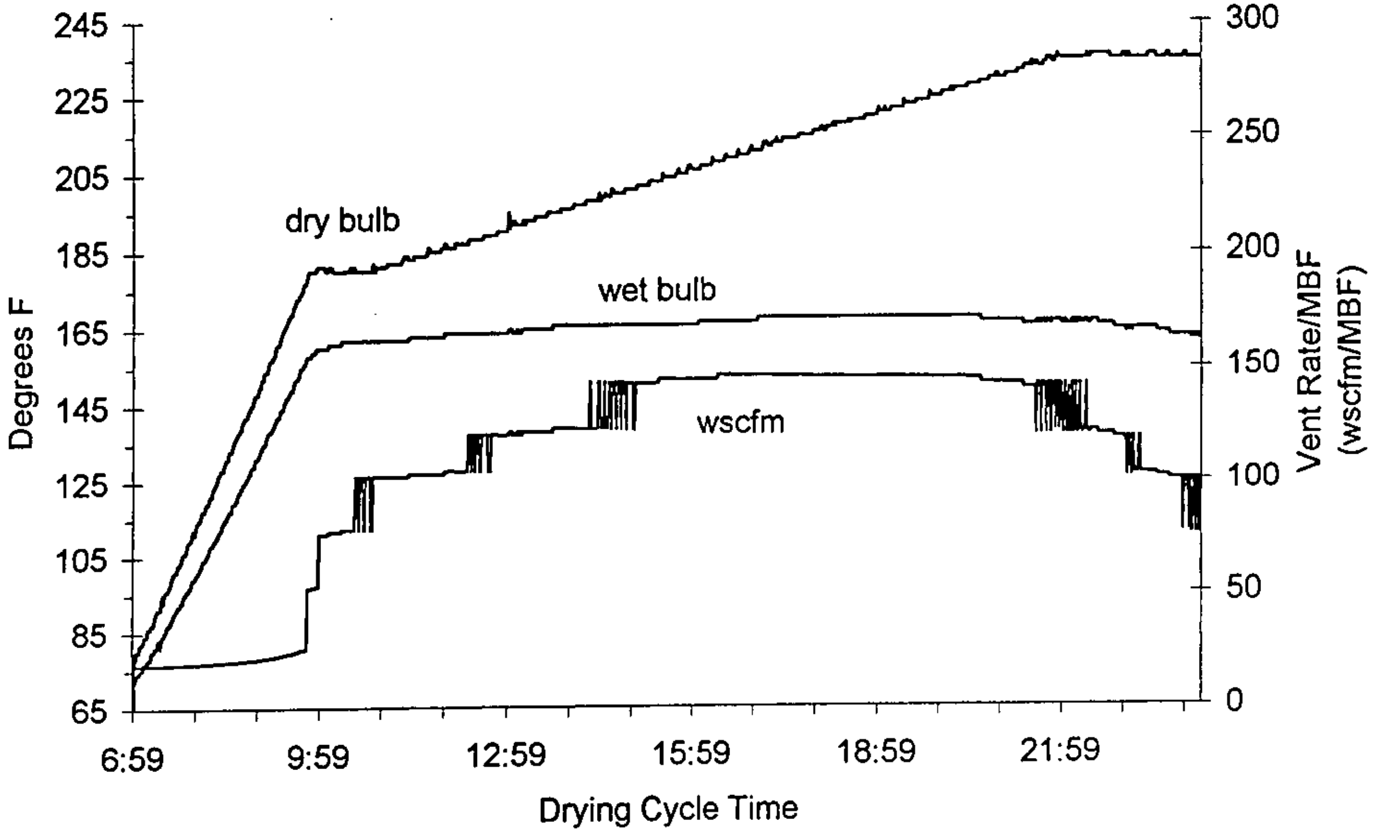
APPENDIX C

SMALL-SCALE KILN WET/DRY BULB TEMPERATURE PROFILES FOR DIRECT-FIRED SAMPLE CHARGES

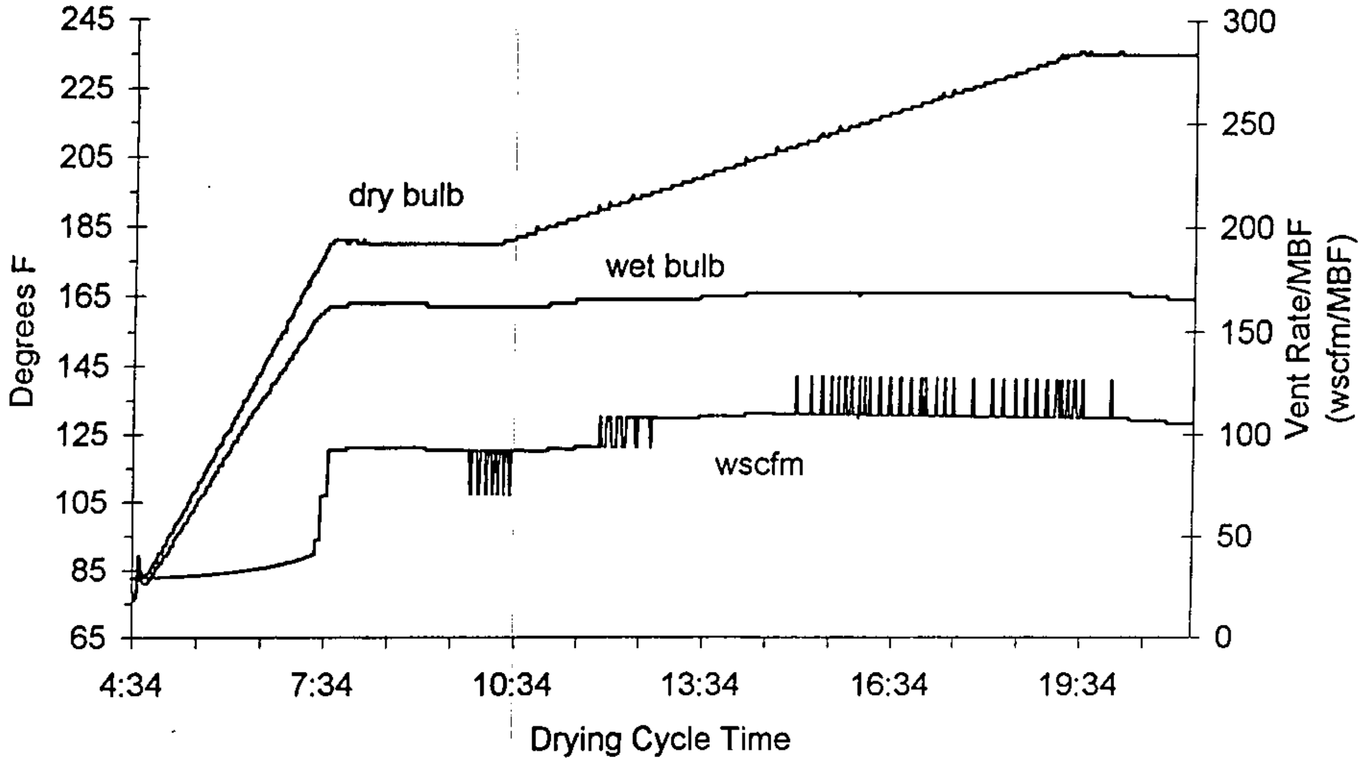
Kiln Charge MSU DF1A
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



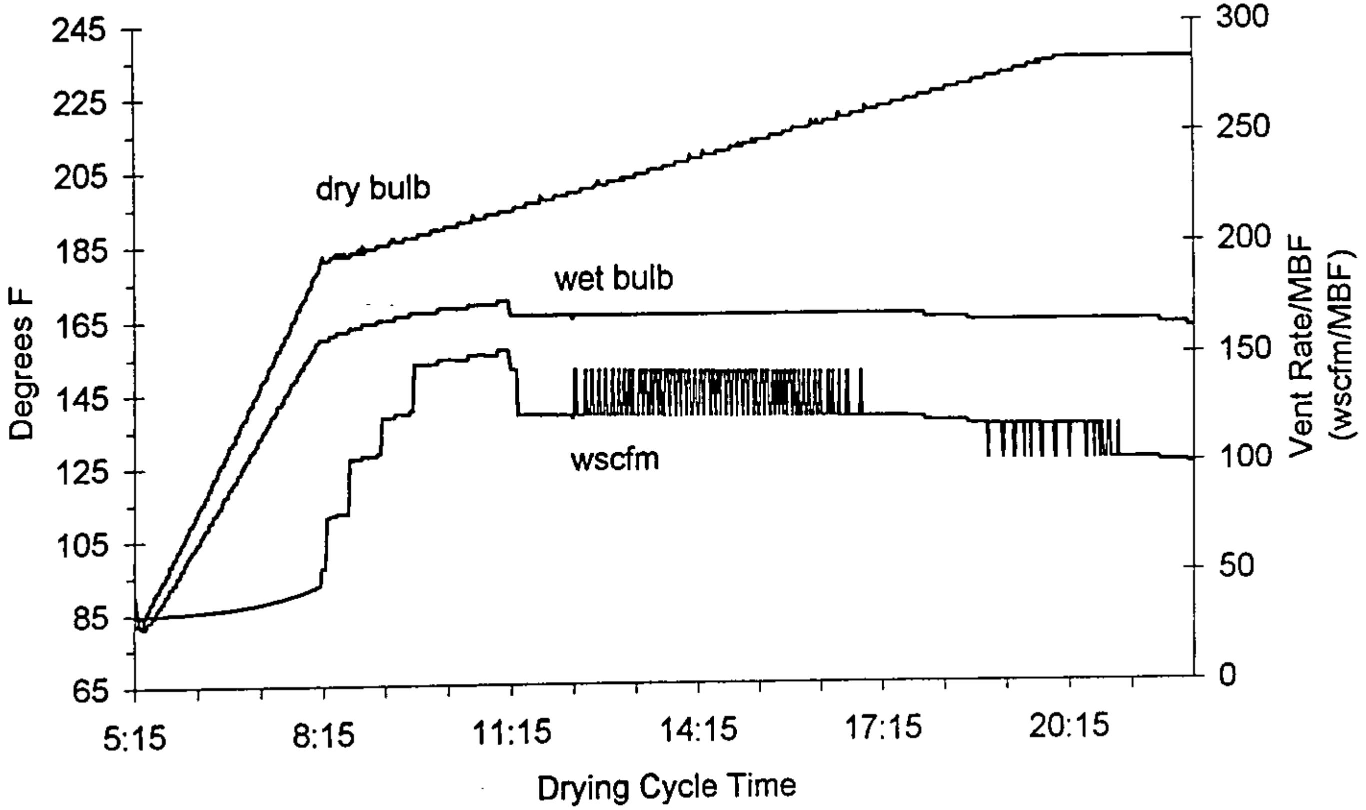
Kiln Charge MSU DF1B
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



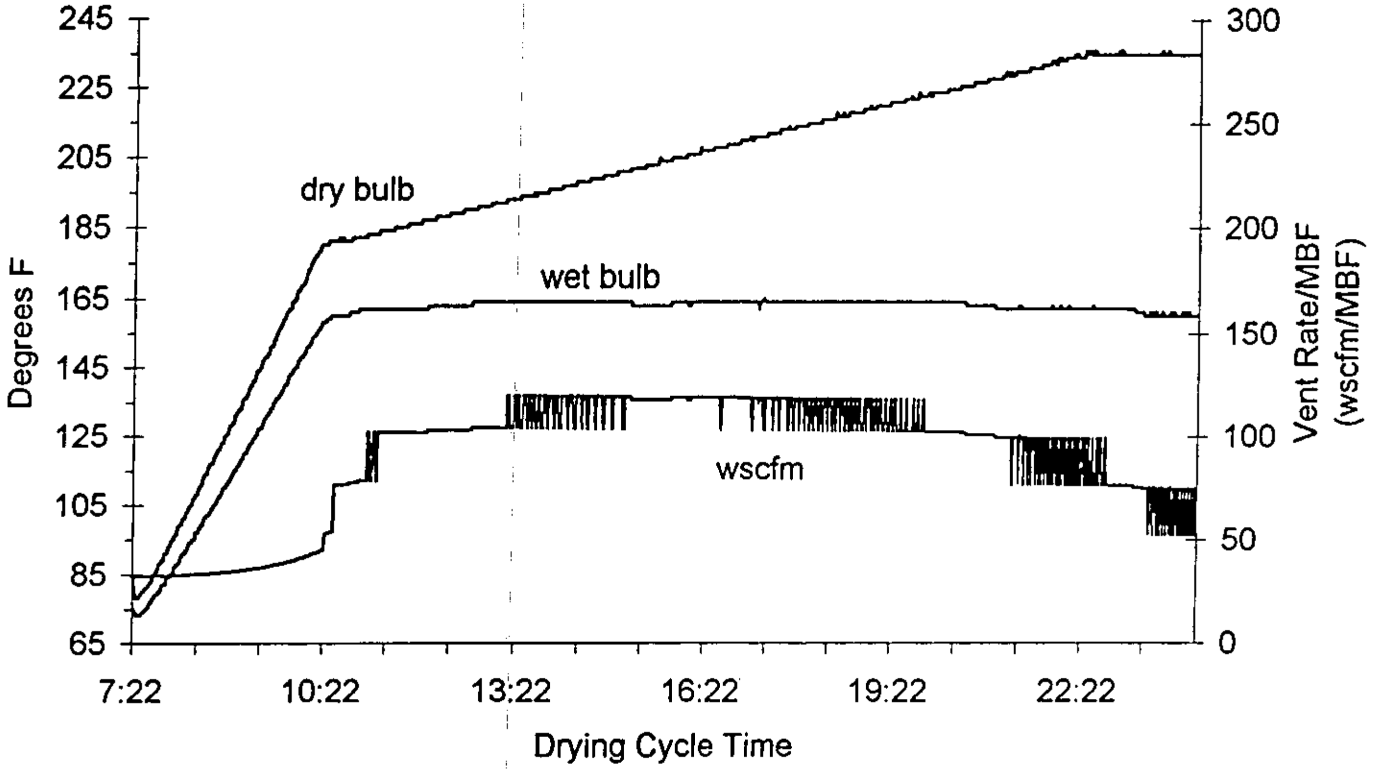
Kiln Charge MSU DF2
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



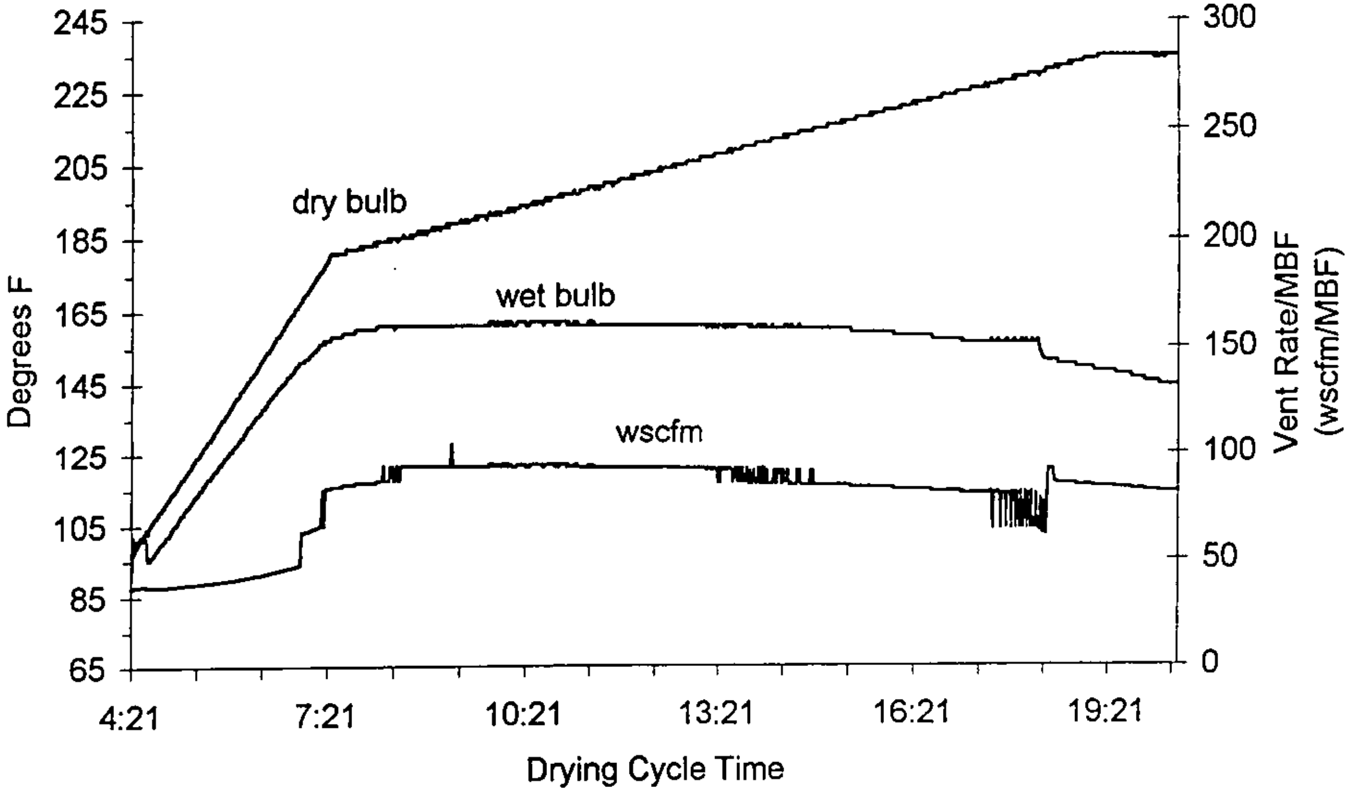
Kiln Charge MSU DF3A
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



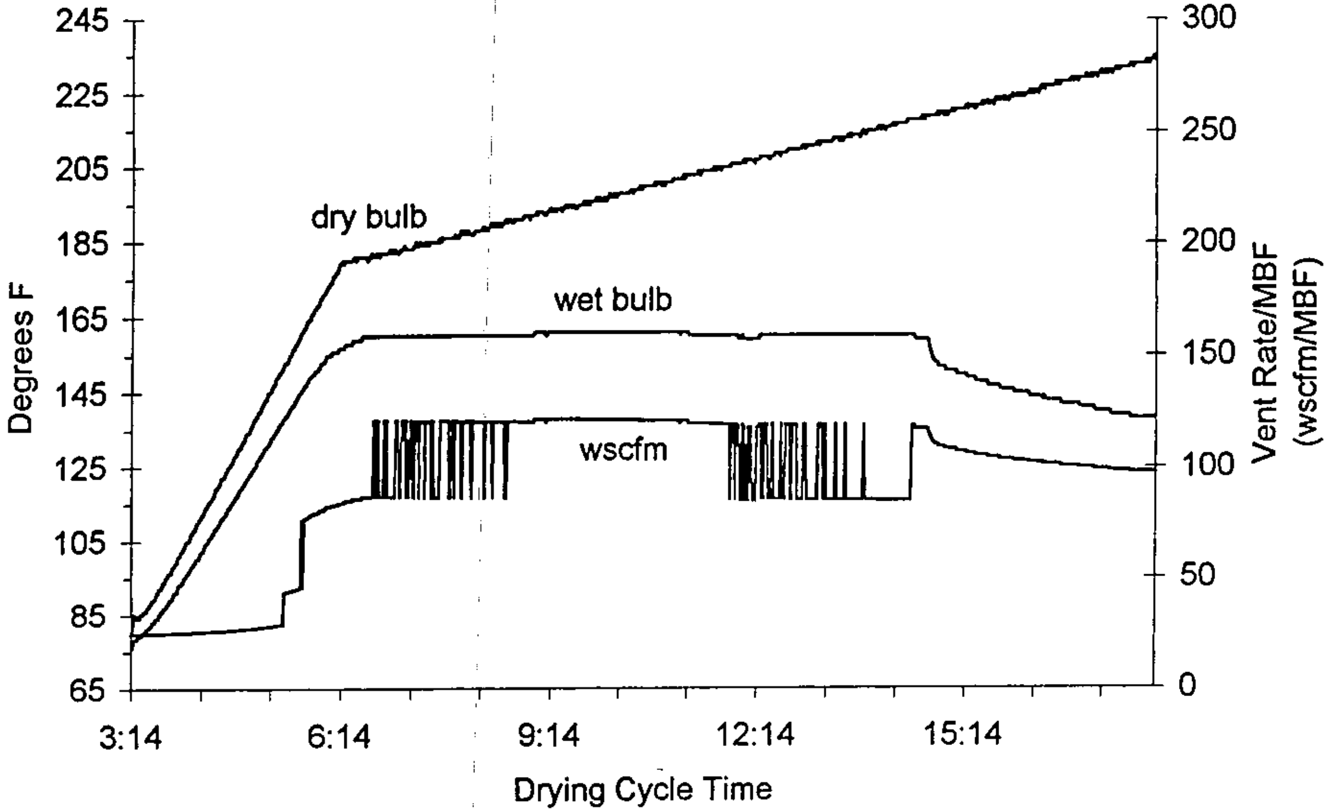
Kiln Charge MSU DF3B
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



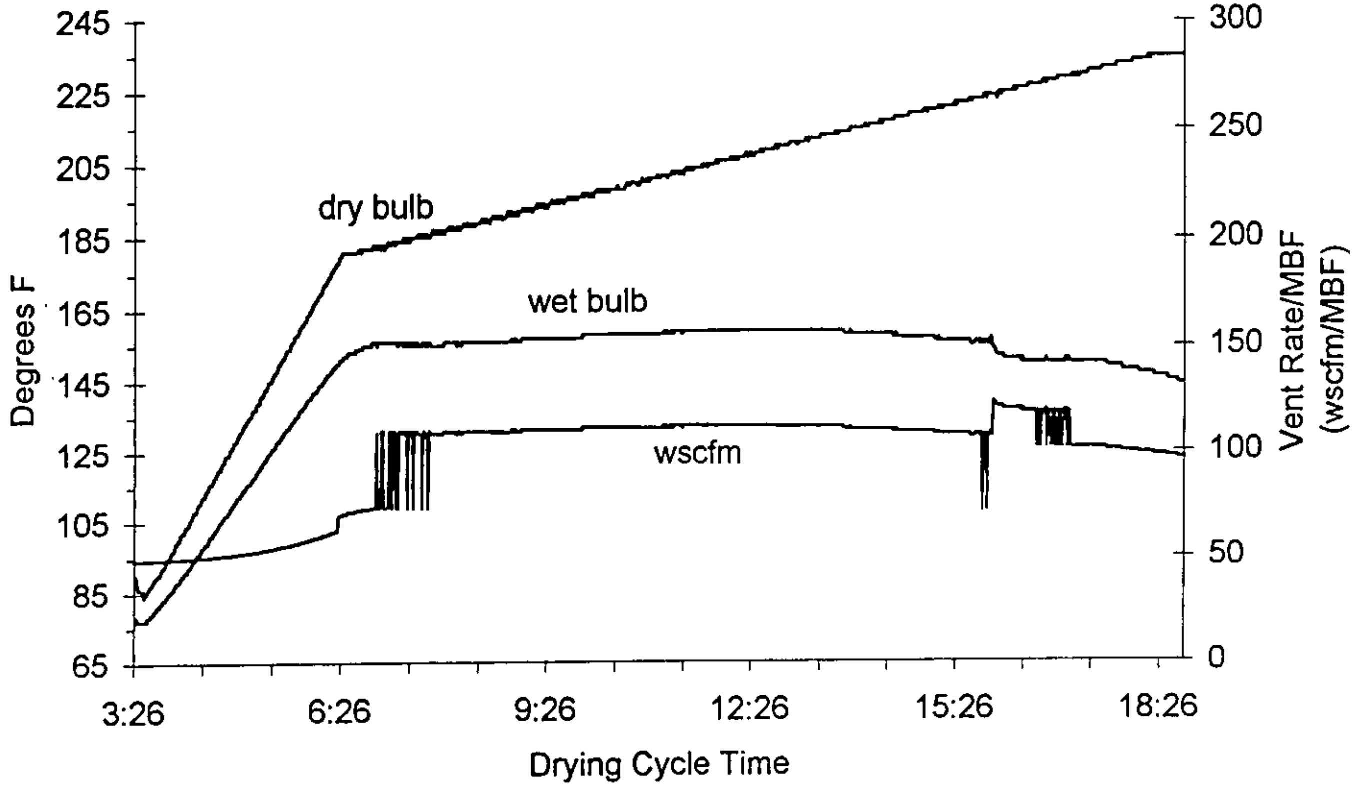
Kiln Charge MSU DF4
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



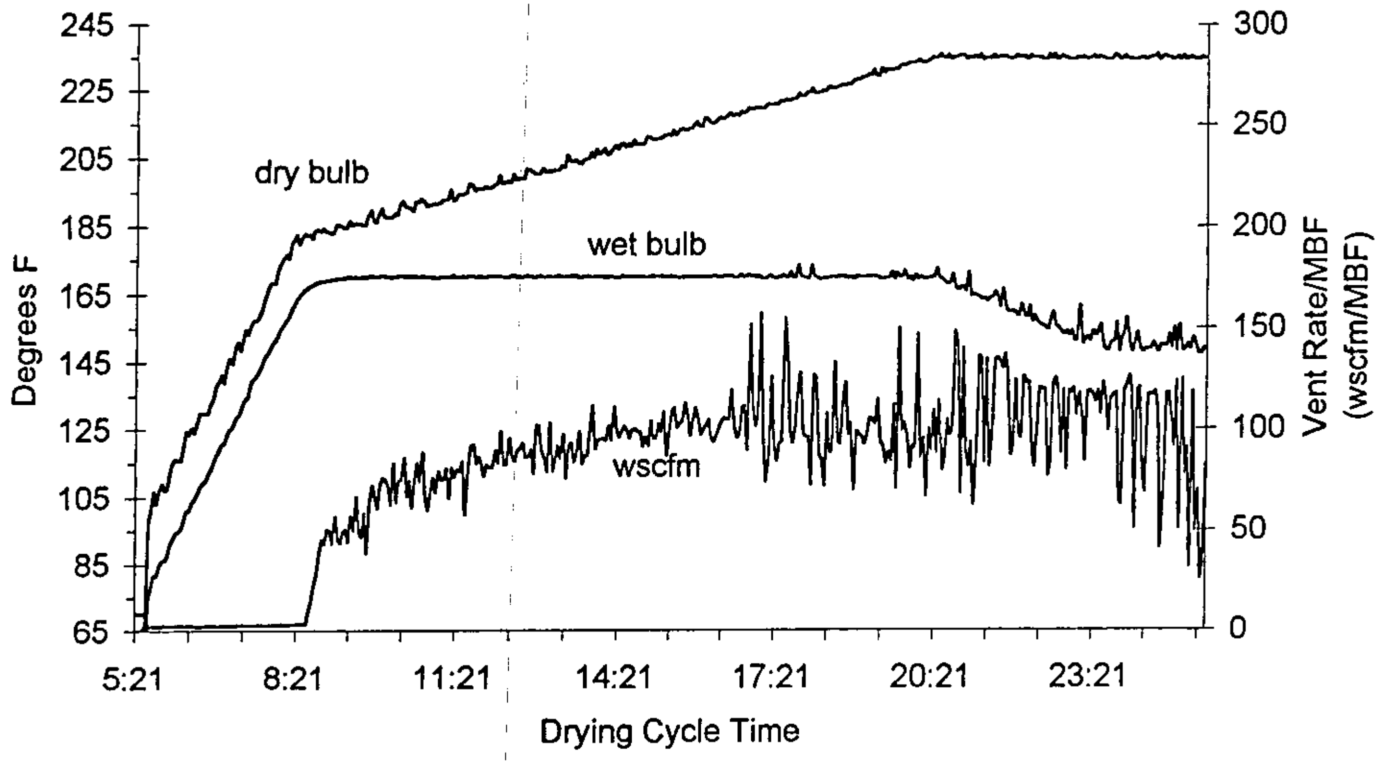
Kiln Charge MSU DF5
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



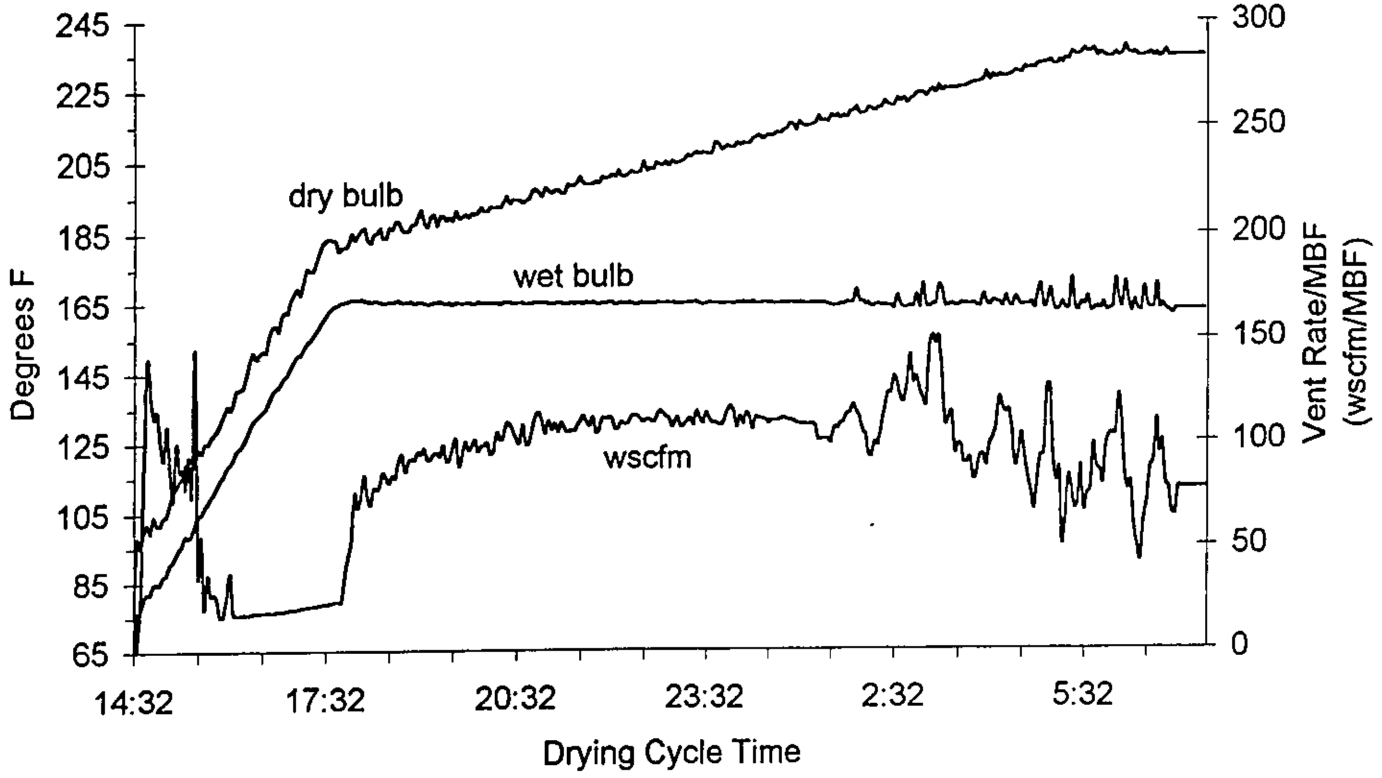
Kiln Charge MSU DF6
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



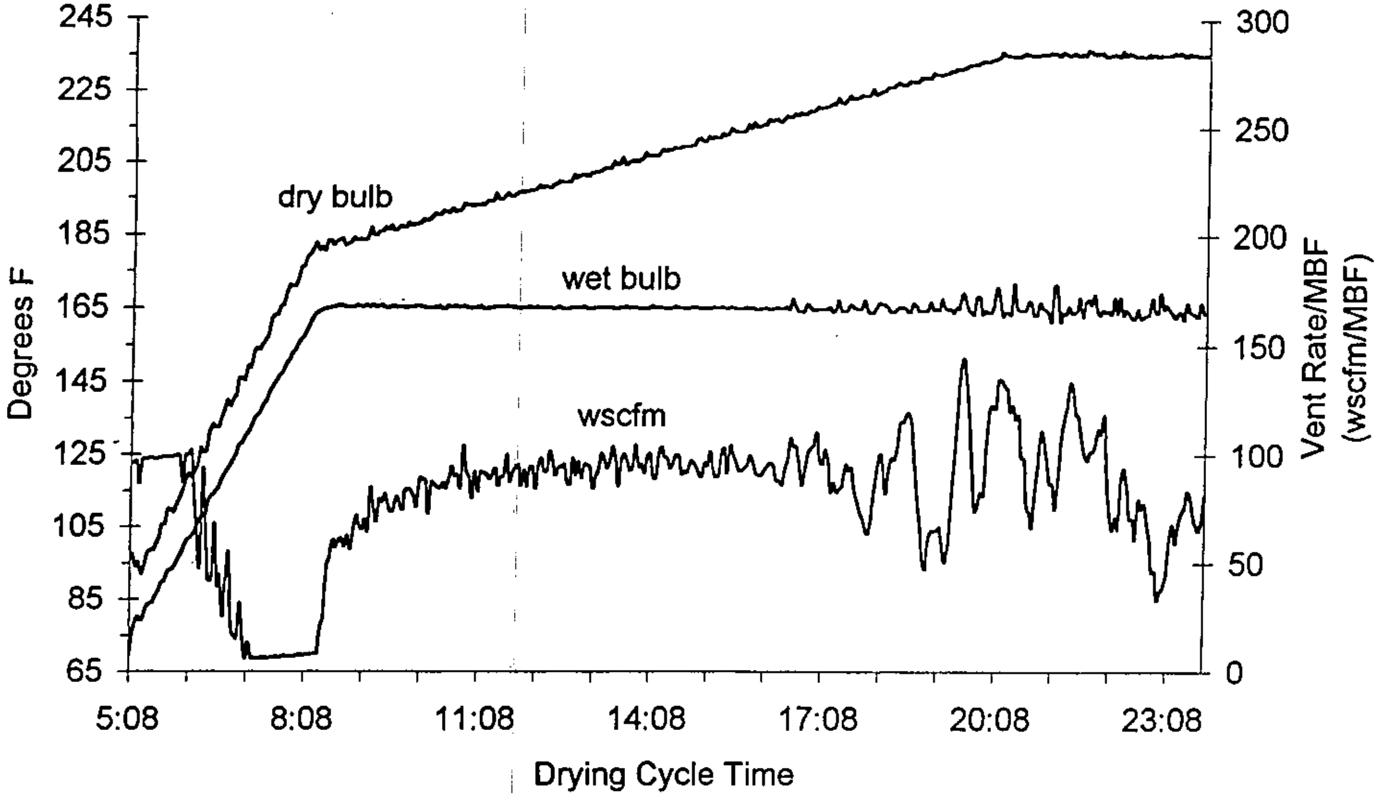
Kiln Charge OSU DF1
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



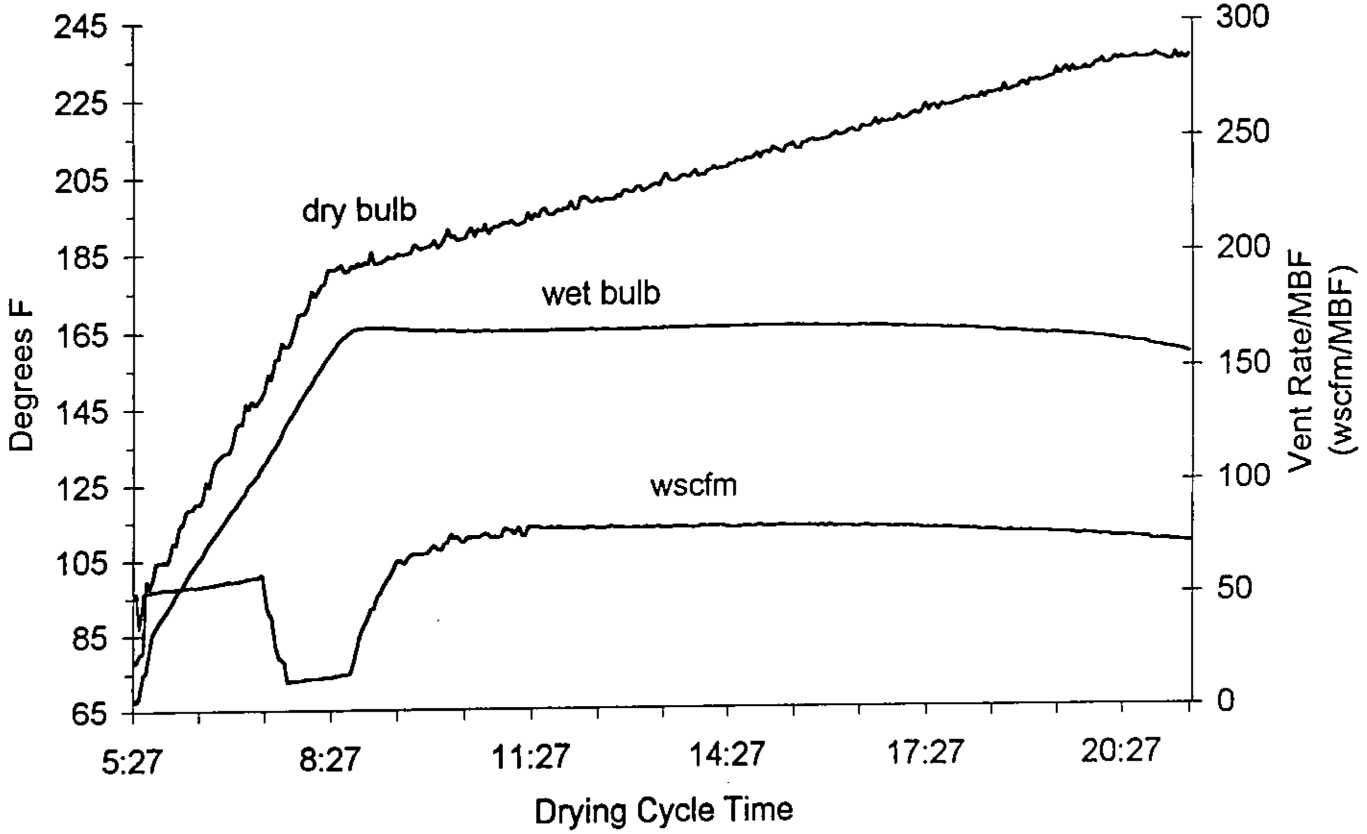
Kiln Charge OSU DF2C
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



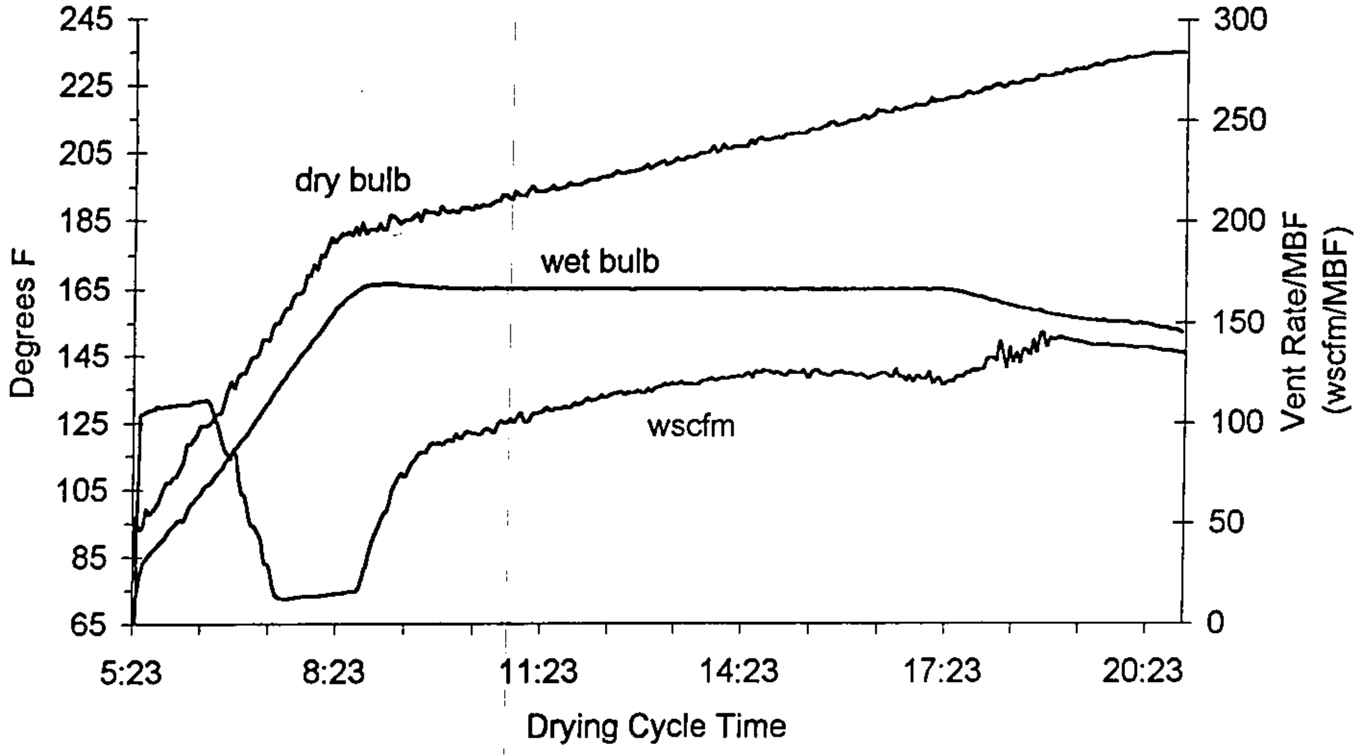
Kiln Charge OSU DF3
Comparison of Wet/Dry Bulb Temperatures to Venting Rate



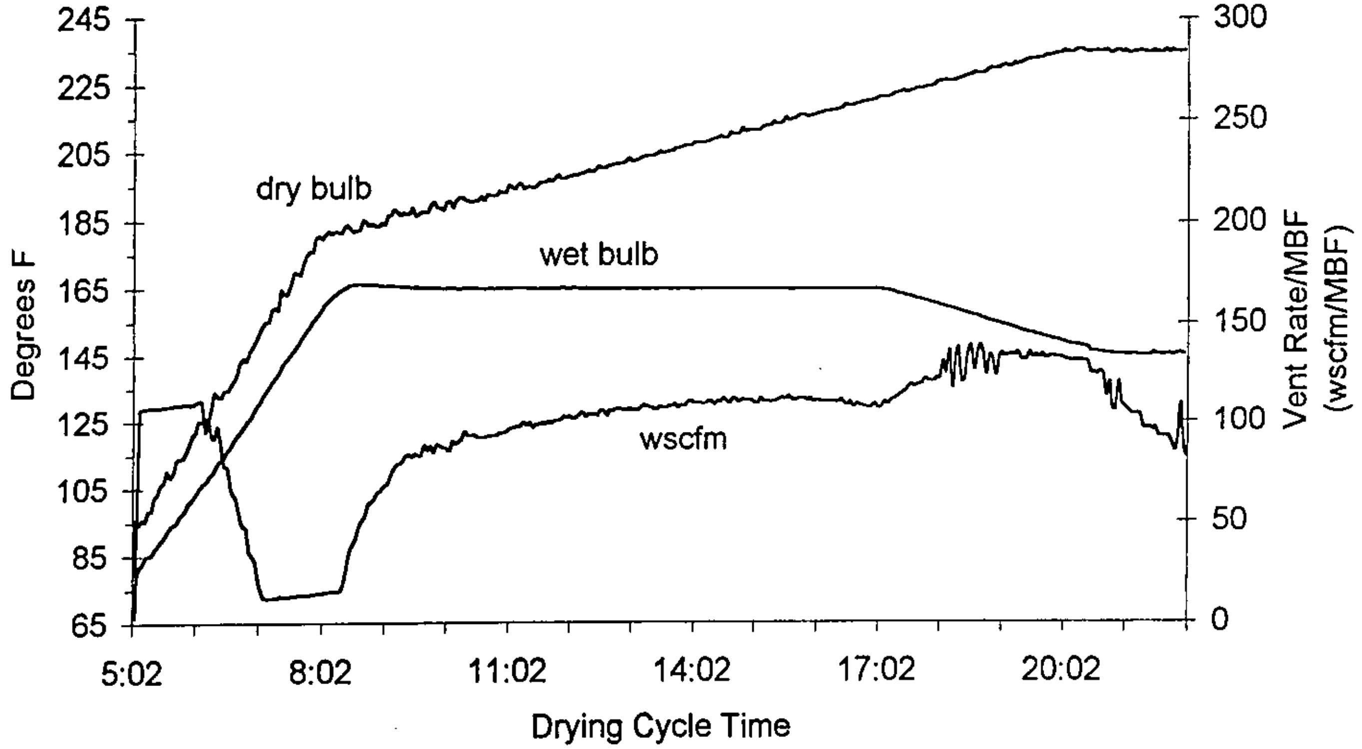
Kiln Charge OSU-DF4
Comparison of Wet/Dry BulbTemperatures to Venting Rate



Kiln Charge OSU-DF5
Comparison of Wet/Dry Bulb Temperature to Venting Rate



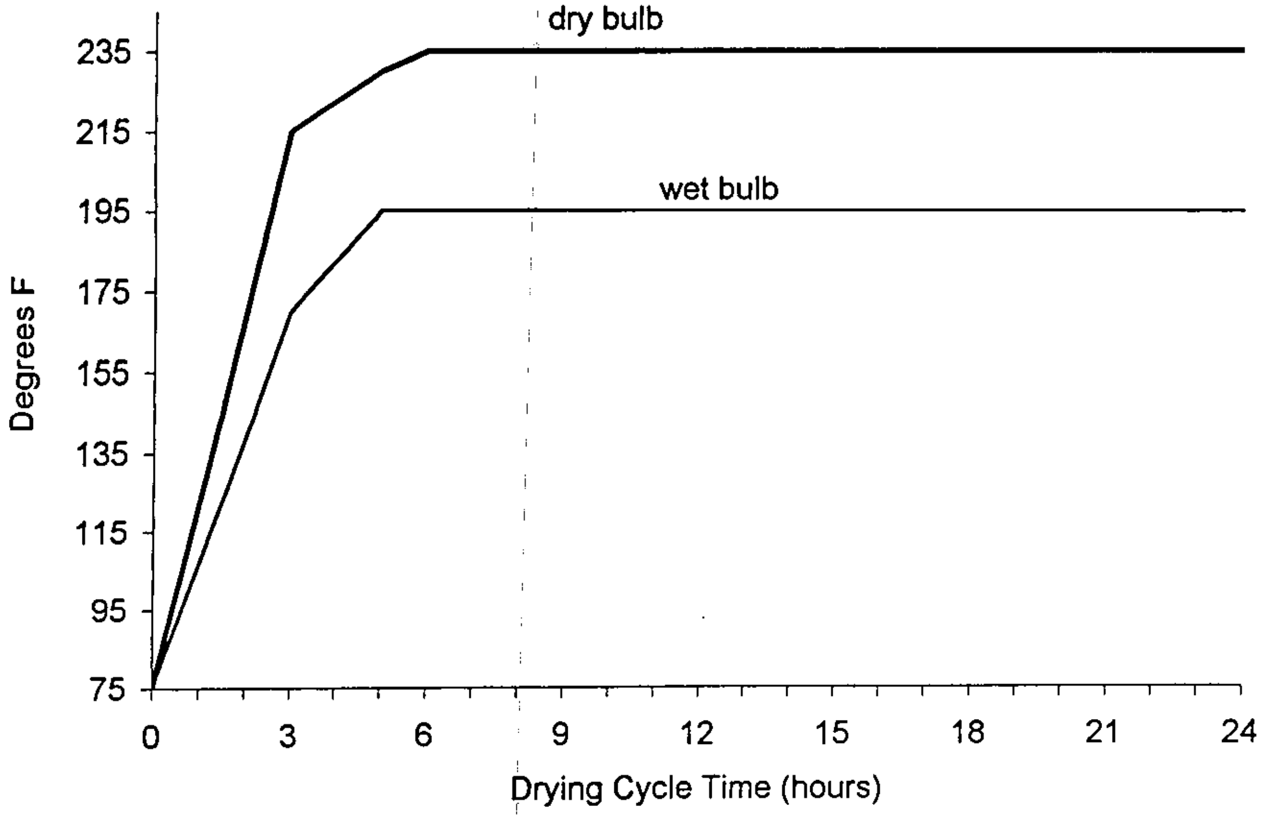
Kiln Charge OSU-DF6
Comparison of Wet/Dry Bulb Temperature to Venting Rate



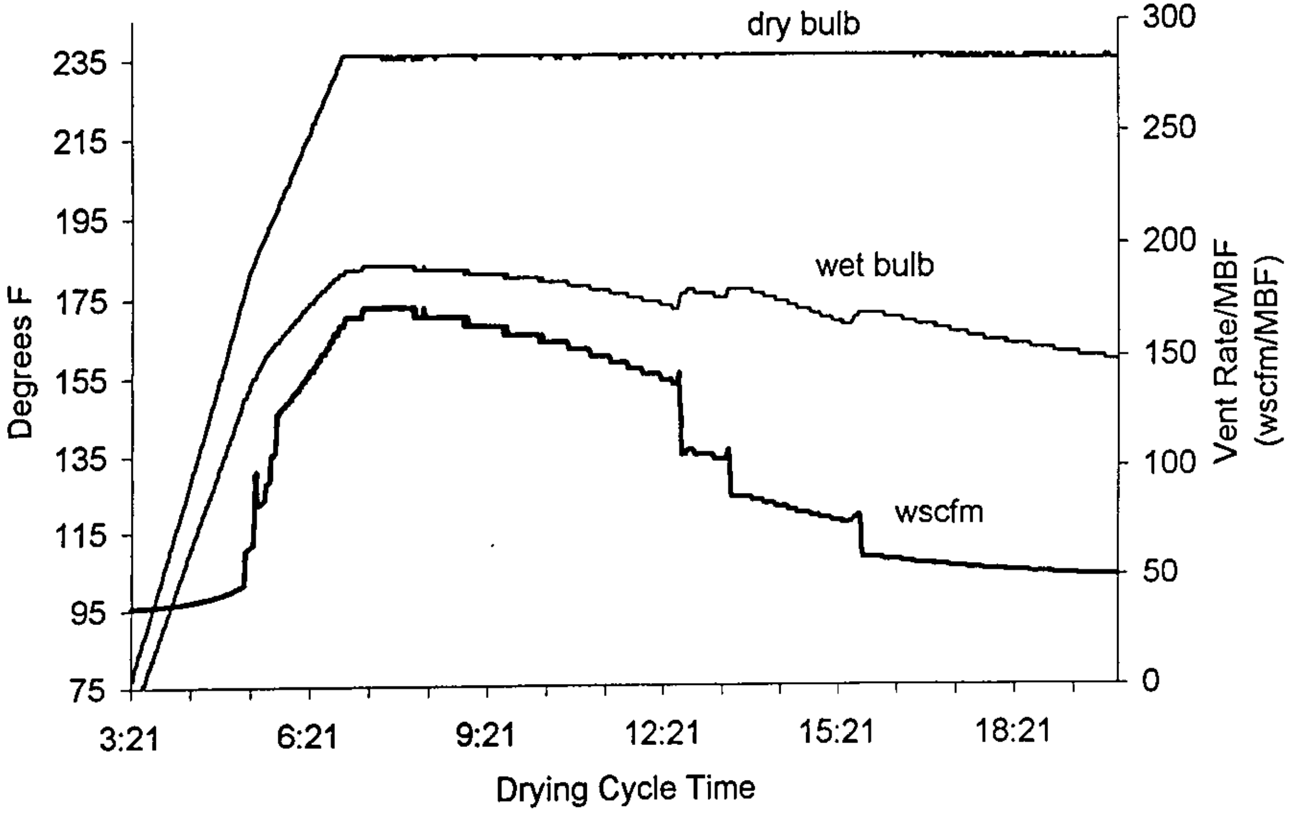
APPENDIX D

FULL-SCALE KILN AND SMALL-SCALE KILN WET/DRY BULB TEMPERATURE PROFILES FOR STEAM KILN TESTING CHARGES

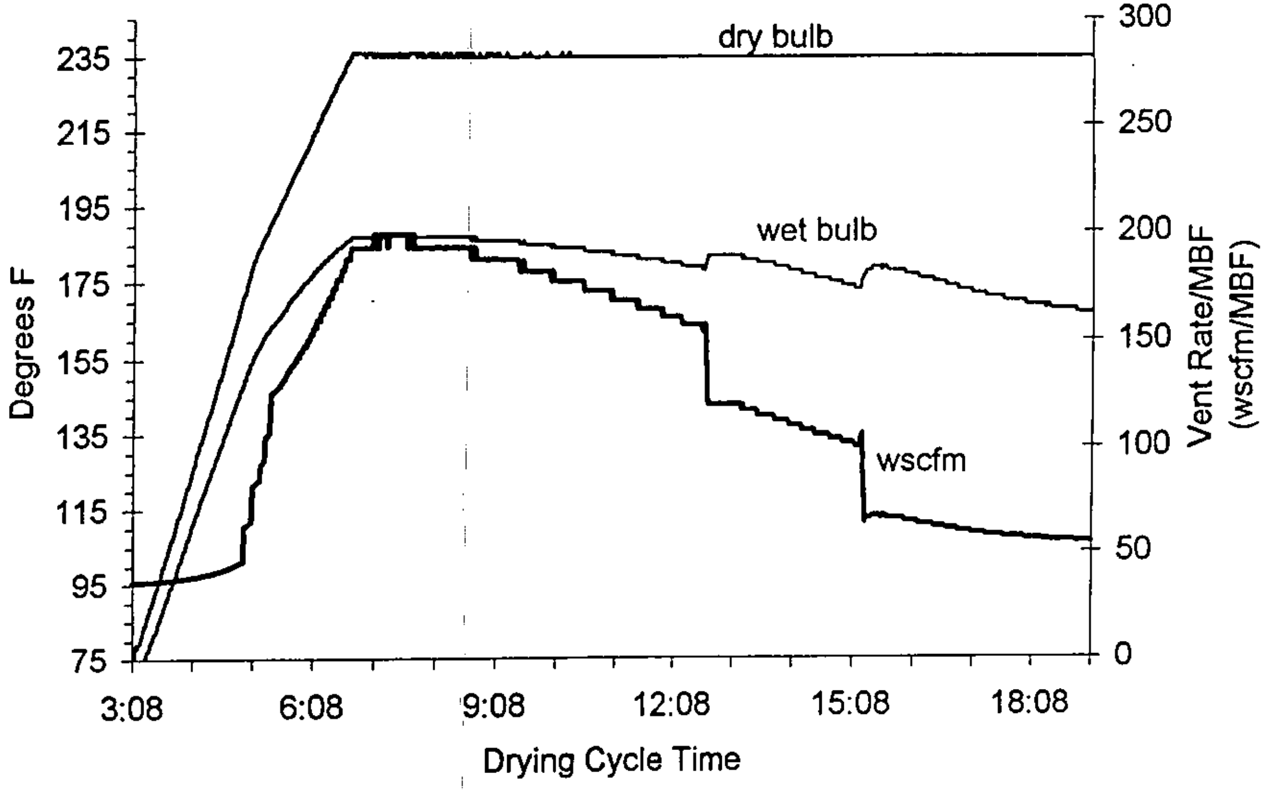
Average Wet/Dry Bulb Temperature
Profile for the Steam-Heated Full-Scale Kiln



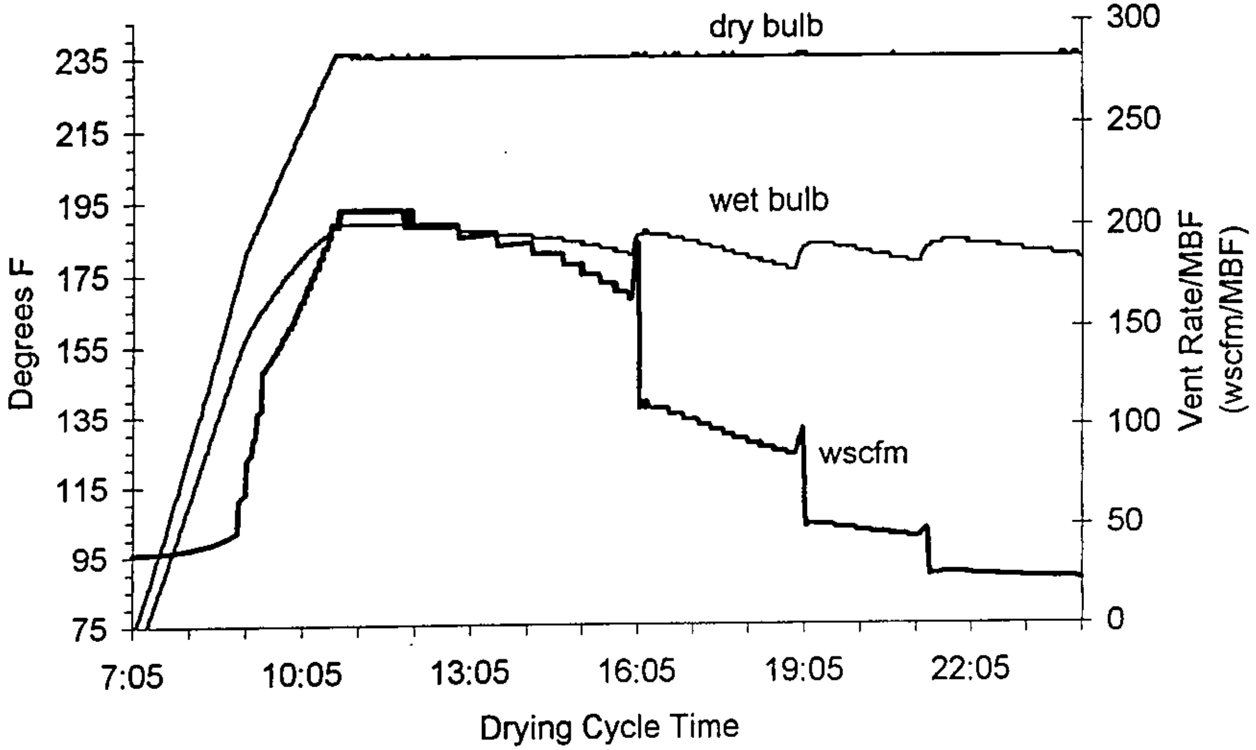
Kiln Charge MSU-INDF1
Comparison of Wet/Dry Bulb Temperature to Venting Rate



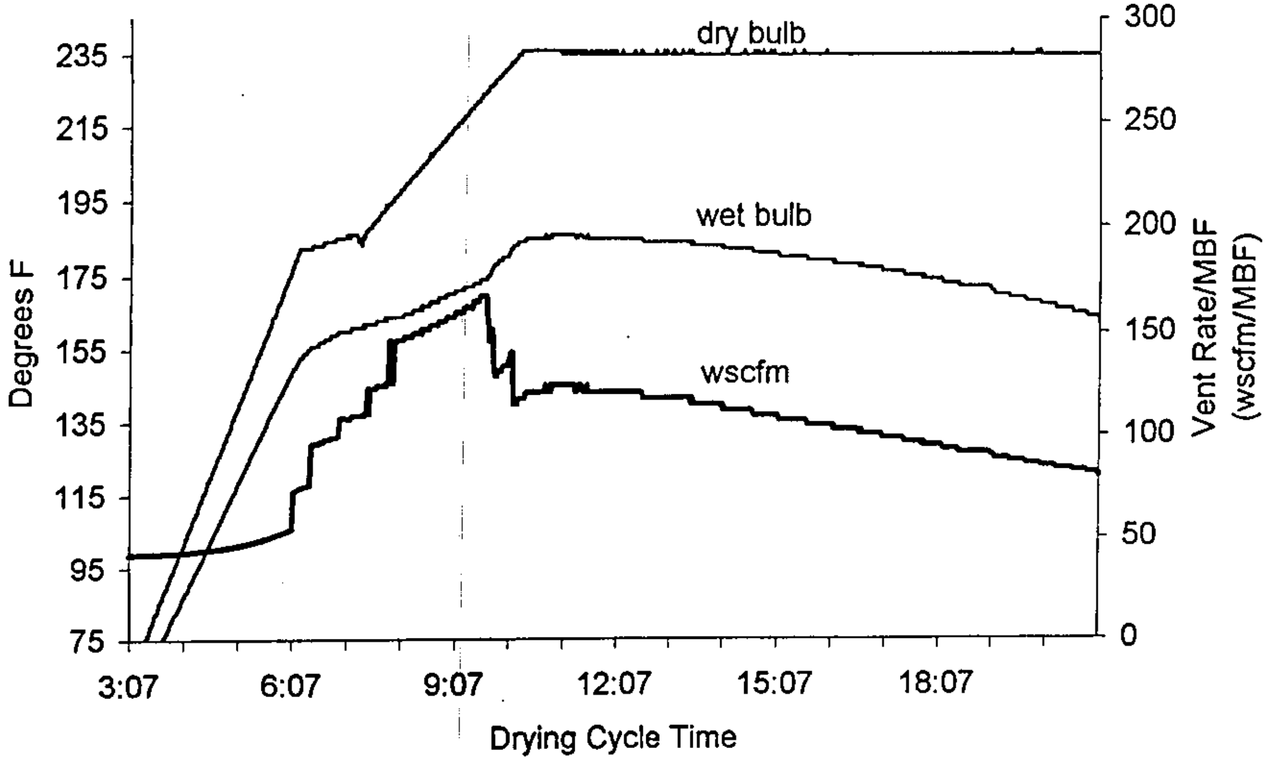
Kiln Charge MSU-INDF2
Comparison of Wet/Dry Bulb Temperature to Venting Rate



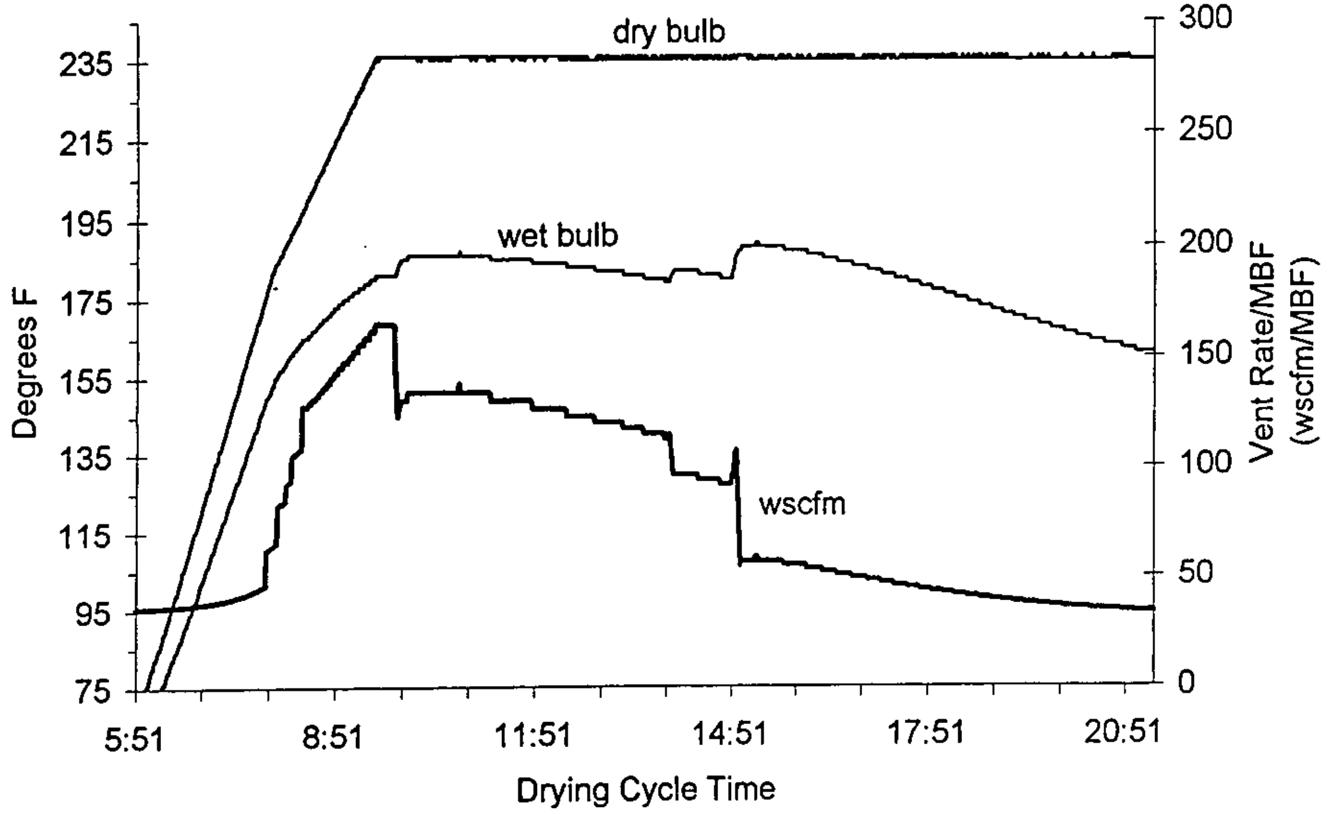
Kiln Charge MSU-INDF3
Comparison of Wet/Dry Bulb Temperature to Venting Rate



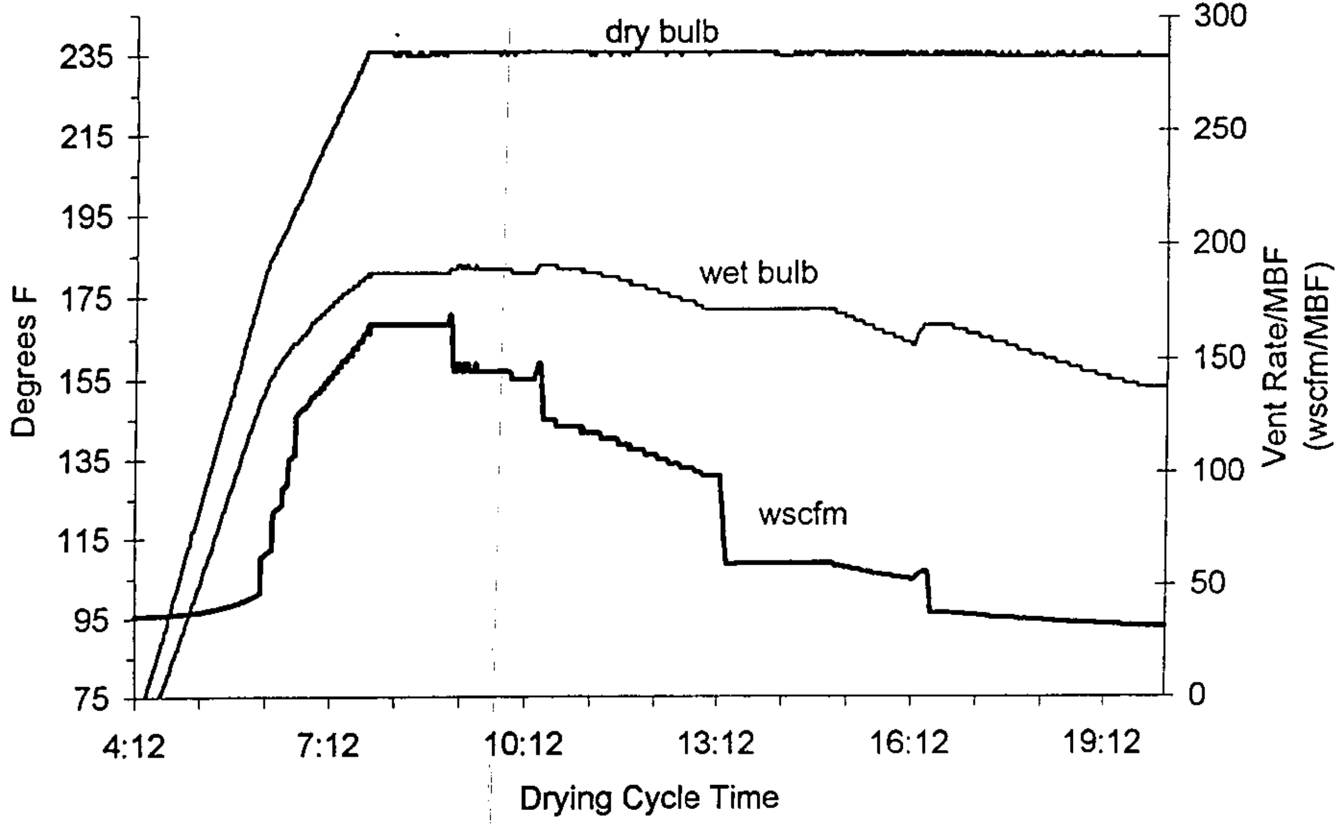
Kiln Charge MSU-INDF5
Comparison of Wet/Dry Bulb Temperature to Venting Rate



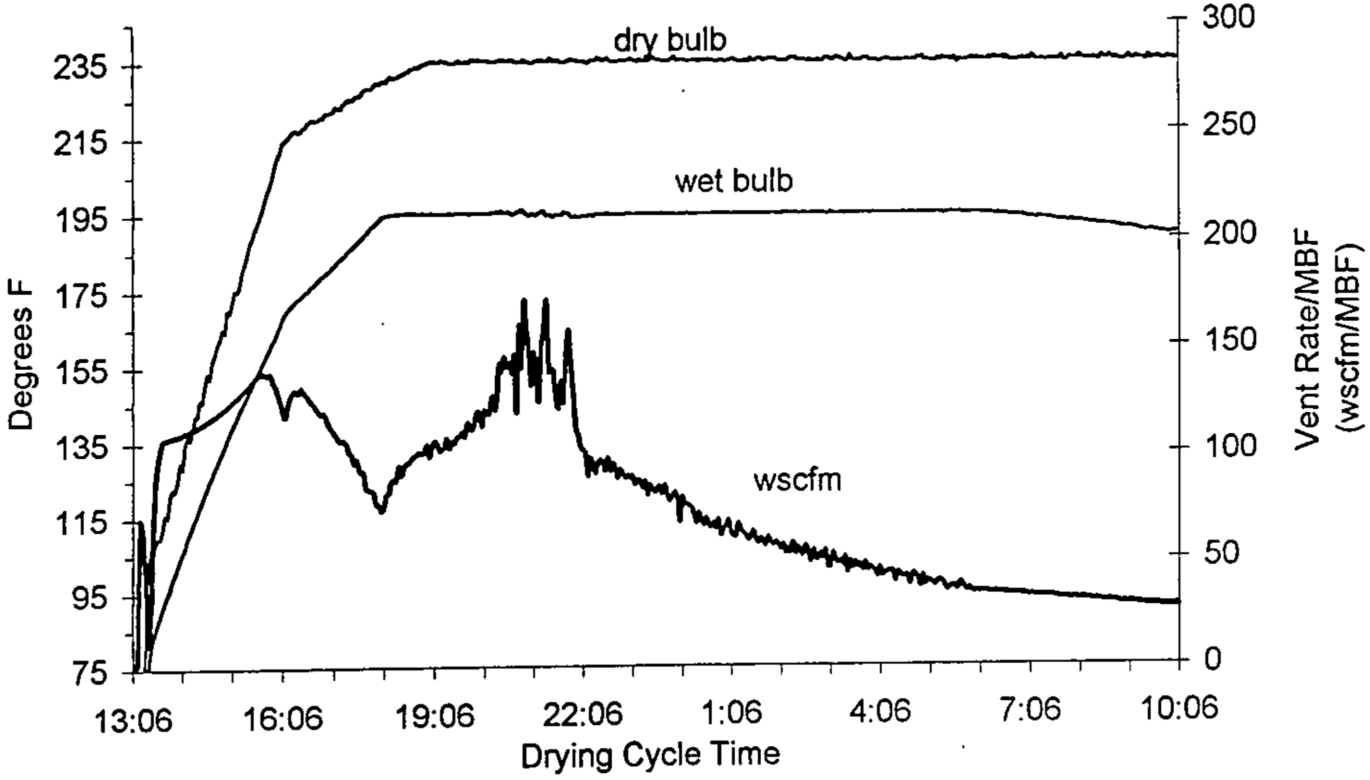
Kiln Charge MSU-INDF6
Comparison of Wet/Dry Bulb Temperature to Venting Rate



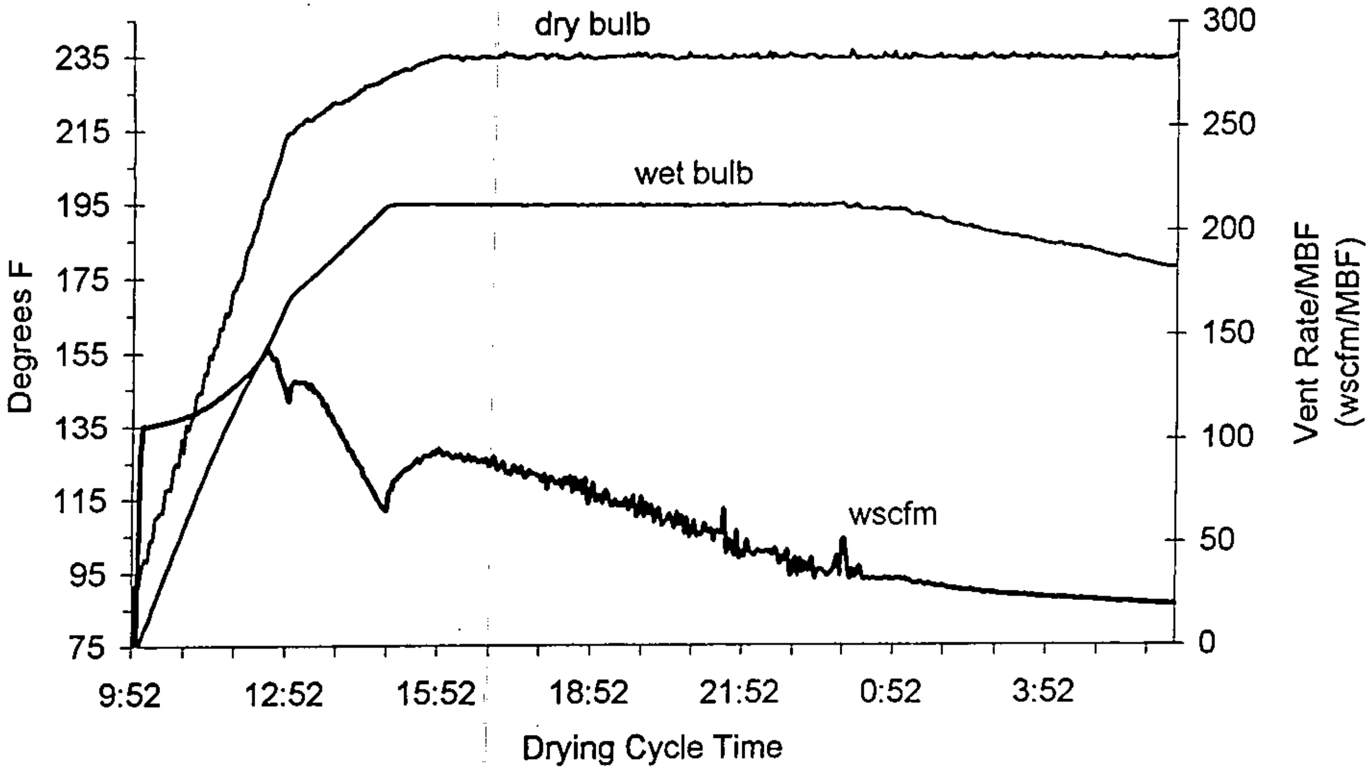
Kiln Charge MSU-INDF7
Comparison of Wet/Dry Bulb Temperature to Venting Rate



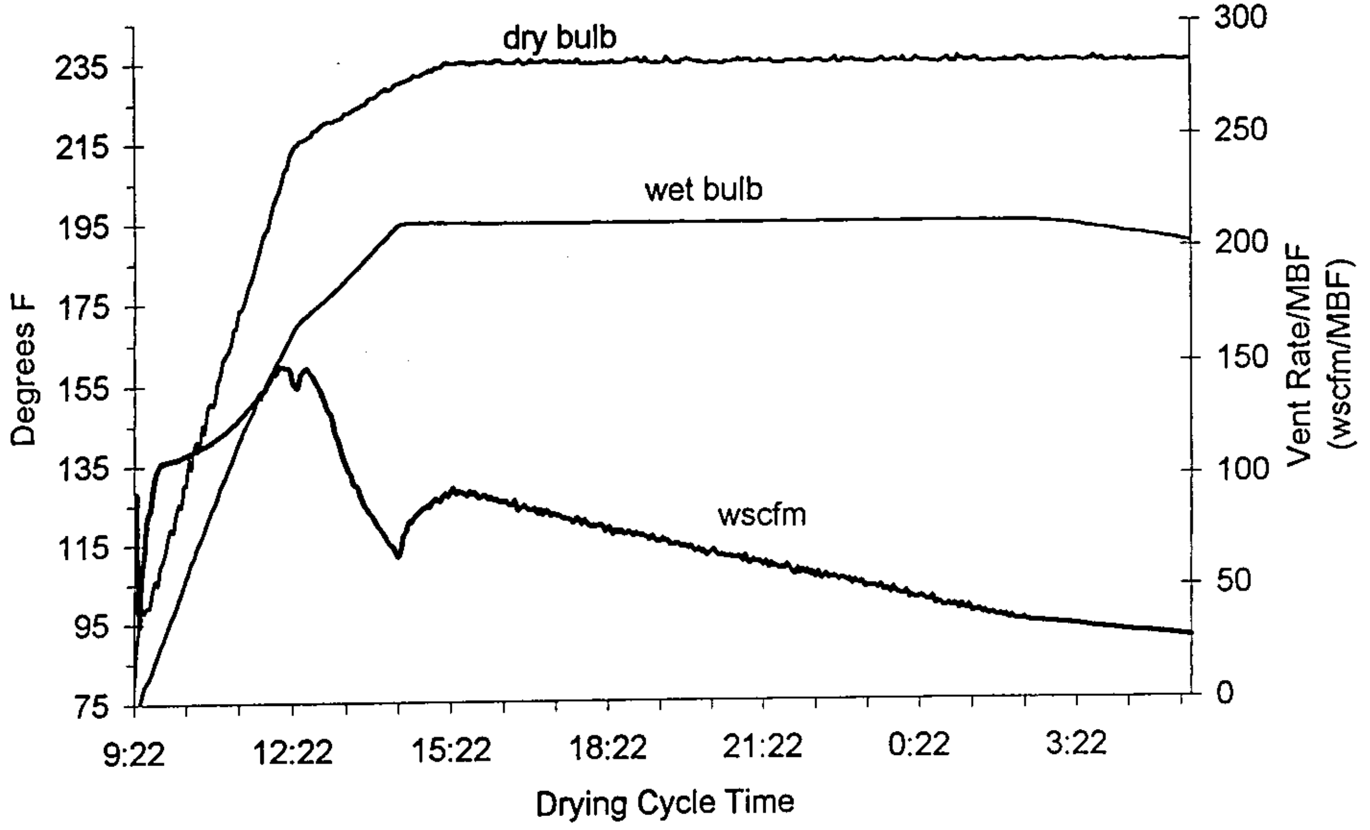
Kiln Charge OSU-INDF1
Comparison of Wet/Dry Bulb Temperature to Venting Rate



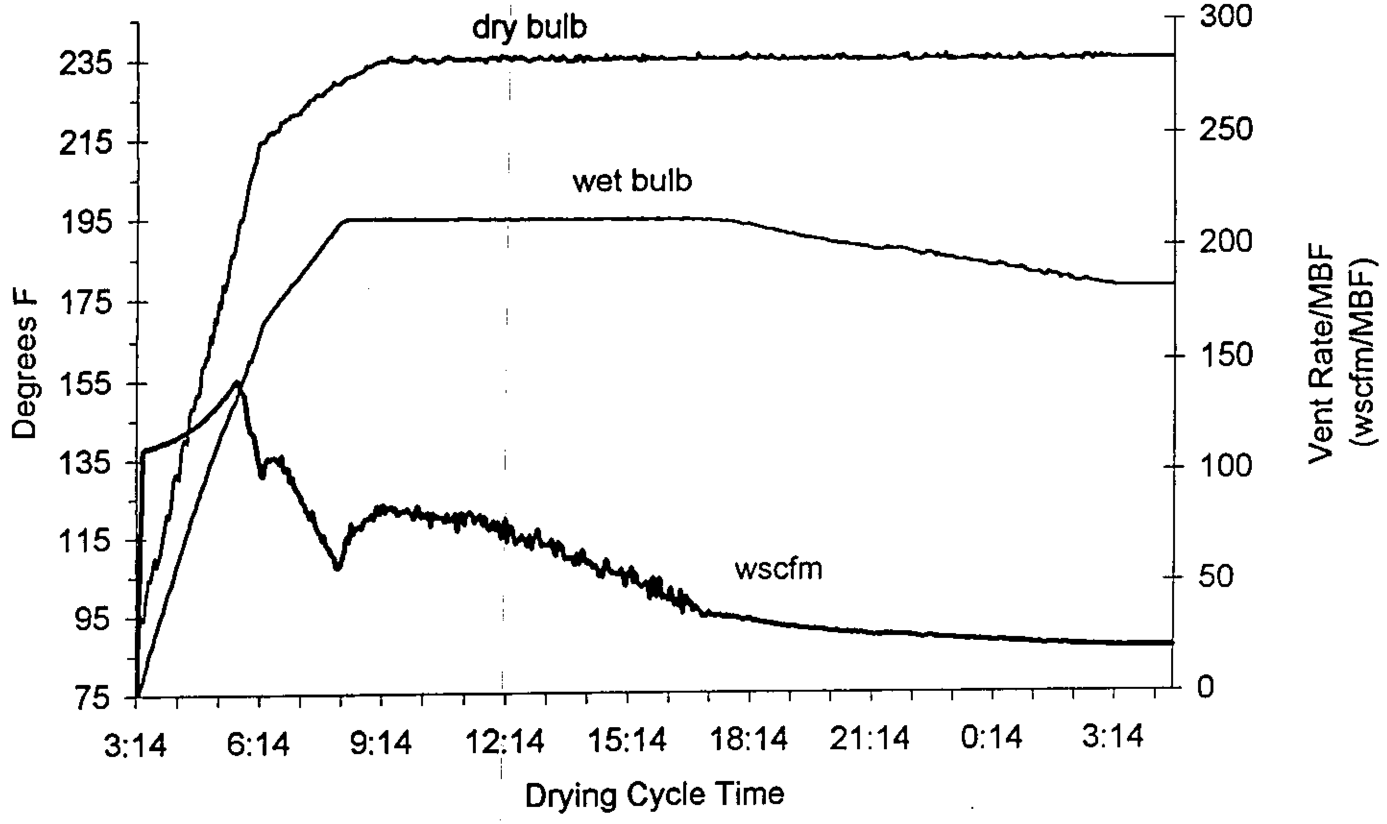
Kiln Charge OSU-INDF2
Comparison of Wet/Dry Bulb Temperature to Venting Rate



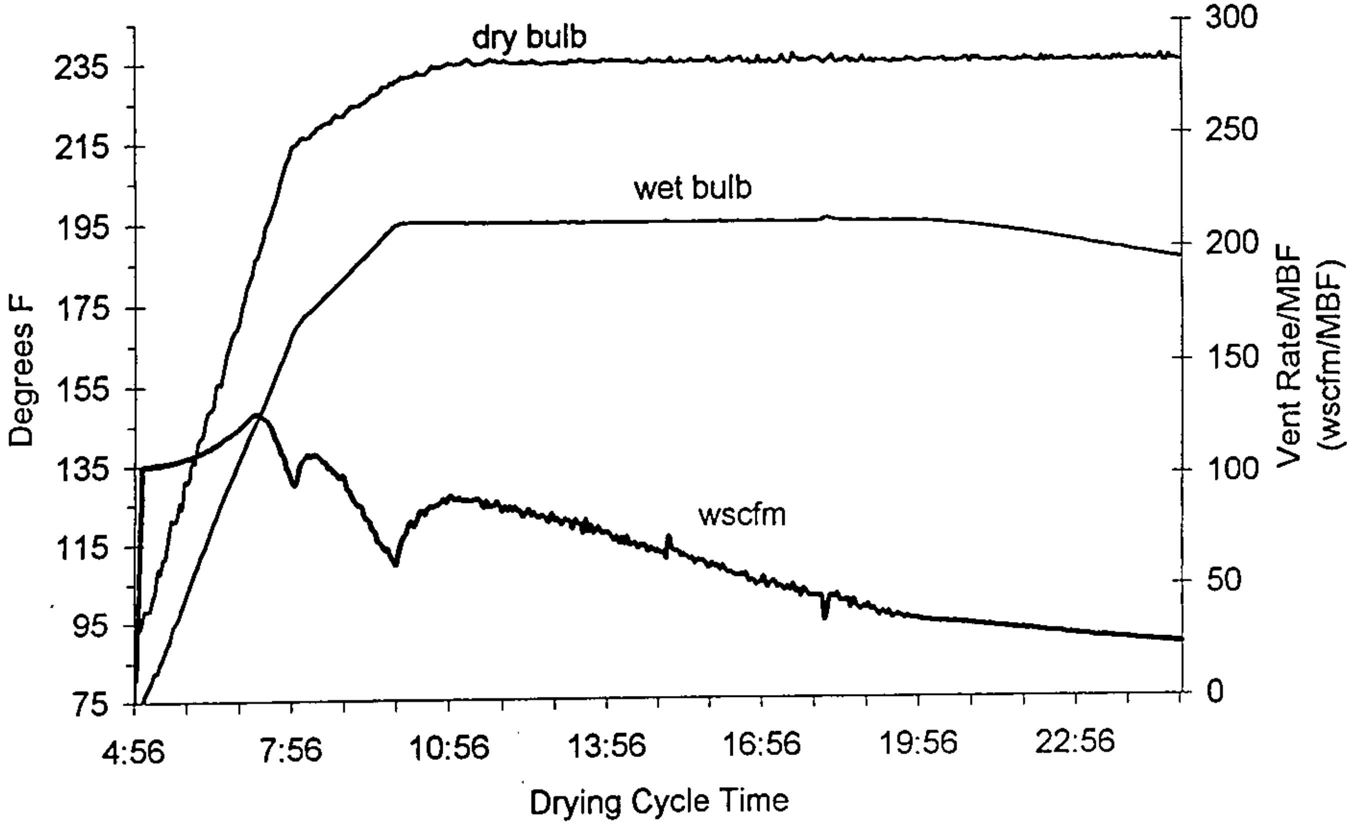
Kiln Charge OSU-INDF3
Comparison of Wet/Dry Bulb Temperature to Venting Rate



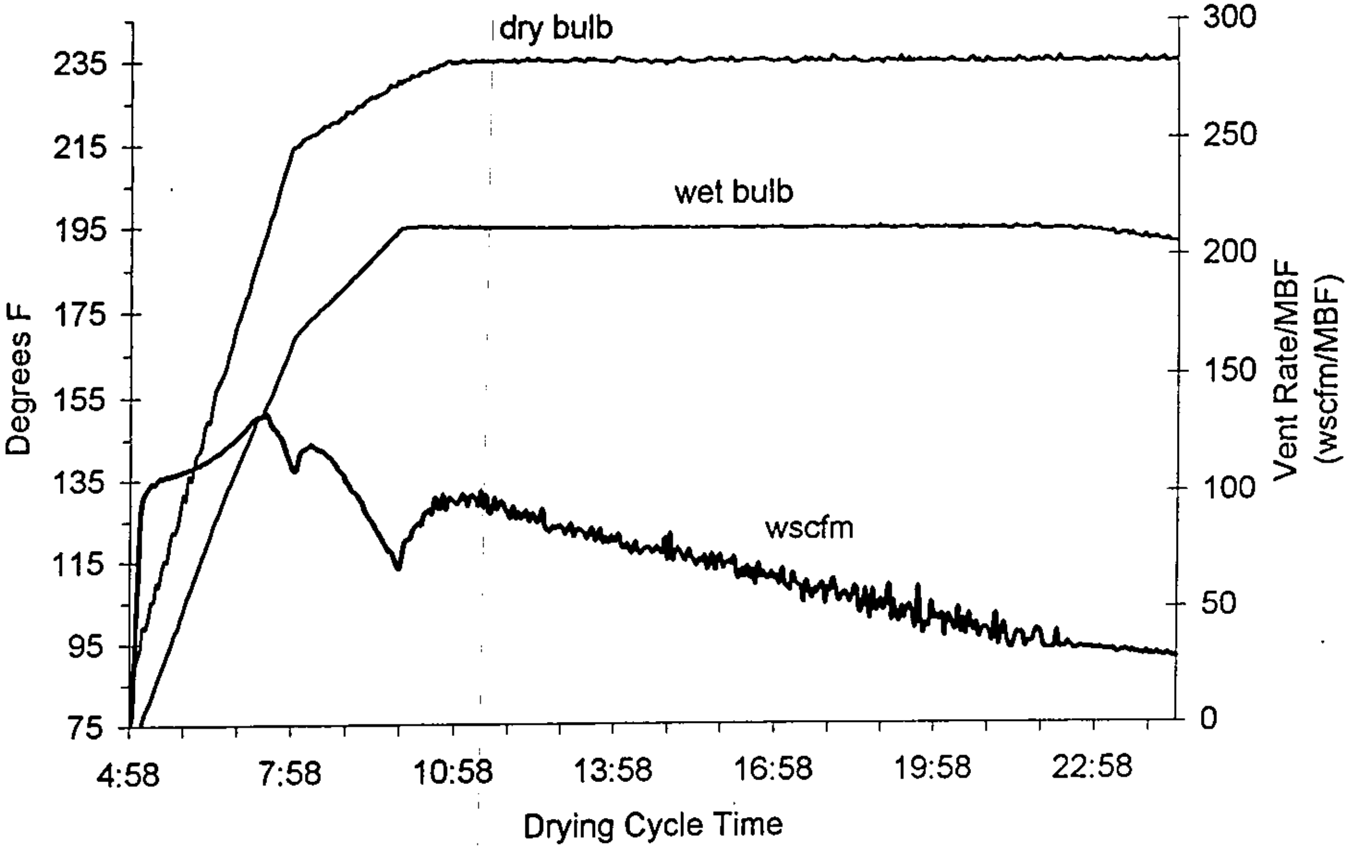
Kiln Charge OSU-INDF5
Comparison of Wet/Dry Bulb Temperature to Venting Rate



Kiln Charge OSU-INDF6
Comparison of Wet/Dry Bulb Temperature to Venting Rate



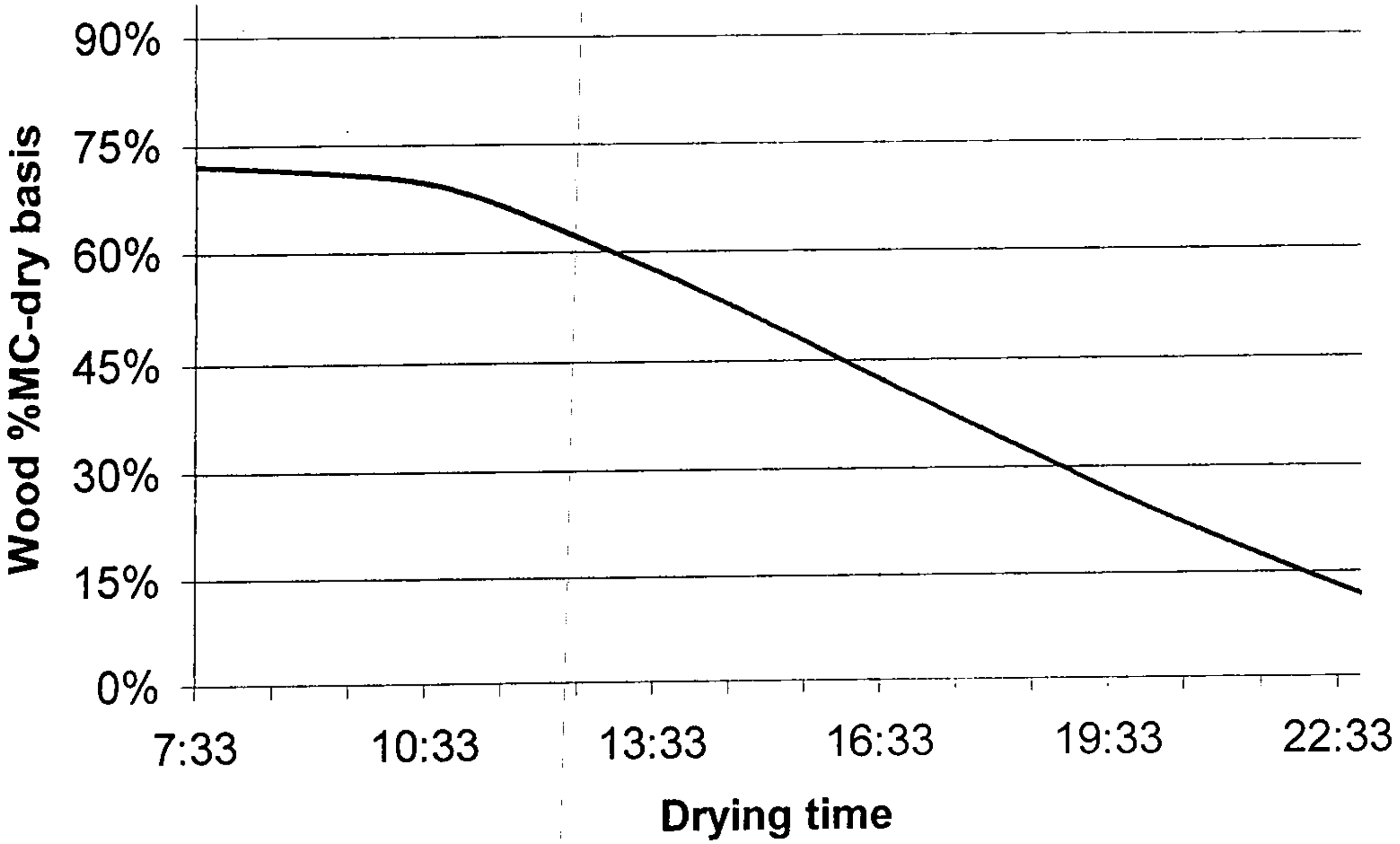
Kiln Charge OSU-INDF7B
Comparison of Wet/Dry Bulb Temperature to Venting Rate



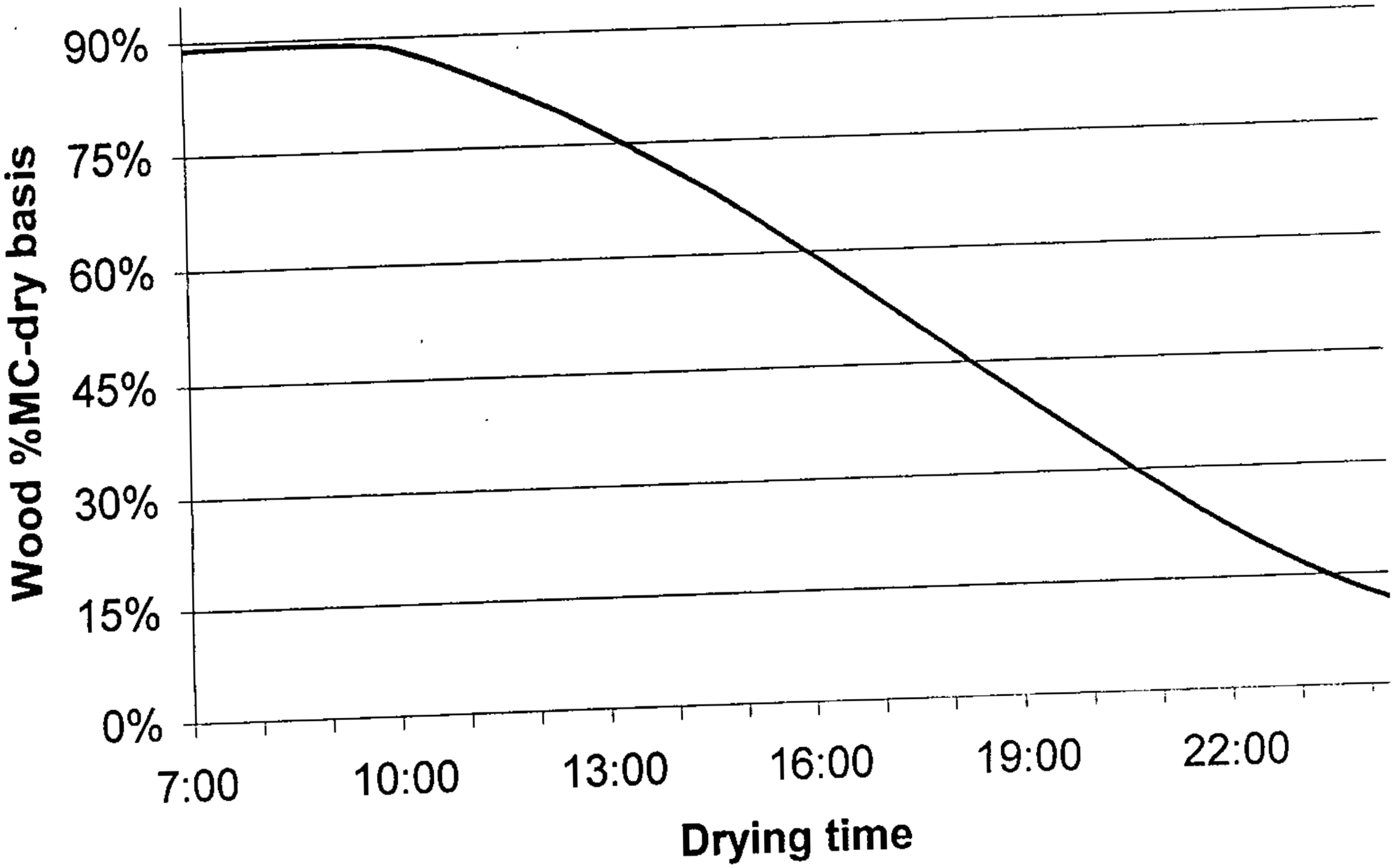
APPENDIX E

PERCENT WOOD MOISTURE CONTENT PROFILES FOR PHASE II DIRECT-FIRED AND STEAM DATA

Kiln Charge MSU DF1A
Change in Wood % Moisture Content
During the Drying Cylce

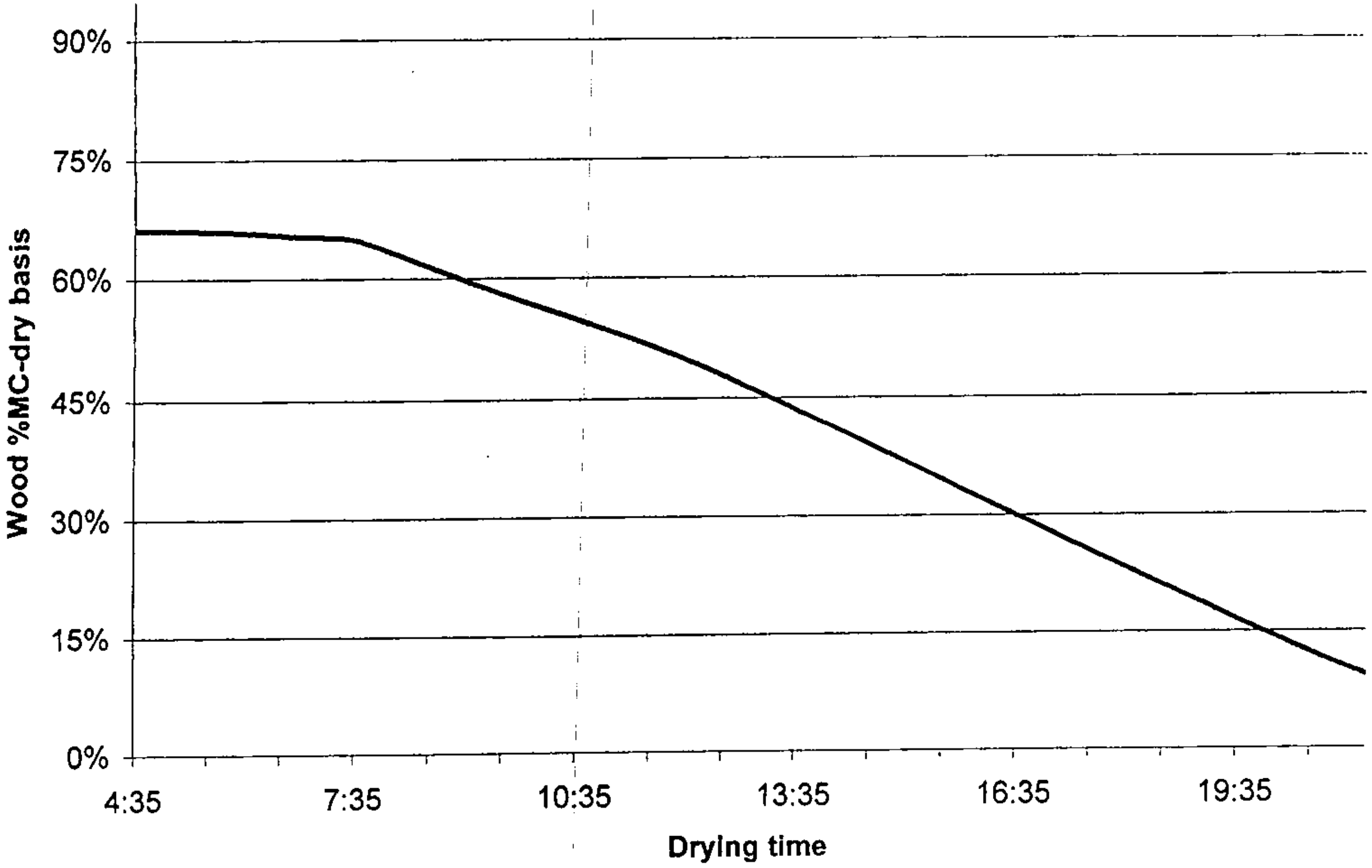


Kiln Charge MSU DF1B
Change in Wood % Moisture Content
During the Drying Cylce

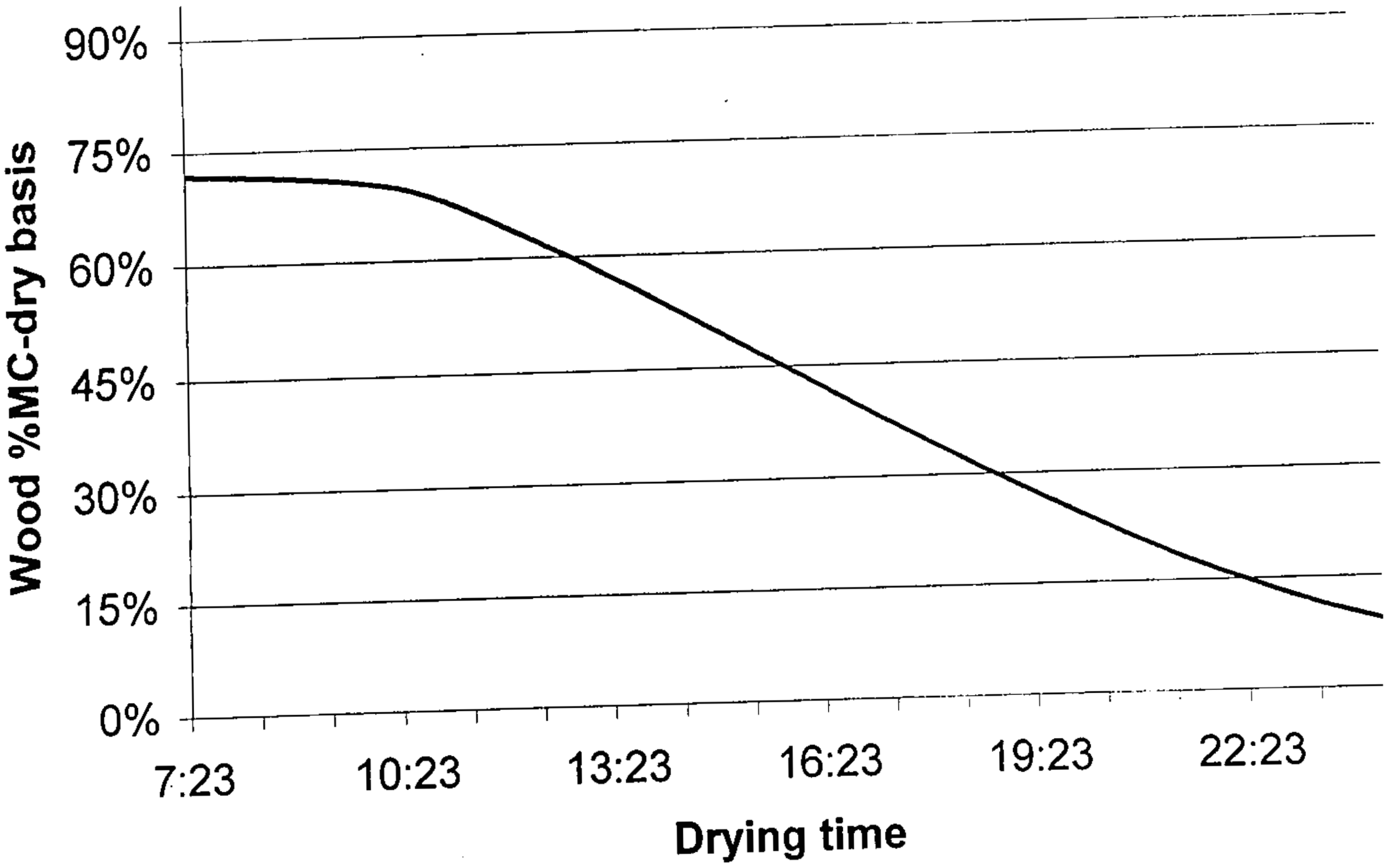


E3

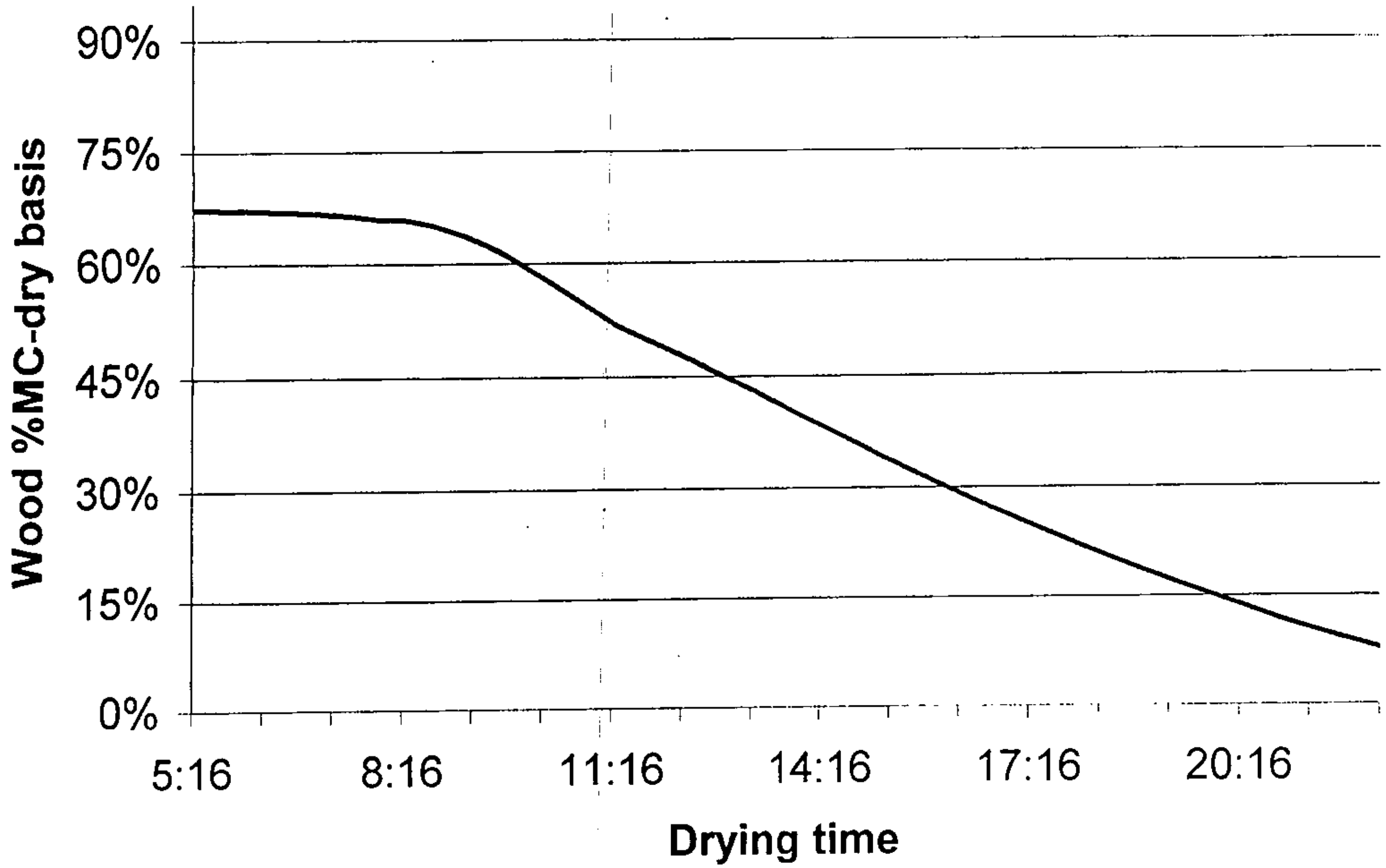
Kiln Charge MSU DF2
Change in Wood % Moisture Content
During the Drying Cylce

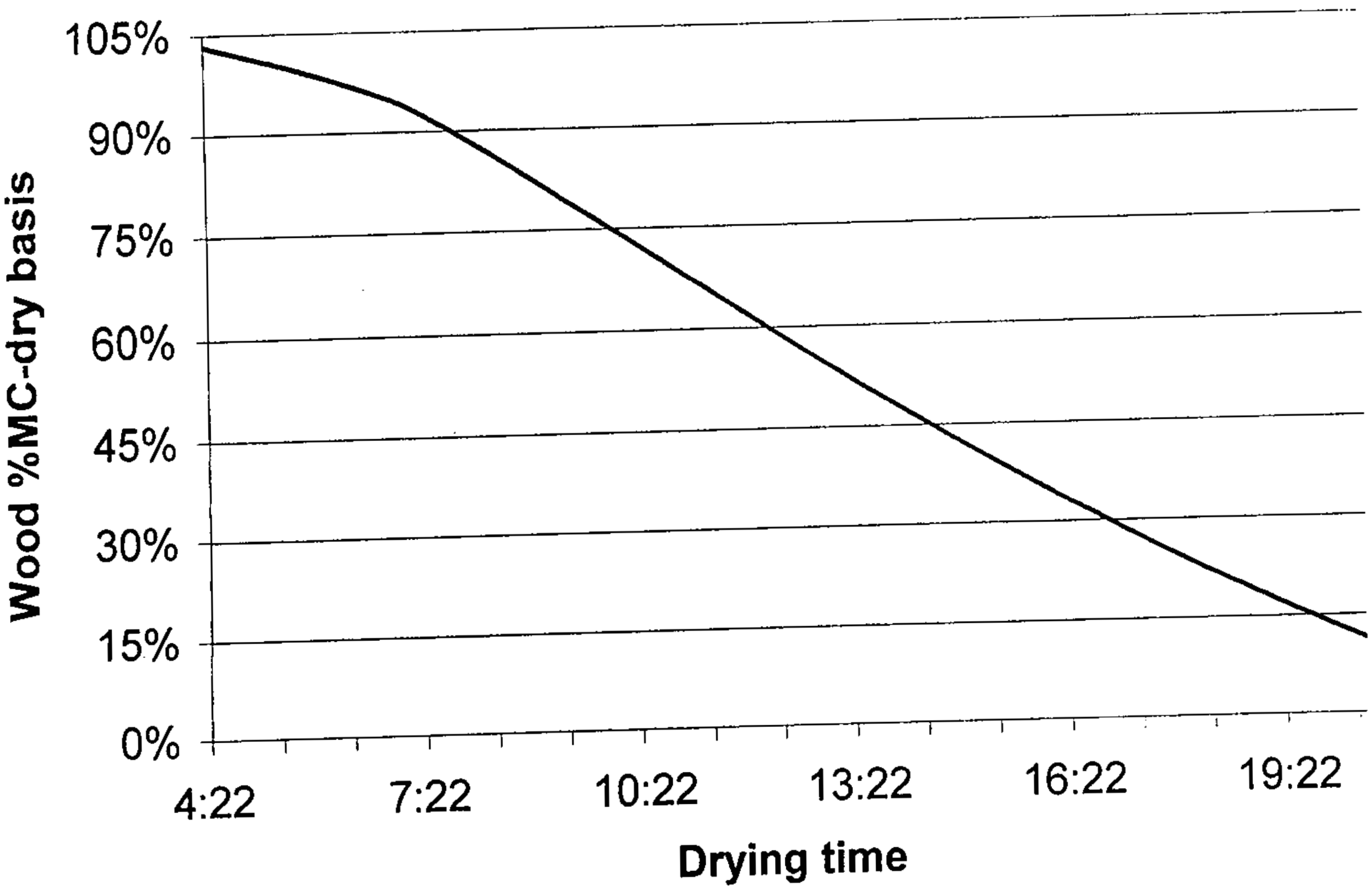


Kiln Charge MSU DF3A
Change in Wood % Moisture Content During the Drying Cylce



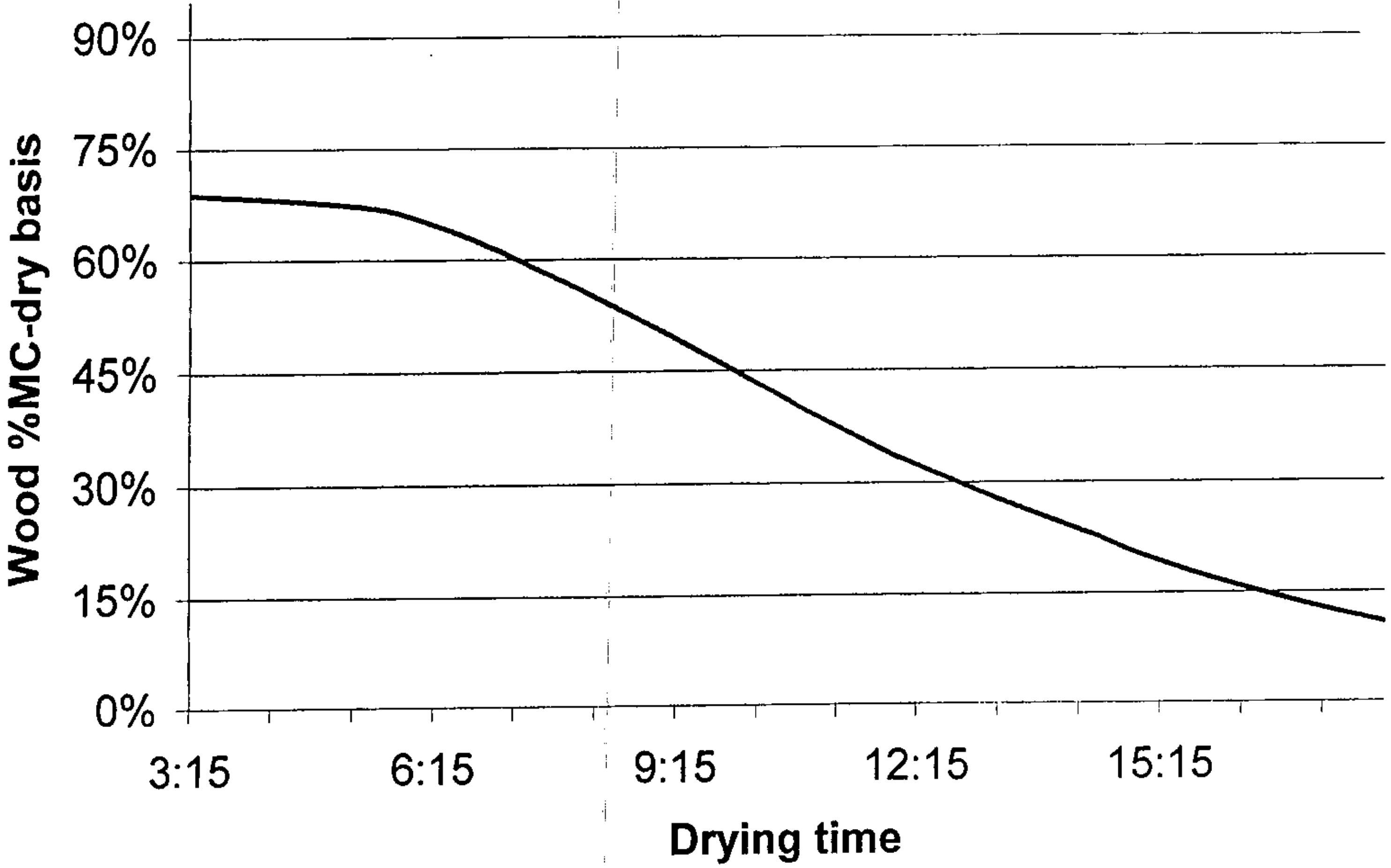
Kiln Charge MSU DF3B
Change in Wood % Moisture Content
During the Drying Cylce



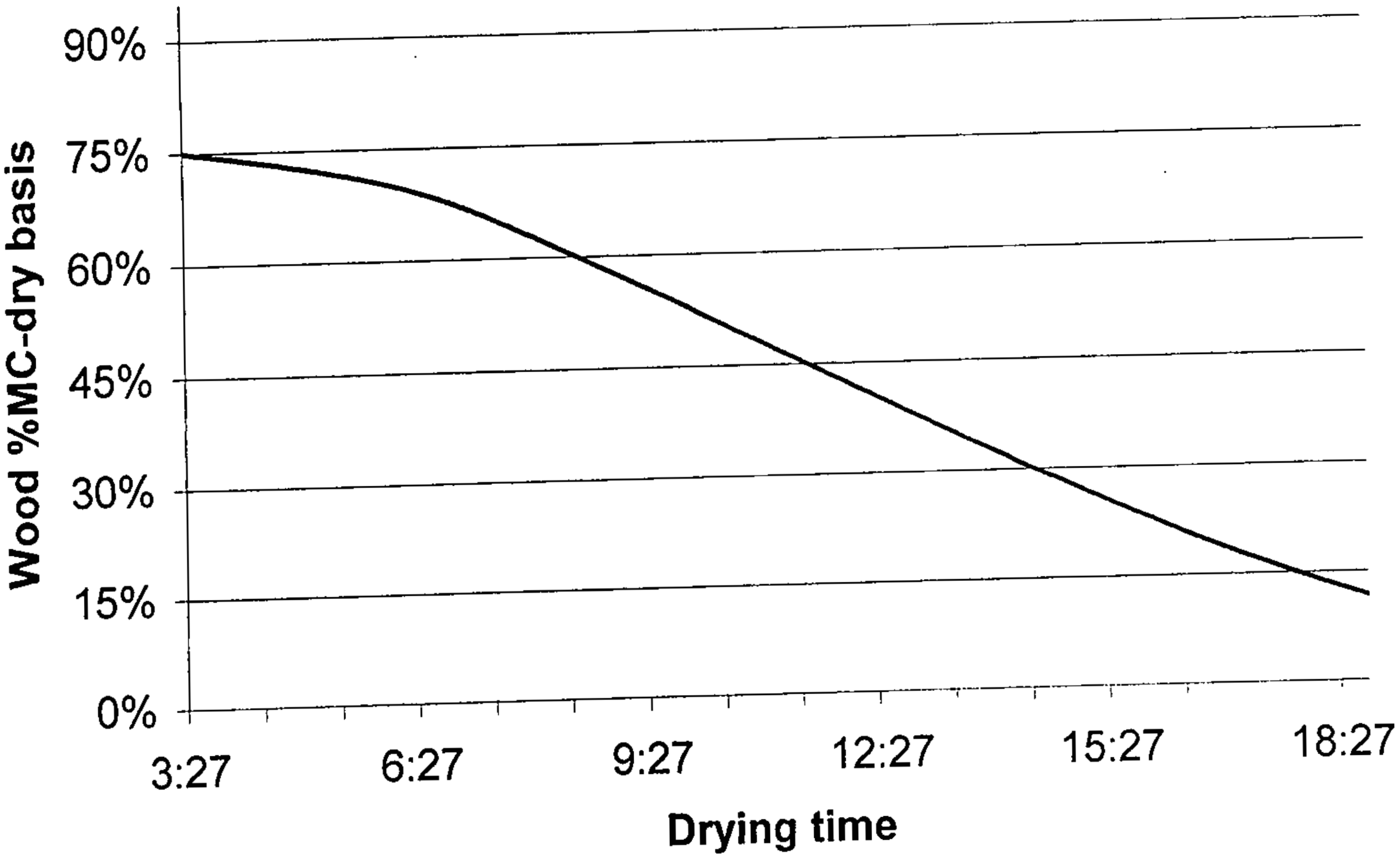


Kiln Charge MSU DF4
Change in Wood % Moisture Content
During the Drying Cylce

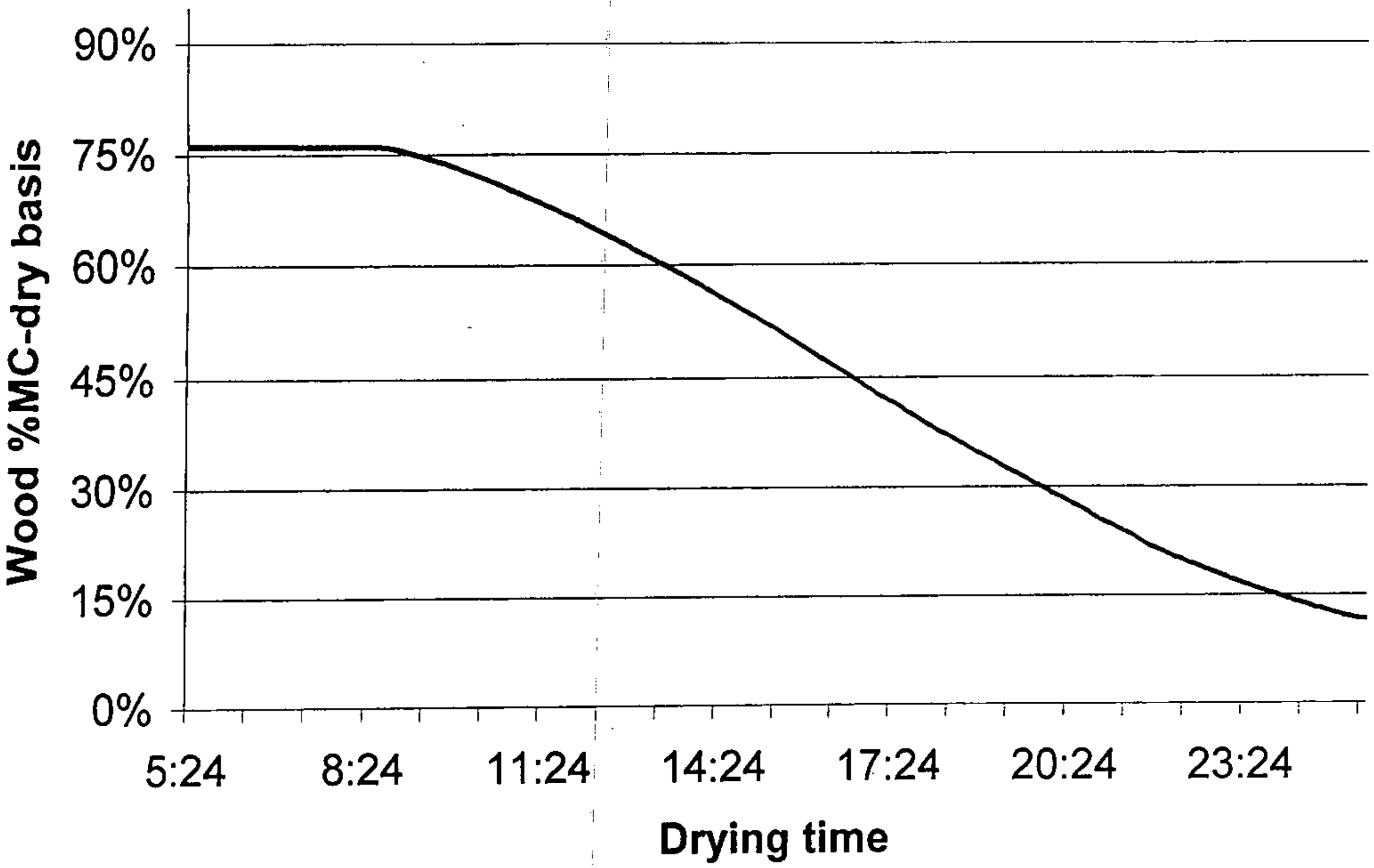
Kiln Charge MSU DF5
Change in Wood % Moisture Content
During the Drying Cylce



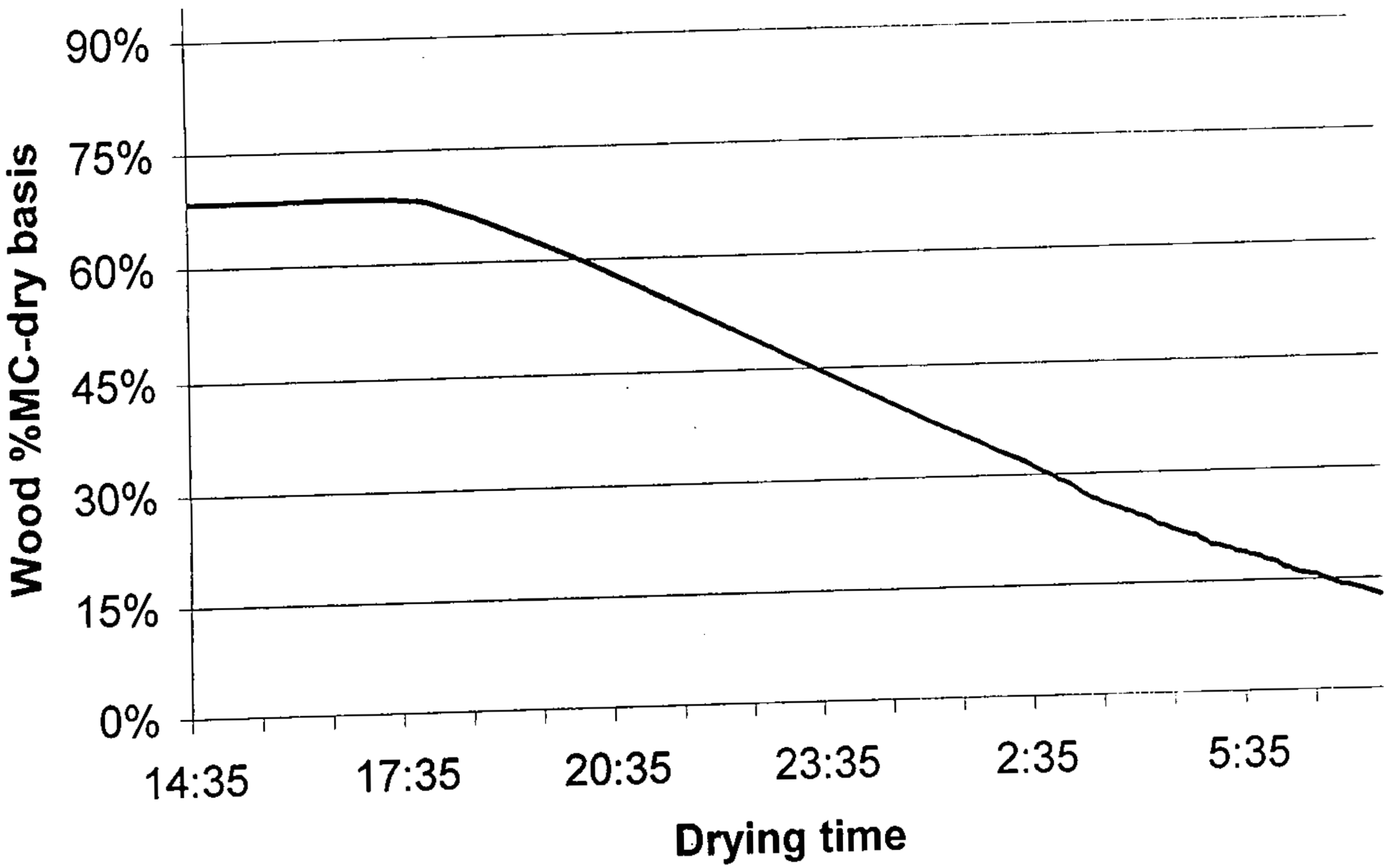
Kiln Charge MSU DF6
Change in Wood % Moisture Content
During the Drying Cylce



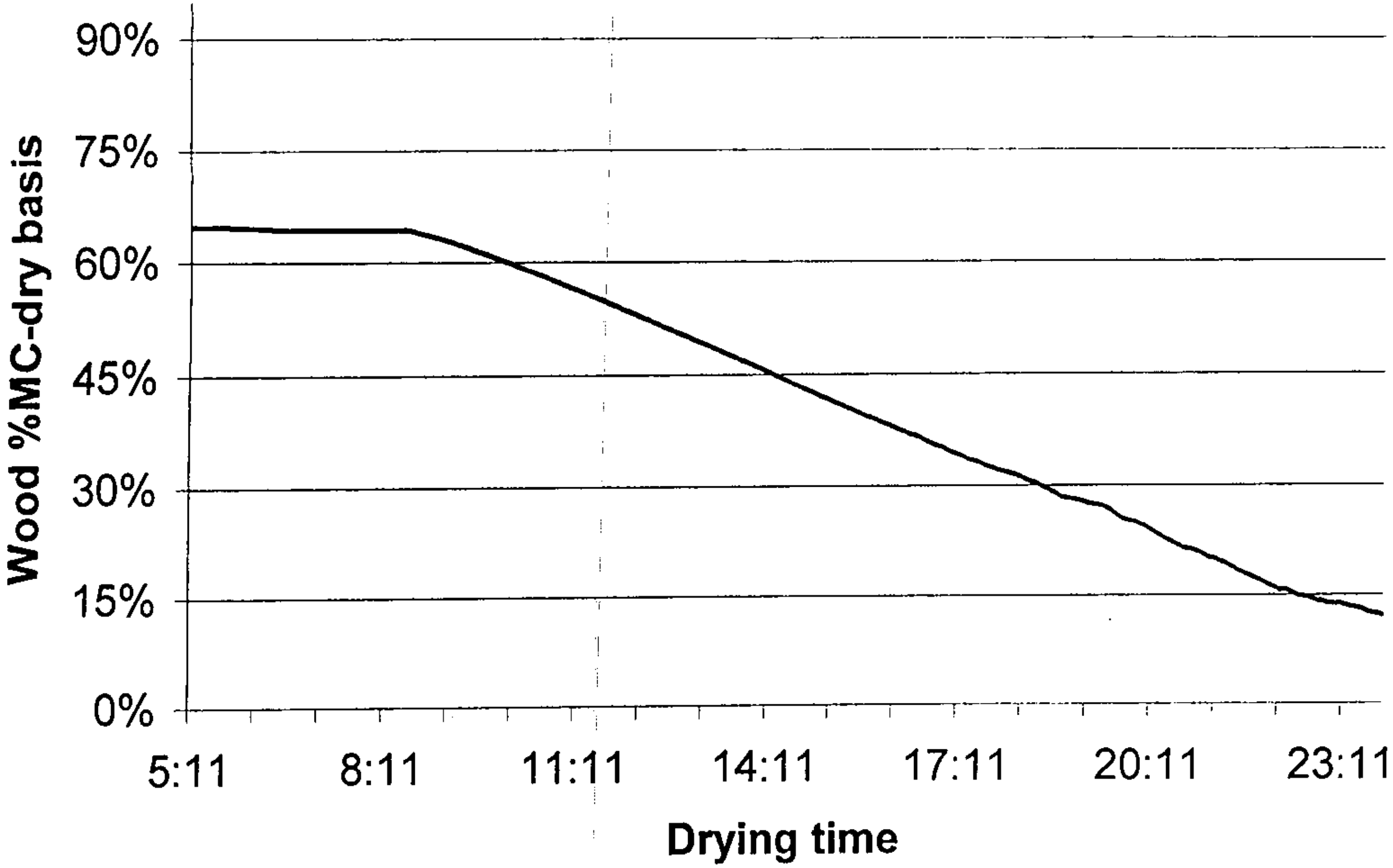
Kiln Charge OSU DF1
Change in Wood % Moisture Content
During the Drying Cylce



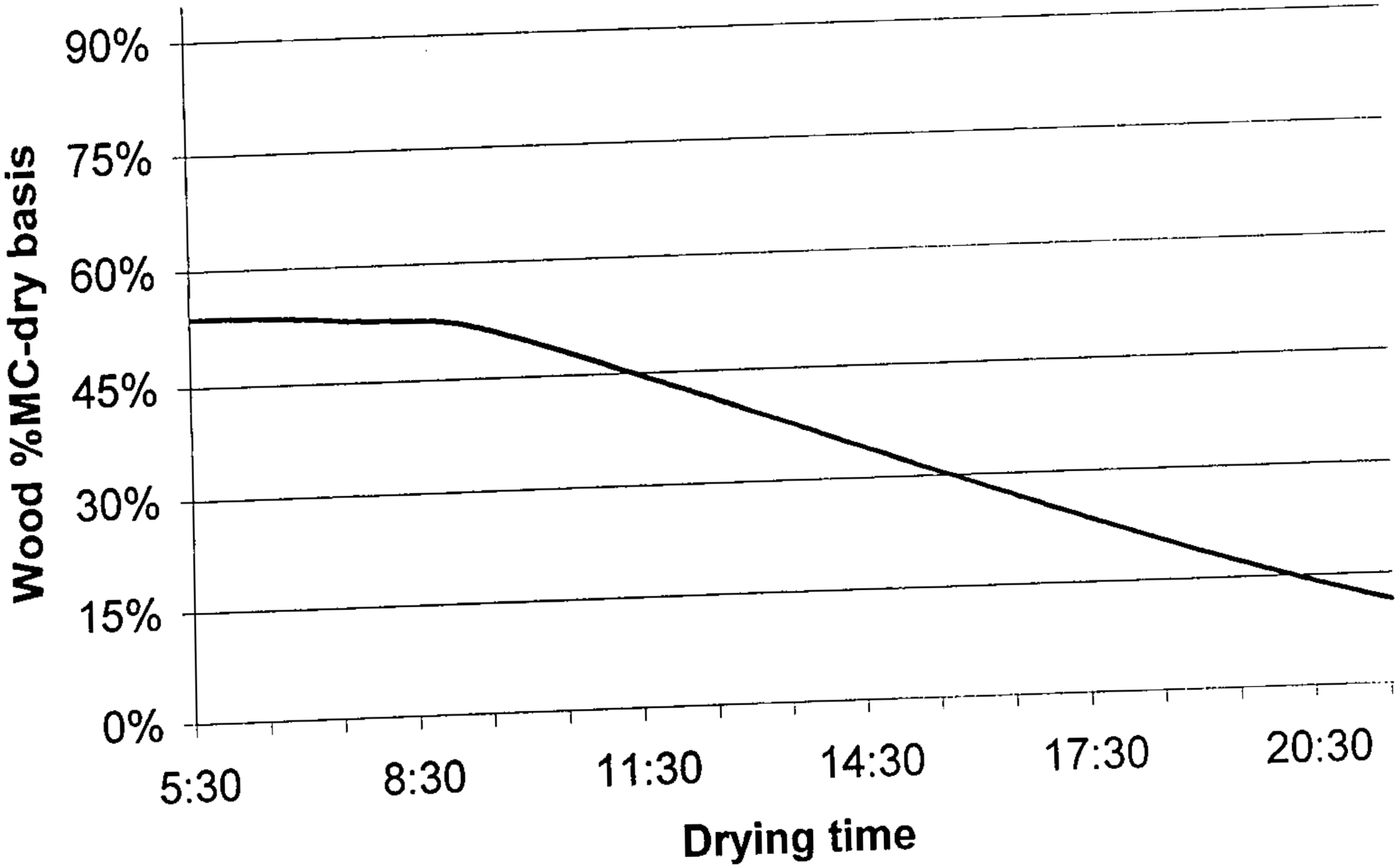
Kiln Charge OSU DF2C
Change in Wood % Moisture Content
During the Drying Cylce



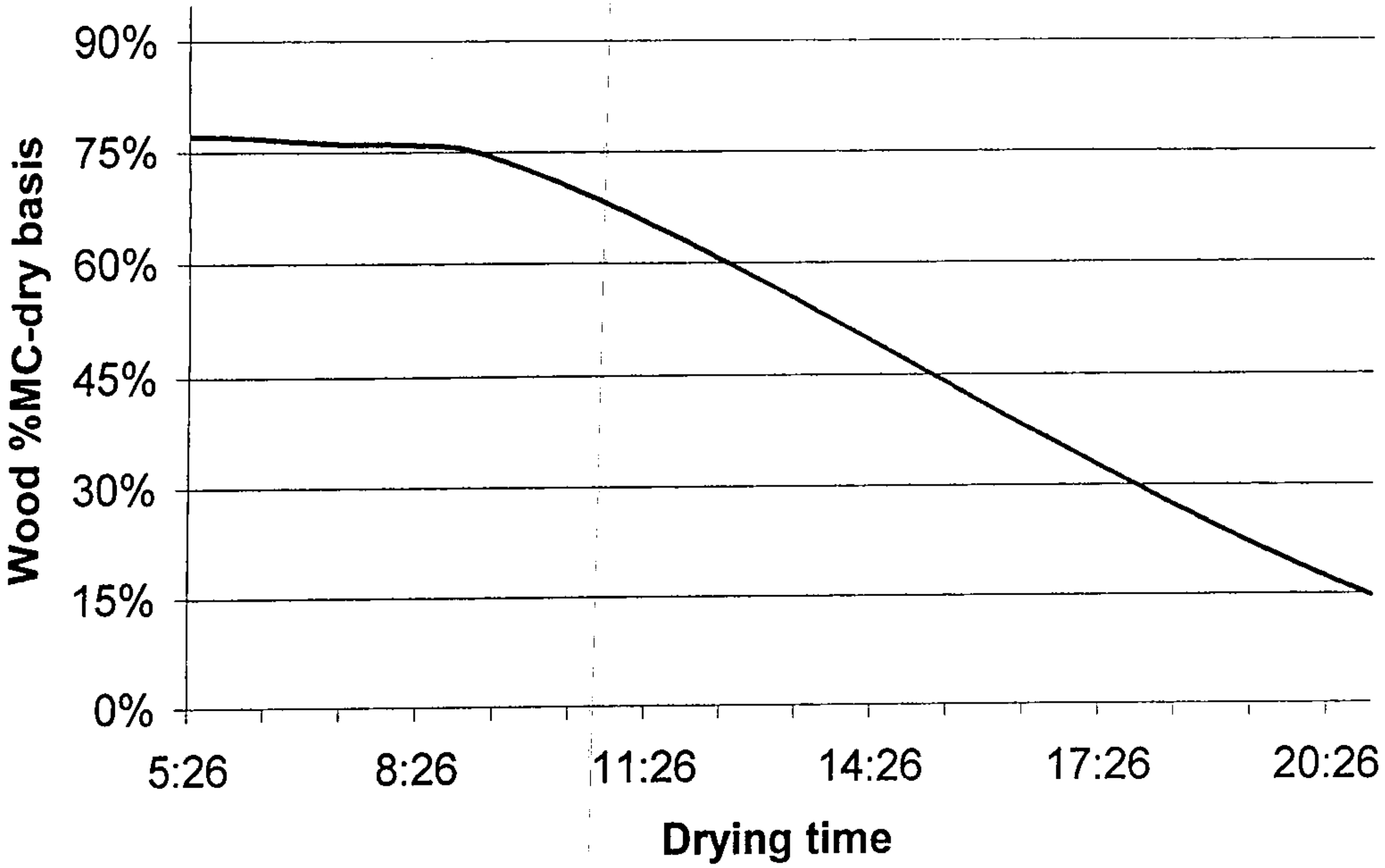
Kiln Charge OSU DF3
Change in Wood % Moisture Content
During the Drying Cylce



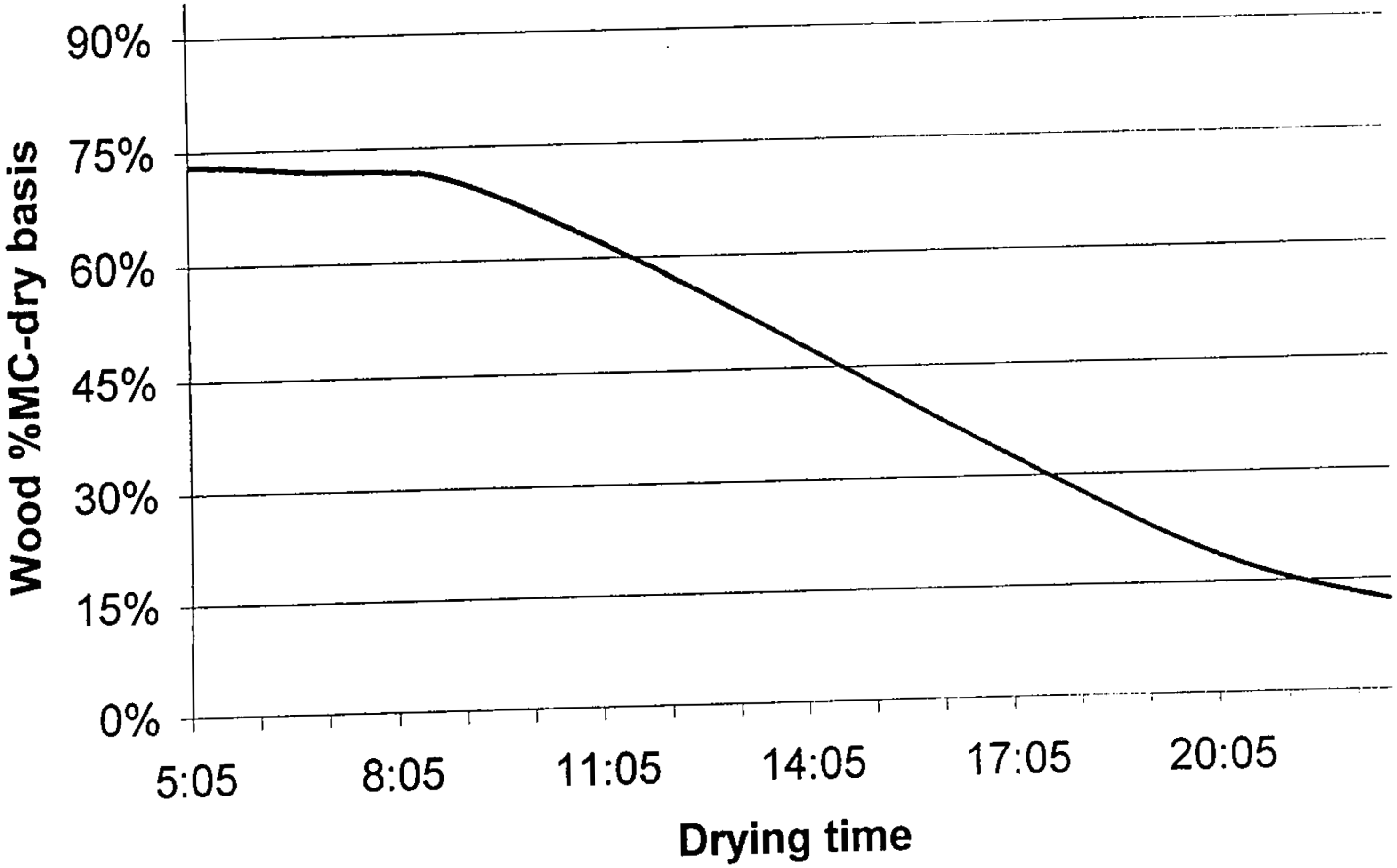
Kiln Charge OSU DF4
Change in Wood % Moisture Content
During the Drying Cylce



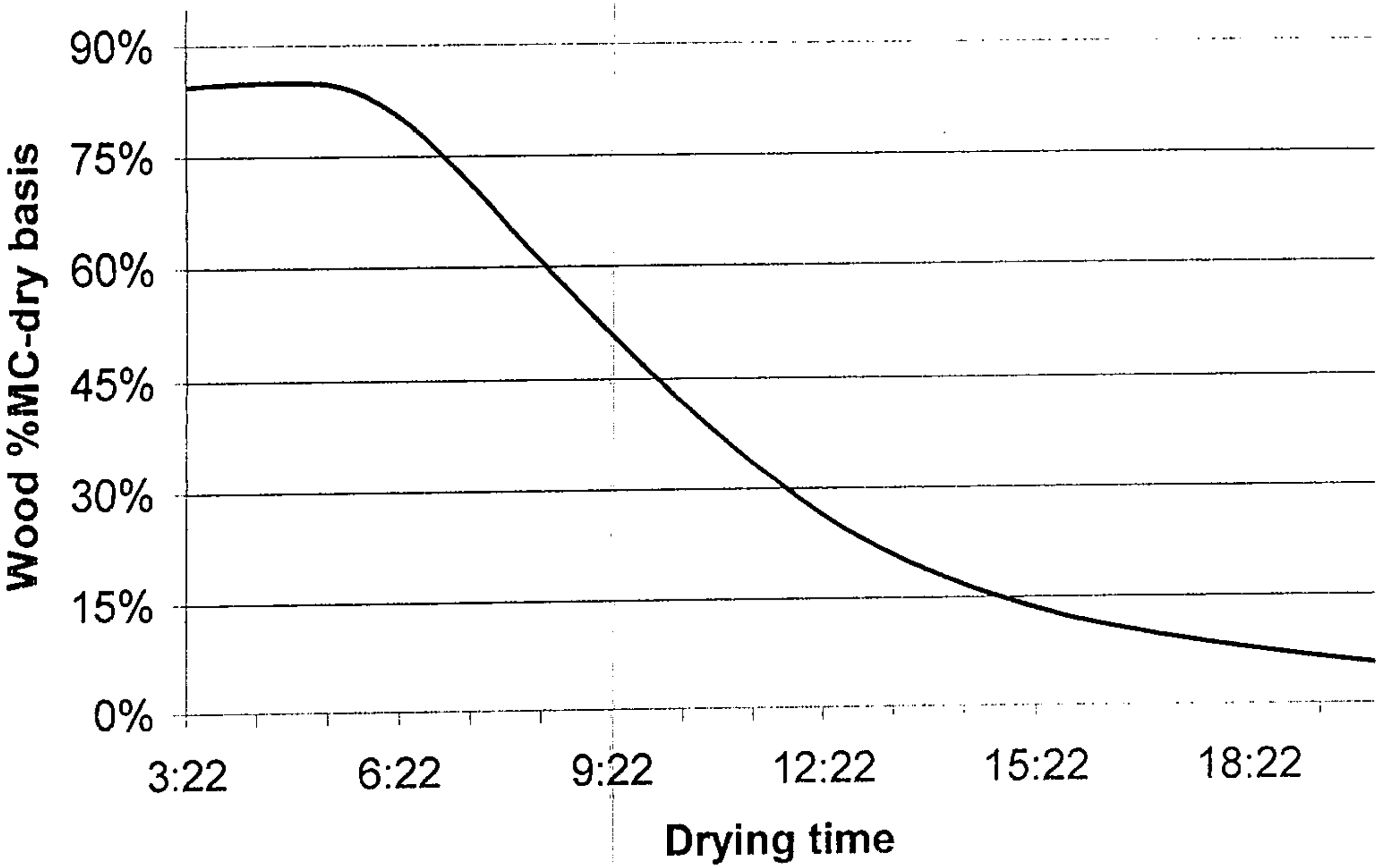
Kiln Charge OSU DF5
Change in Wood % Moisture Content
During the Drying Cylce

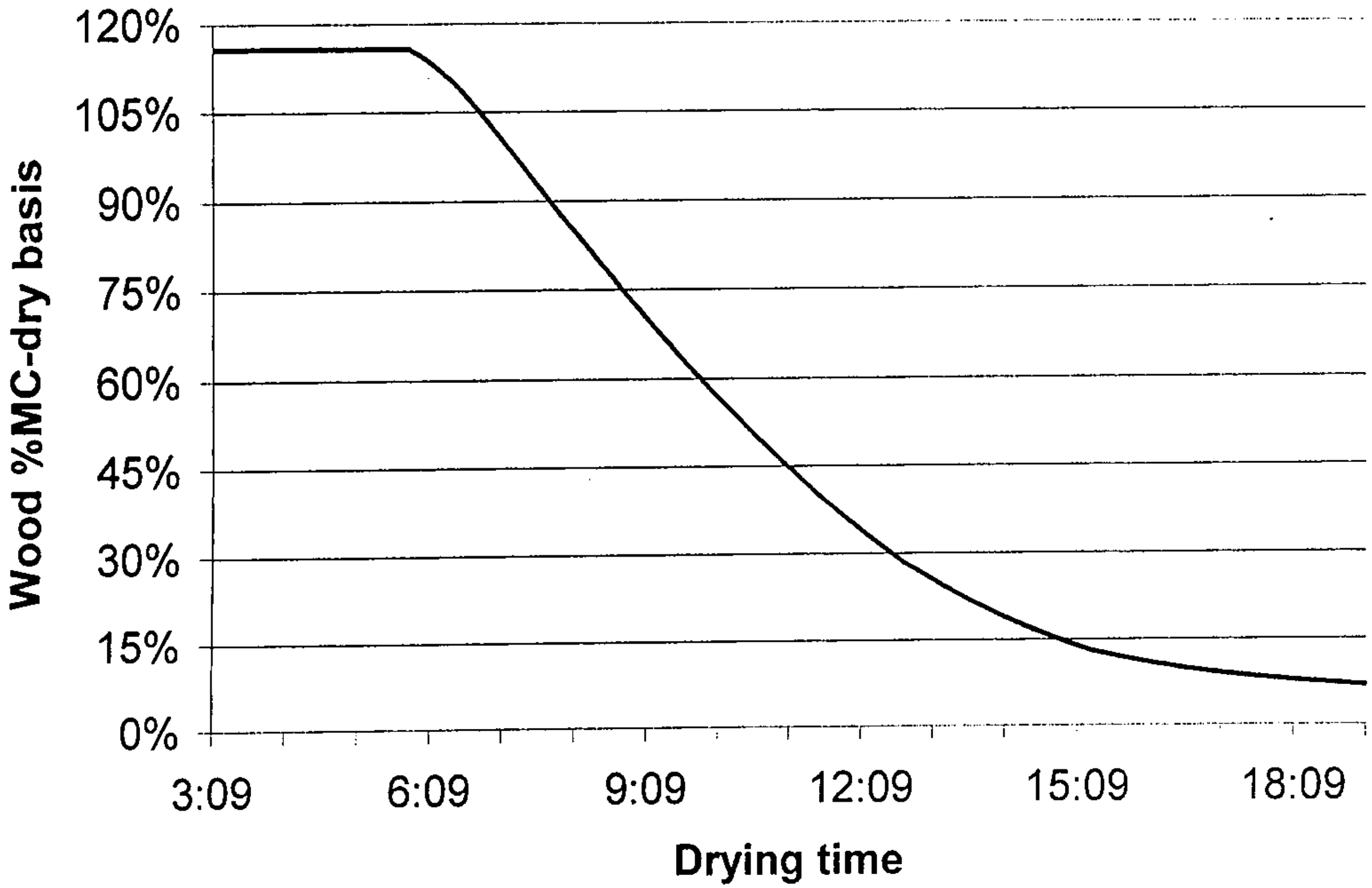


Kiln Charge OSU DF6
Change in Wood % Moisture Content
During the Drying Cylce



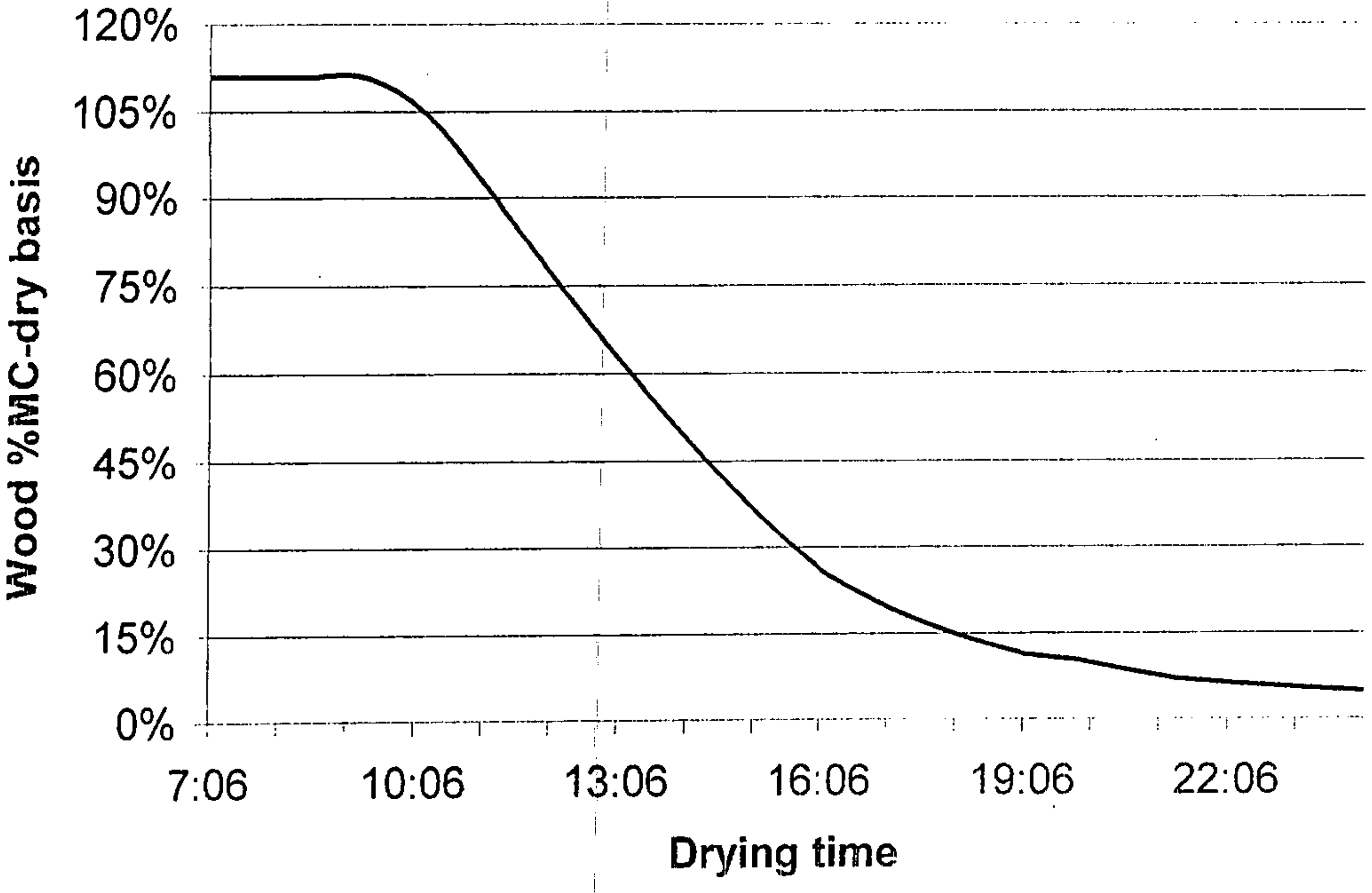
Kiln Charge MSU INDF1
Change in Wood % Moisture Content
During the Drying Cylce



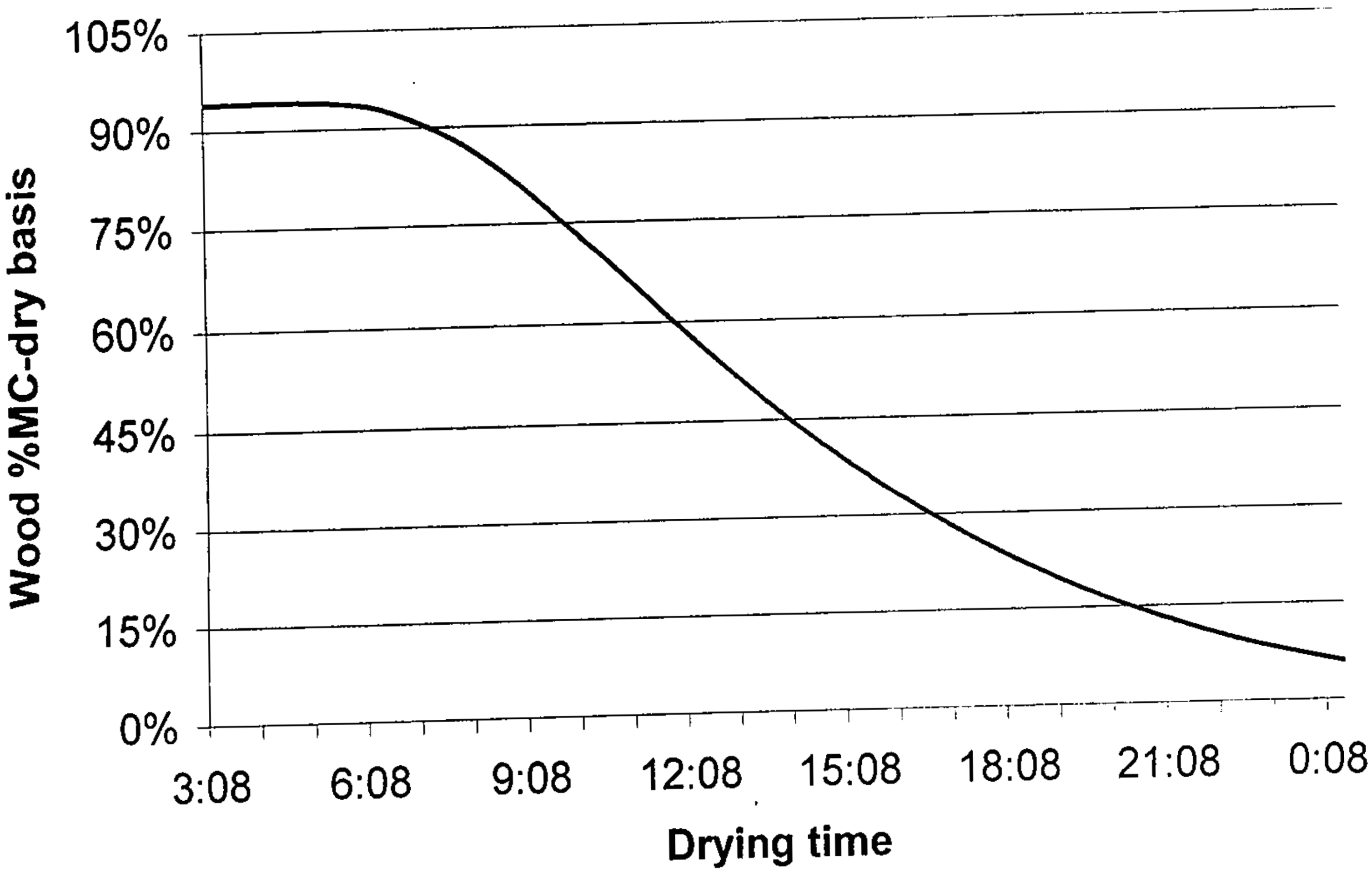


Kiln Charge MSU INDF2
Change in Wood % Moisture Content
During the Drying Cylce

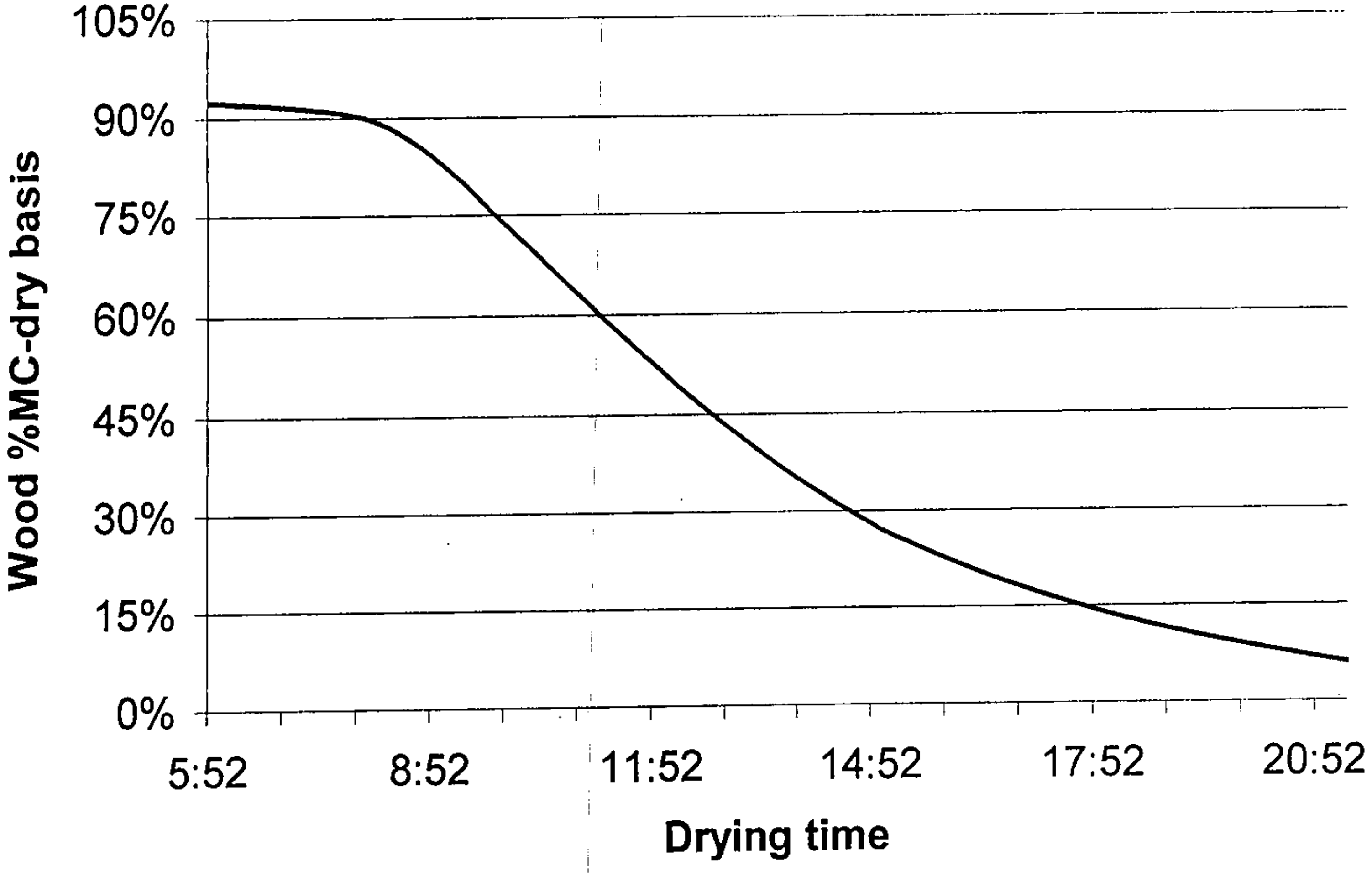
Kiln Charge MSU INDF3
Change in Wood % Moisture Content
During the Drying Cylce

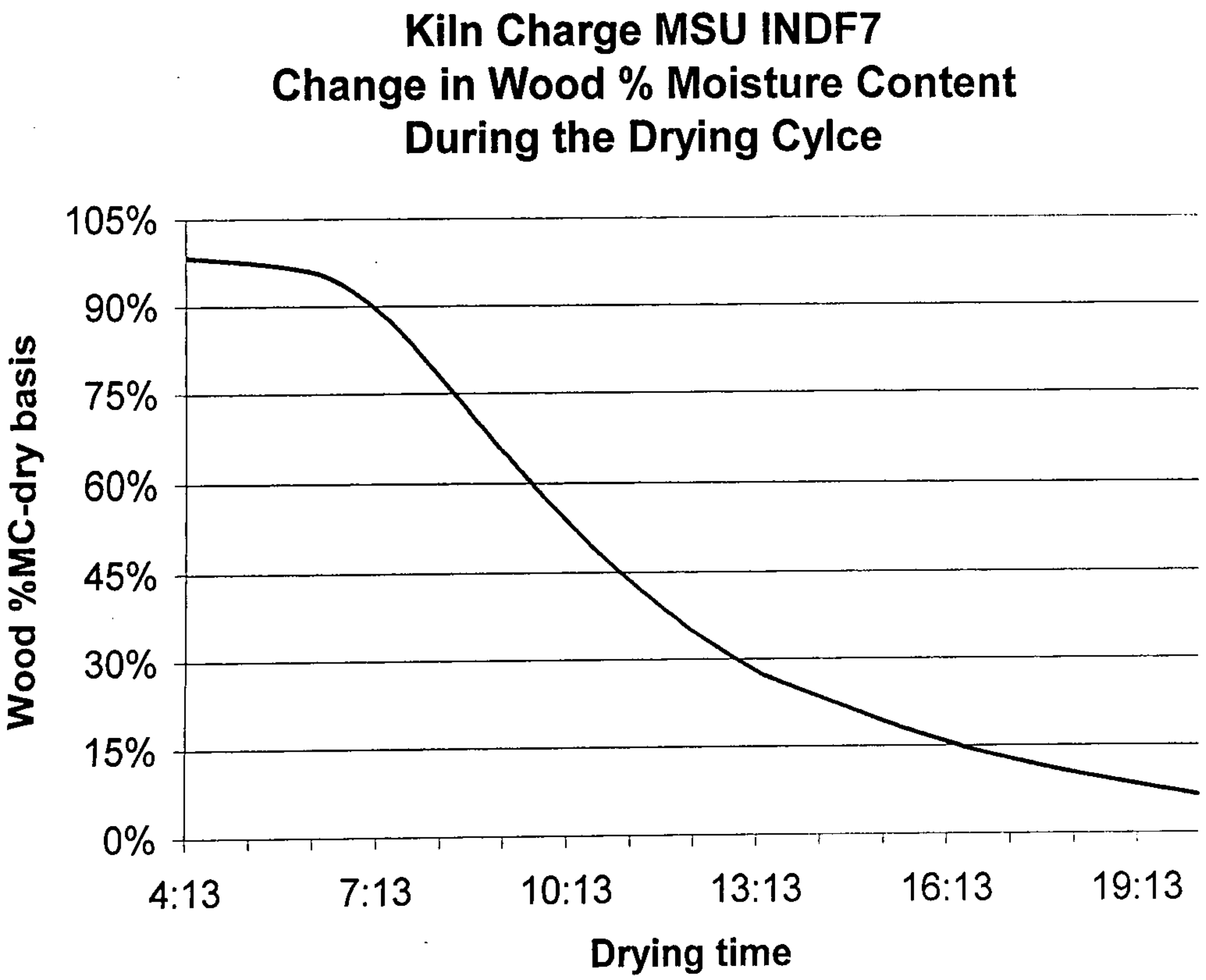


Kiln Charge MSU INDF5
Change in Wood % Moisture Content
During the Drying Cylce



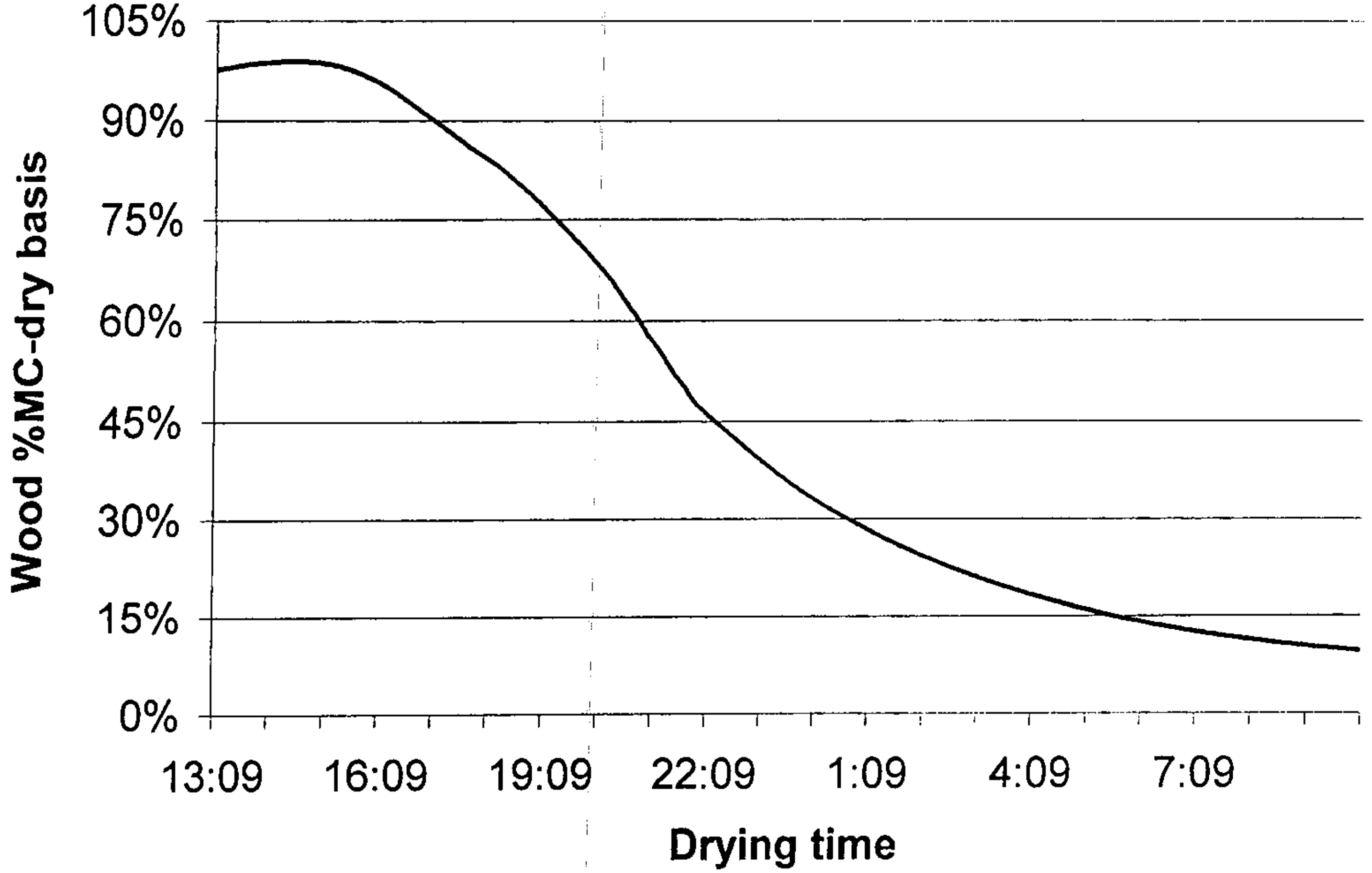
Kiln Charge MSU INDF6
Change in Wood % Moisture Content
During the Drying Cylce



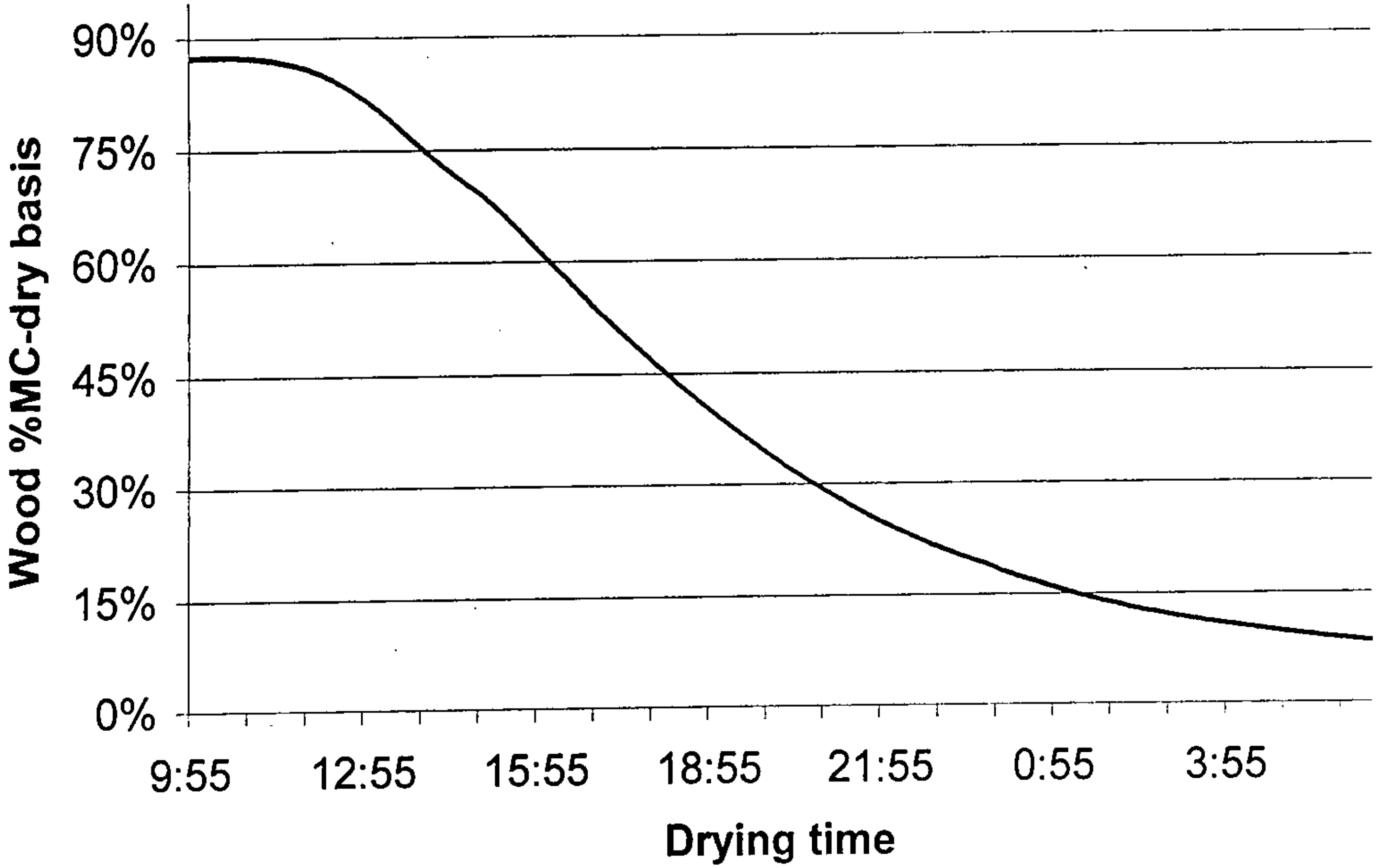


Kiln Charge MSU INDF7
Change in Wood % Moisture Content
During the Drying Cylce

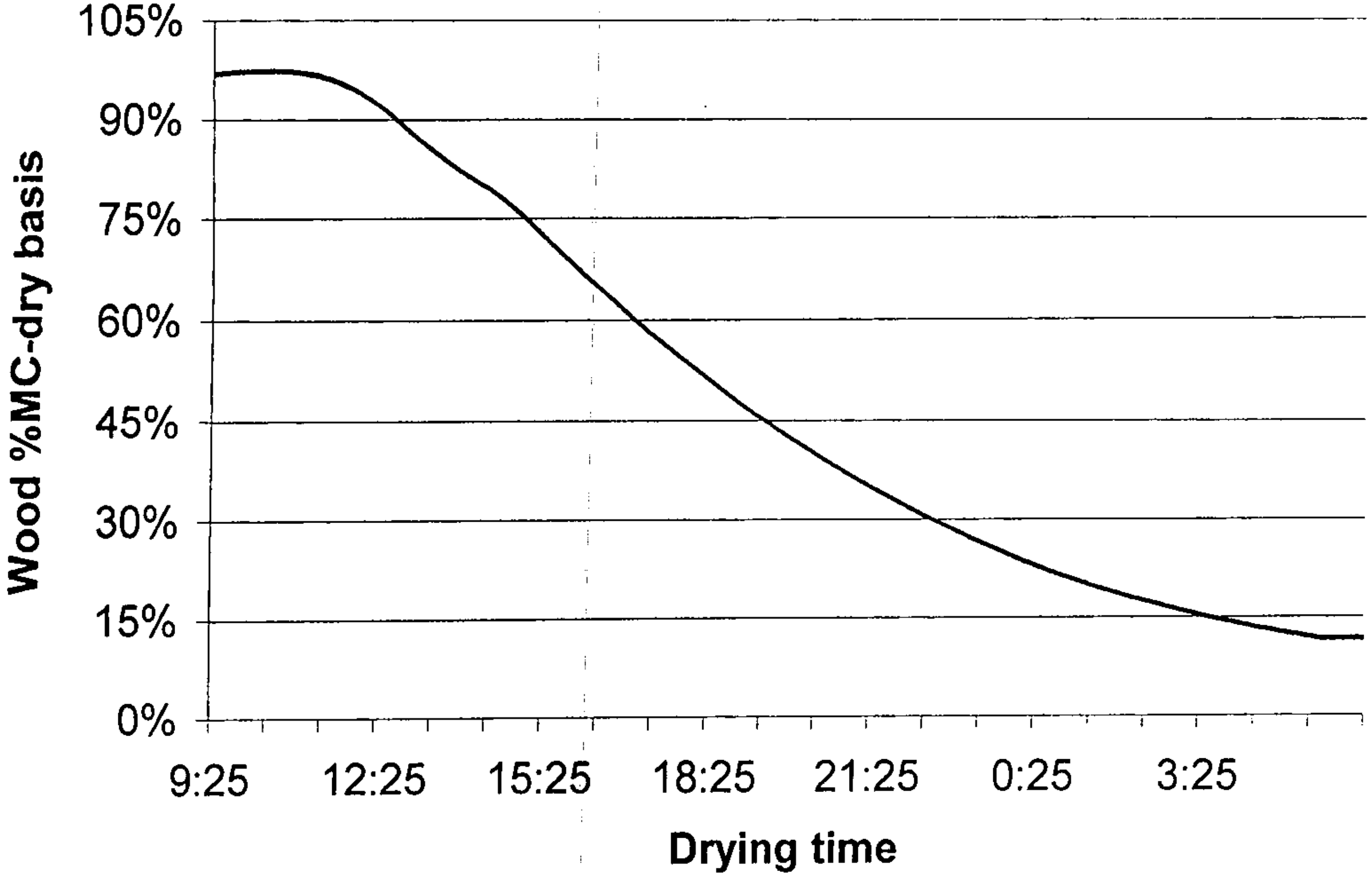
Kiln Charge OSU INDF1
Change in Wood % Moisture Content During the Drying Cylce



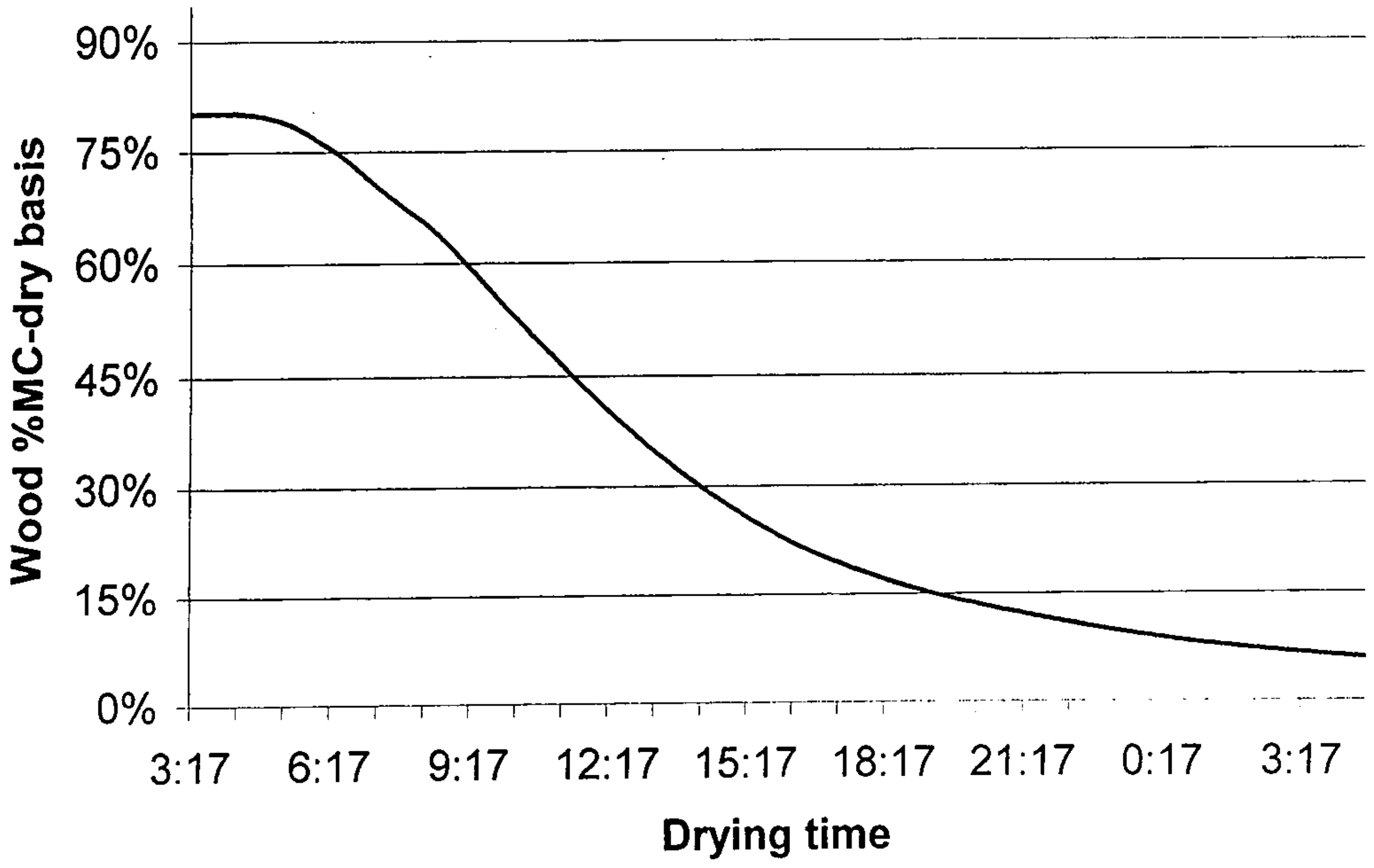
Kiln Charge OSU INDF2
Change in Wood % Moisture Content
During the Drying Cylce



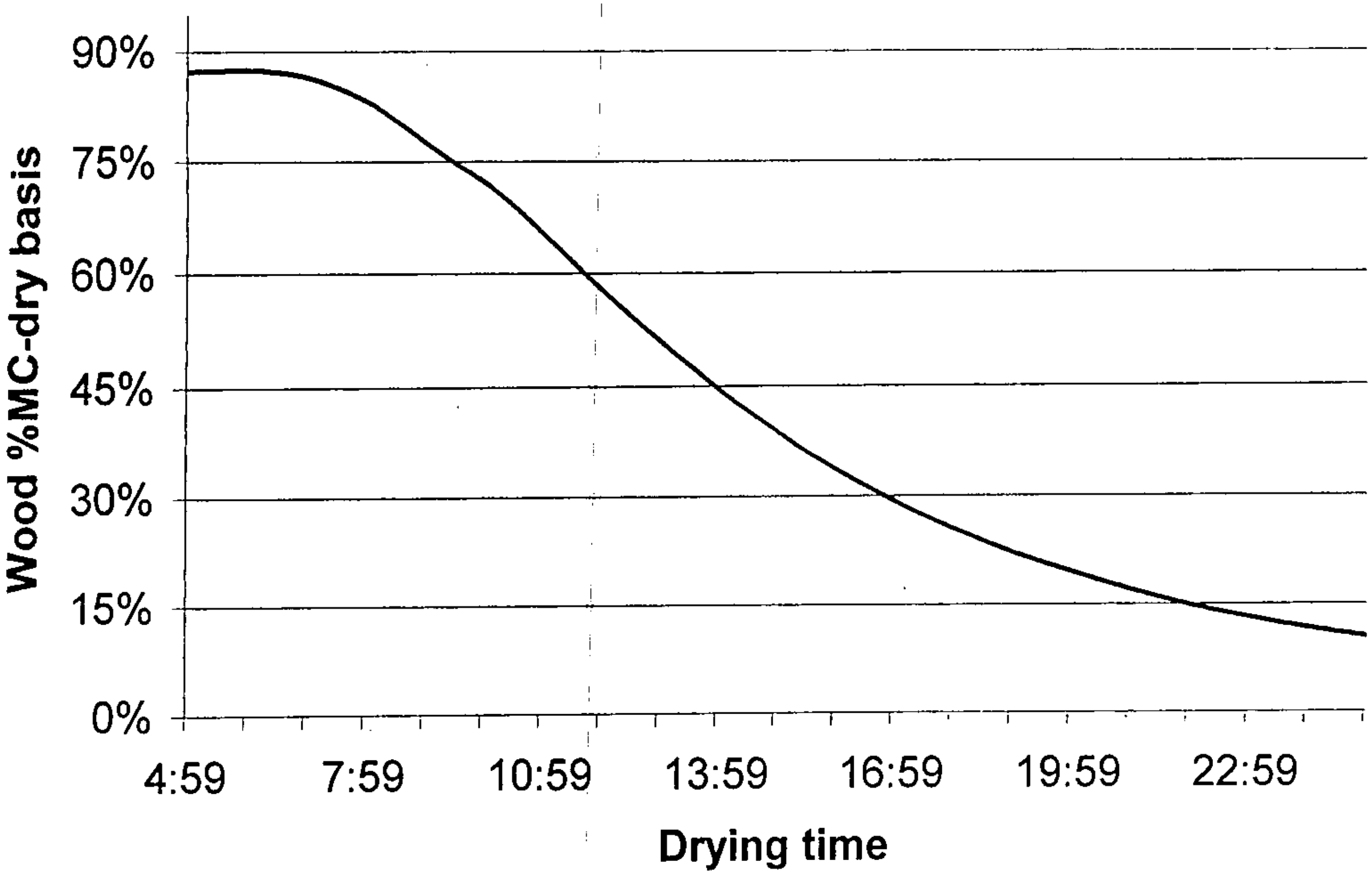
Kiln Charge OSU INDF3
Change in Wood % Moisture Content
During the Drying Cylce



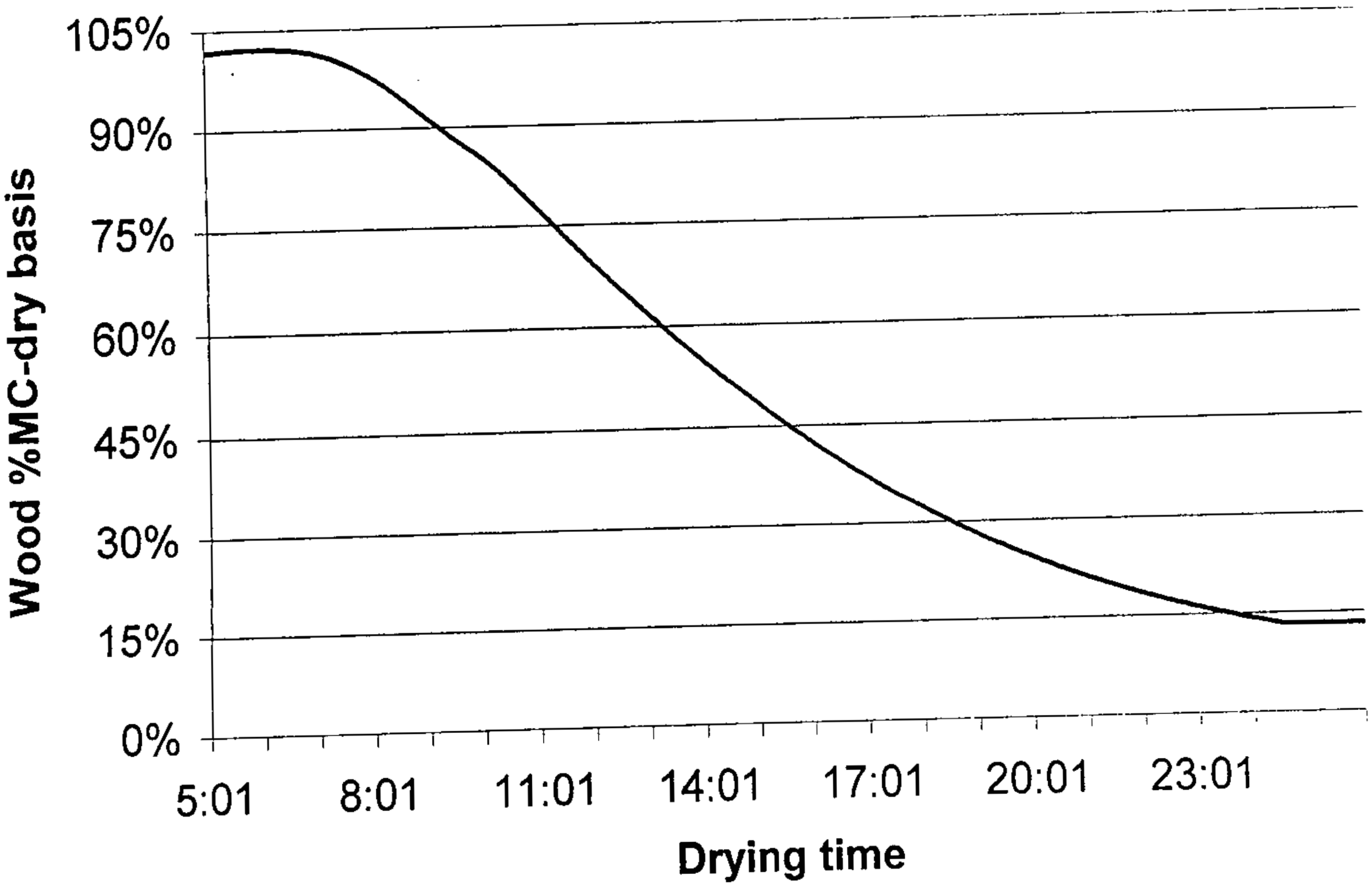
Kiln Charge OSU INDF5
Change in Wood % Moisture Content
During the Drying Cylce



Kiln Charge OSU INDF6
Change in Wood % Moisture Content
During the Drying Cylce



Kiln Charge OSU INDF7
Change in Wood % Moisture Content During the Drying Cylce



APPENDIX F

LUMBER MOISTURE CONTENT

TABLE F.1: Direct-fired Lumber Packet Data

FSK Lumber Pack Data for DF1

Forklift Weight			42,440	Lbs	Oven-dry density (Lb.s/BF) value from Small-Scale Kiln lumber samples:							2.26			
	Lumber Data														
Pack Number	T x W (in^2)	L ft	Number of boards	Pack Volume (bd ft)	Starting Total Weight (lbs)	Starting Pack Weight (lbs)	Starting Wet Wt. of Wood (lbs/BF)	Kiln Dry Total Weight (lbs)	Kiln Dry Pack Weight (lbs)	Kiln Dry Wet Wt. of Wood (lbs/BF)	Starting Lumber* (%MC-dry)	Kiln dry lumber* (%MC-dry)	Weight of Water loss (lbs)	Percent Change in Water per BF	Weight of Water Released/BF (lbs/BF)
59 top	12	12	319	3,828	59,400	16,960	4.43	52,020	9,580	2.50	96%	11%	7,380	85%	1.93
49- middle	12	12	319	3,828	59,400	16,960	4.43	52,760	10,320	2.70	96%	19%	6,640	77%	1.73
33-middle	12	14	319	4,466	62,040	19,600	4.39	53,480	11,040	2.47	94%	9%	8,560	85%	1.92
66-top	12	16	319	5,104	64,470	22,030	4.32	54,920	12,480	2.45	91%	8%	9,550	83%	1.87
56-middle	12	16	319	5,104	65,160	22,720	4.45	55,140	12,700	2.49	97%	10%	10,020	87%	1.96
57-middle	12	18	319	5,742	66,400	23,960	4.17	56,900	14,460	2.52	85%	11%	9,500	73%	1.65
41-top	12	20	319	6,380	67,840	25,400	3.98	58,700	16,260	2.55	76%	13%	9,140	63%	1.43
			Average:				4.31			2.52	91%	12%		79%	1.79

FSK Lumber Pack Data for DF2

Forklift Weight			42,440	Lbs	Oven-dry density (Lb.s/BF) value from Small-Scale Kiln lumber samples:							2.07			
	Lumber Data														
Pack Number	T x W (in^2)	L ft	No. Bds	Pack Volume (bd ft)	Starting Total Weight (lbs)	Starting Pack Weight (lbs)	Starting Wet Wt. of Wood (lbs/BF)	Kiln Dry Total Weight (lbs)	Kiln Dry Pack Weight (lbs)	Kiln Dry Wet Wt. of Wood (lbs/BF)	Starting Lumber* (%MC-dry)	Kiln dry lumber* (%MC-dry)	Weight of Water loss (lbs)	Percent Change in Water per BF	Weight of Water Released/BF (lbs/BF)
45-middle	8	8	454	2,421	52,780	10,340	4.27	48,100	5,660	2.34	106%	13%	4,680	93%	1.93
26-middle	8	10	454	3,027	55,620	13,180	4.35	49,680	7,240	2.39	110%	16%	5,940	95%	1.96
28-top	8	12	454	3,632	58,720	16,280	4.48	51,080	8,640	2.38	116%	15%	7,640	102%	2.10
60-middle	8	14	454	4,237	60,800	18,360	4.33	57,220	14,780	3.49	109%	68%**	3,580	41%	0.84
8-bottom	8	14	454	4,237	61,020	18,580	4.38	56,800	14,360	3.39	112%	63%**	4,220	48%	1.00
51-middle	8	16	454	4,843	63,740	21,300	4.40	54,460	12,020	2.48	112%	20%	9,280	93%	1.92
61-middle	8	20	454	6,053	67,380	24,940	4.12	56,740	14,300	2.36	99%	14%	10,640	85%	1.76
			Average:				4.33			2.69	109%	15%		79%	1.64

**Numbers not included in the average.

FSK Lumber Pack Data for DF3

Forklift Weight			42,440	Lbs	Oven-dry density (Lb.s/BF) value from Small-Scale Kiln lumber samples:							2.23			
	Lumber Data														
Pack Number	T x W (in^2)	L ft	No. Bds	Pack Volume (bd ft)	Starting Total Weight (lbs)	Starting Pack Weight (lbs)	Starting Wet Wt. of Wood (lbs/BF)	Kiln Dry Total Weight (lbs)	Kiln Dry Pack Weight (lbs)	Kiln Dry Wet Wt. of Wood (lbs/BF)	Starting Lumber* (%MC-dry)	Kiln dry lumber* (%MC-dry)	Weight of Water loss (lbs)	Percent Change in Water per BF	Weight of Water Released/BF (lbs/BF)
11-middle	12	8	319	2,552	53,940	11,500	4.51	48,940	6,500	2.55	102%	14%	5,000	88%	1.96
45-middle	12	10	319	3,190	56,520	14,080	4.41	50,340	7,900	2.48	98%	11%	6,180	87%	1.94
10-middle	12	10	319	3,190	56,620	14,180	4.45	50,720	8,280	2.60	100%	17%	5,900	83%	1.85
7-middle	12	12	319	3,828	59,380	16,940	4.43	51,900	9,460	2.47	99%	11%	7,480	88%	1.95
58-middle	12	12	319	3,828	59,360	16,920	4.42	51,880	9,440	2.47	98%	11%	7,480	88%	1.95
20-middle	12	12	319	3,828	59,520	17,080	4.46	51,800	9,360	2.45	100%	10%	7,720	91%	2.02
74-middle	12	16	319	5,104	65,220	22,780	4.46	55,460	13,020	2.55	100%	15%	9,760	86%	1.91
			Average:				4.45			2.51	100%	13%		87%	1.94

*Note: %MC-dry values were calculated for each kiln charge were based on the oven-dry density determined from the sample charges sent to the small-scale kilns.

APPENDIX G

LUMBER SAMPLING METHOD

Table G.1: Random Number and Color Code Designations

Total Number of Columns	Number of Lumber Columns Required	Ordered Color ID	Random Numbers Assigned	Random Color Identification	Random Numbers Sorted
1	1	YE	26262	BL	19
2	2	YE	9990	OR	244
3	1	GY	43569	GR	561
4	2	GY	7772	BL	1442
5	3	GY	82211	OR	2277
6	4	GY	28018	BL	4006
7	1	GR	561	OR	4313
8	2	GR	84491	BL	4596
9	3	GR	32519	BL	5038
10	4	GR	33960	OR	5202
11	1	OR	77866	OR	5214
12	2	OR	11757	OR	5965
13	3	OR	10049	BL	6024
14	4	OR	47489	OR	6127
15	5	OR	22557	GY	7772
16	6	OR	58538	OR	9152
17	7	OR	49510	BL	9352
18	8	OR	10277	BL	9411
19	9	OR	98879	BL	9664
20	10	OR	72099	YE	9990
21	11	OR	12123	OR	10049
22	12	OR	89654	OR	10277
23	13	OR	6127	OR	10428
24	14	OR	84400	OR	11757
25	15	OR	79001	BL	12112
26	16	OR	24149	OR	12123
27	17	OR	16068	BL	12340
28	18	OR	244	BL	13023
29	19	OR	5965	OR	14453
30	20	OR	92057	OR	14475
31	21	OR	85386	OR	15412
32	22	OR	70448	BL	15877
33	23	OR	81117	BL	15937
34	24	OR	21135	OR	16068
35	25	OR	53294	BL	16737
36	26	OR	54316	OR	17449
37	27	OR	79385	OR	20650
38	28	OR	99253	OR	20755
39	29	OR	9152	BL	20935
40	30	OR	81233	OR	21135
41	31	OR	17449	BL	22472
42	32	OR	81642	OR	22557
43	33	OR	15412	BL	22876
44	34	OR	20650	BL	23536

Table G.1: Random Number and Color Code Designations

Total Number of Columns	Number of Lumber Columns Required	Ordered Color ID	Random Numbers Assigned	Random Color Identification	Random Numbers Sorted
45	35	OR	78353	OR	24149
46	36	OR	61894	BL	26183
47	37	OR	14453	YE	26262
48	38	OR	79360	BL	26793
49	39	OR	2277	GY	28018
50	40	OR	77964	BL	30949
51	41	OR	51681	BL	32103
52	42	OR	20755	BL	32148
53	43	OR	5214	OR	32253
54	44	OR	5202	GR	32519
55	45	OR	75236	BL	33405
56	46	OR	4313	OR	33621
57	47	OR	33621	GR	33960
58	48	OR	10428	BL	34035
59	49	OR	71815	BL	35767
60	50	OR	32253	BL	37486
61	51	OR	75615	BL	38266
62	52	OR	14475	BL	41064
63	53	OR	75277	BL	41463
64	1	BL	55642	GY	43569
65	2	BL	26183	BL	43837
66	3	BL	38266	BL	46144
67	4	BL	67287	OR	47489
68	5	BL	30949	BL	48540
69	6	BL	48540	OR	49510
70	7	BL	67614	BL	49742
71	8	BL	63644	BL	49868
72	9	BL	4006	OR	51681
73	10	BL	41064	OR	53294
74	11	BL	9411	OR	54316
75	12	BL	71744	BL	55642
76	13	BL	93570	BL	56555
77	14	BL	16737	OR	58538
78	15	BL	22472	BL	58983
79	16	BL	9664	BL	59357
80	17	BL	79309	OR	61894
81	18	BL	1442	BL	62538
82	19	BL	19	BL	63640
83	20	BL	46144	BL	63644
84	21	BL	32148	BL	64797
85	22	BL	66716	BL	65230
86	23	BL	91523	BL	66716
87	24	BL	5038	BL	67287
88	25	BL	62538	BL	67614

Table G.1: Random Number and Color Code Designations

Total Number of Columns	Number of Lumber Columns Required	Ordered Color ID	Random Numbers Assigned	Random Color Identification	Random Numbers Sorted
89	26	BL	59357	OR	70448
90	27	BL	9352	BL	71744
91	28	BL	77089	OR	71815
92	29	BL	6024	BL	72064
93	30	BL	81223	OR	72099
94	31	BL	35767	BL	72458
95	32	BL	43837	OR	75236
96	33	BL	15877	OR	75277
97	34	BL	91925	OR	75615
98	35	BL	64797	BL	77089
99	36	BL	37486	OR	77866
100	37	BL	65230	OR	77964
101	38	BL	49868	OR	78353
102	39	BL	26793	OR	79001
103	40	BL	63640	BL	79309
104	41	BL	12112	OR	79360
105	42	BL	13023	OR	79385
106	43	BL	95855	OR	81117
107	44	BL	32103	BL	81223
108	45	BL	86205	OR	81233
109	46	BL	22876	OR	81642
110	47	BL	72458	GY	82211
111	48	BL	97328	BL	82658
112	49	BL	82658	OR	84400
113	50	BL	33405	GR	84491
114	51	BL	49742	OR	85386
115	52	BL	4596	BL	86205
116	53	BL	12340	BL	89184
117	54	BL	89512	BL	89512
118	55	BL	94030	OR	89654
119	56	BL	89184	BL	91523
120	57	BL	58983	BL	91925
121	58	BL	23536	OR	92057
122	59	BL	41463	BL	93570
123	60	BL	56555	BL	94030
124	61	BL	72064	BL	95855
125	62	BL	34035	BL	97328
126	63	BL	15937	OR	98879
127	64	BL	20935	OR	99253

Table G.2: Configuration of FSK DF1 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	BF capacity of kiln	SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	15	28.8	3	=	86.25	28.2%
OSU requires	48	44	20	73.3	3	=	220	71.8%
					Total BF		306.25	

	INDICATE Type of board being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards
Packet 2x6x8s	0	0	48	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x6x10s	1	3	36	9,600	7.6%	23.20	2.32	0.77	1	3
Packet 2x6x12s	1	6	30	23,040	18.2%	55.68	4.64	0.77	1	6
Packet 2x6x14s	1	6	24	26,880	21.2%	64.96	4.64	0.77	1	6
Packet 2x6x16s	1	6	24	30,720	24.2%	74.24	4.64	0.77	1	6
Packet 2x6x18s	1	3	18	17,280	13.6%	41.76	2.32	0.77	1	3
Packet 2x6x20s	1	3	18	19,200	15.2%	46.40	2.32	0.77	1	3
TOTAL ==>	6	27		126,720	100.00%	306.25	20.88			27

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x6x8s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.0	0.0	0.0%	0.0%	0.0	
Packet 2x6x10s	7.6%	1.0	0.50	1.5	6.7%	7.3%	1.0	0.5	1.0	6.7%	5.0%	4.5	YES
Packet 2x6x12s	18.2%	3.0	1.50	4.0	20.0%	19.5%	3.0	1.5	4.0	20.0%	20.0%	16.5	YES
Packet 2x6x14s	21.2%	3.0	1.50	4.0	20.0%	19.5%	3.0	1.5	4.0	20.0%	20.0%	16.5	YES
Packet 2x6x16s	24.2%	4.0	2.00	5.0	26.7%	24.4%	4.0	2.0	5.0	26.7%	25.0%	21.0	YES
Packet 2x6x18s	13.6%	2.0	1.00	3.0	13.3%	14.6%	2.0	1.0	3.0	13.3%	15.0%	12.0	YES
Packet 2x6x20s	15.2%	2.0	1.00	3.0	13.3%	14.6%	2.0	1.0	3.0	13.3%	15.0%	12.0	YES
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		15.0		20.5			15.0		20.0		Sum	82.5	YES
Is this the right configuration?		YES		NO, too many			YES		YES				

Table G.3: Configuration of FSK DF2 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	Kiln charge of 2x BF capacity of kiln	8 in^2 SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	25	31.9	3	=	95.83	39.5%
OSU requires	48	44	20	48.9	3	=	146.67	60.5%
					Total BF		242.5	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards
Packet 2x4x8s	1	3	48	7,296	6.1%	14.70	2.76	0.92	1	3
Packet 2x4x10s	1	3	36	9,120	7.6%	18.37	2.76	0.92	1	3
Packet 2x4x12s	1	9	30	32,832	27.3%	66.14	8.27	0.92	1	9
Packet 2x4x14s	1	9	24	38,304	31.8%	77.16	8.27	0.92	1	9
Packet 2x4x16s	1	3	24	14,592	12.1%	29.39	2.76	0.92	1	3
Packet 2x4x18s	0	0	18	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x4x20s	1	3	18	18,240	15.2%	36.74	2.76	0.92	1	3
TOTAL ==>	6	30		120,384	100.00%	242.50	27.56			30

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces		CALCULATED No. of samples each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces		ADJUSTED o. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
		24 inch pieces	48 inch pieces				24 inch pieces	48 inch pieces					
Packet 2x4x8s	6.1%	1.5	0.75	1.0	5.9%	5.1%	1.0	0.50	1.00	4.0%	5.0%	4.5	YES
Packet 2x4x10s	7.6%	2.0	1.00	1.5	7.8%	7.7%	2.0	1.00	1.50	8.0%	7.5%	7.5	YES
Packet 2x4x12s	27.3%	7.0	3.50	5.5	27.5%	28.2%	7.0	3.50	5.50	28.0%	27.5%	27.0	YES
Packet 2x4x14s	31.8%	8.0	4.00	6.0	31.4%	30.8%	8.0	4.00	6.50	32.0%	32.5%	31.5	YES
Packet 2x4x16s	12.1%	3.0	1.50	2.5	11.8%	12.8%	3.0	1.50	2.50	12.0%	12.5%	12.0	YES
Packet 2x4x18s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x20s	15.2%	4.0	2.00	3.0	15.7%	15.4%	4.0	2.00	3.00	16.0%	15.0%	15.0	YES
	100.0%									100.0%	100.0%		
Total boards		25.5		19.5			25.0		20.0		Sum	97.5	YES
Is this the right configuration?		NO, too many		NO, too few			YES		YES				

Table G.4: Configuration of FSK DF3 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	BF capacity of kiln	SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	15	28.8	3	=	86.25	28.2%
OSU requires	48	44	20	73.3	3	=	220	71.8%
					Total BF		306.25	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards
Packet 2x6x8s	1	3	48	7,680	6.5%	19.76	2.47	0.82	1	3
Packet 2x6x10s	1	6	36	19,200	16.1%	49.40	4.94	0.82	1	6
Packet 2x6x12s	1	9	30	34,560	29.0%	88.91	7.41	0.82	1	9
Packet 2x6x14s	0	0	24	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x6x16s	1	9	24	46,080	38.7%	118.55	7.41	0.82	1	9
Packet 2x6x18s	0	0	18	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x6x20s	1	3	18	19,200	16.1%	49.40	2.47	0.82	1	3
TOTAL ==>	4	27		119,040	106.5%	306.25	22.23			27

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x6x8s	6.5%	1.0	0.50	1.0	6.7%	5.0%	1.0	0.5	1.0	6.7%	5.0%	4.5	YES
Packet 2x6x10s	16.1%	2.0	1.00	3.0	13.3%	15.0%	2.0	1.0	3.0	13.3%	15.0%	12.0	YES
Packet 2x6x12s	29.0%	4.0	2.00	6.0	26.7%	30.0%	4.0	2.0	6.0	26.7%	30.0%	24.0	YES
Packet 2x6x14s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.0	0.0	0.0%	0.0%	0.0	
Packet 2x6x16s	38.7%	6.0	3.00	7.0	40.0%	35.0%	6.0	3.0	7.0	40.0%	35.0%	30.0	YES
Packet 2x6x18s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.0	0.0	0.0%	0.0%	0.0	
Packet 2x6x20s	16.1%	2.0	1.00	3.0	13.3%	15.0%	2.0	1.0	3.0	13.3%	15.0%	12.0	YES
	106.5%				100.0%	100.0%				100.0%	100.0%		
Total boards		15.0		20.0			15.0		20.0		Sum	82.5	YES
Is this the right configuration?		YES		YES			YES		YES				

Table G.5: Configuration of FSK DF4 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	Kiln charge of 2x4 BF capacity of kiln	8 in^2 SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	25	31.9	3	=	95.83	30.3%
OSU requires	48	44	30	73.3	3	=	220.00	69.7%
					Total BF		315.8333333	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards
Packet 2x4x8s	1	3	48	7,296	6.1%	19.14	3.59	1.20	2	6
Packet 2x4x10s	1	3	36	9,120	7.6%	23.93	3.59	1.20	2	6
Packet 2x4x12s	1	9	30	32,832	27.3%	86.14	10.77	1.20	2	18
Packet 2x4x14s	1	3	24	12,768	10.6%	33.50	3.59	1.20	2	6
Packet 2x4x16s	1	12	24	58,368	48.5%	153.13	14.36	1.20	2	24
Packet 2x4x18s	0	0	18	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x4x20s	0	0	18	0	0.0%	0.00	0.00	0.00	0	0
TOTAL ==>	5	30		120,384	100.00%	315.83	35.89			60

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using		CALCULATED No. of samples each OSU Charge	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using		ADJUSTED No. of samples for each OSU Charge	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
		24 inch pieces	48 inch pieces	48 inch pieces			24 inch pieces	48 inch pieces	48 inch pieces				
Packet 2x4x8s	6.1%	1.5	0.75	2.0	5.9%	6.8%	1.0	0.50	2.00	4.0%	6.7%	7.5	YES
Packet 2x4x10s	7.6%	2.0	1.00	2.0	7.8%	6.8%	2.0	1.00	2.00	8.0%	6.7%	9.0	YES
Packet 2x4x12s	27.3%	7.0	3.50	8.0	27.5%	27.1%	7.0	3.50	8.00	28.0%	26.7%	34.5	YES
Packet 2x4x14s	10.6%	3.0	1.50	3.0	11.8%	10.2%	3.0	1.50	3.00	12.0%	10.0%	13.5	YES
Packet 2x4x16s	48.5%	12.0	6.00	14.5	47.1%	49.2%	12.0	6.00	15.00	48.0%	50.0%	63.0	YES
Packet 2x4x18s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x20s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		25.5		29.5			25.0		30.0		Sum	127.5	YES
Is this the right configuration?		NO, too many		NO, too few			YES		YES				

Table G.6: Configuration of FSK DF5 and Lumber Sample Requirements For MSU and OSU.

8 in^2

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	Kiln charge of 2x4s BF capacity of kiln	SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	25	31.9	3	=	95.83	30.3%
OSU requires	48	44	30	73.3	3	=	220.00	69.7%
					Total BF	.	315.8333333	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards
Packet 2x4x8s	0	0	48	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x4x10s	1	9	36	27,360	22.7%	71.78	10.77	1.20	2	18
Packet 2x4x12s	1	9	30	32,832	27.3%	86.14	10.77	1.20	2	18
Packet 2x4x14s	1	3	24	12,768	10.6%	33.50	3.59	1.20	2	6
Packet 2x4x16s	1	6	24	29,184	24.2%	76.57	7.18	1.20	2	12
Packet 2x4x18s	0	0	18	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x4x20s	1	3	18	18,240	15.2%	47.85	3.59	1.20	2	6
TOTAL ==>	5	30		120,384	100.00%	315.83	35.89			60

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	48 inch pieces	CALCULATED No. of samples each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x4x8s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x10s	22.7%	6.0	3.00	7.0	23.1%	23.7%	5.0	2.50	7.00	20.0%	23.3%	28.5	YES
Packet 2x4x12s	27.3%	7.0	3.50	8.0	26.9%	27.1%	7.0	3.50	8.00	28.0%	26.7%	34.5	YES
Packet 2x4x14s	10.6%	3.0	1.50	3.0	11.5%	10.2%	3.0	1.50	3.00	12.0%	10.0%	13.5	YES
Packet 2x4x16s	24.2%	6.0	3.00	7.0	23.1%	23.7%	6.0	3.00	7.50	24.0%	25.0%	31.5	YES
Packet 2x4x18s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x20s	15.2%	4.0	2.00	4.5	15.4%	15.3%	4.0	2.00	4.50	16.0%	15.0%	19.5	YES
Total boards	100.0%	26.0		29.5	100.0%	100.0%	25.0		30.0	100.0%	100.0% Sum	127.5	YES
Is this the right configuration?		NO, too many		NO, too few			YES		YES				

Table G.7: Configuration of FSK DF6 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	BF capacity of kiln	SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	15	28.8	3	=	86.25	28.2%
OSU requires	48	44	20	73.3	3	=	220	71.8%
					Total BF		306.25	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards
Packet 2x6x8s	0	0	48	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x6x10s	0	0	36	0	0.0%	0.00	0.00	0.00	0	0
Packet 2x6x12s	1	9	30	34,560	27.3%	83.52	6.96	0.77	1	9
Packet 2x6x14s	1	3	24	13,440	10.6%	32.48	2.32	0.77	1	3
Packet 2x6x16s	1	12	24	61,440	48.5%	148.48	9.28	0.77	1	12
Packet 2x6x18s	1	3	18	17,280	13.6%	41.76	2.32	0.77	1	3
Packet 2x6x20s	0	0	18	0	0.0%	0.00	0.00	0.00	0	0
TOTAL ==>	4	27		126,720	100.00%	306.25	20.88			27

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED o. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x6x8s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.0	0.0	0.0%	0.0%	0.0	
Packet 2x6x10s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.0	0.0	0.0%	0.0%	0.0	
Packet 2x6x12s	27.3%	4.0	2.00	5.5	27.6%	26.8%	4.0	2.0	5.0	26.7%	25.0%	21.0	YES
Packet 2x6x14s	10.6%	1.5	0.75	2.0	10.3%	9.8%	2.0	1.0	2.0	13.3%	10.0%	9.0	YES
Packet 2x6x16s	48.5%	7.0	3.50	10.0	48.3%	48.8%	7.0	3.5	10.0	46.7%	50.0%	40.5	YES
Packet 2x6x18s	13.6%	2.0	1.00	3.0	13.8%	14.6%	2.0	1.0	3.0	13.3%	15.0%	12.0	YES
Packet 2x6x20s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.0	0.0	0.0%	0.0%	0.0	
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		14.5		20.5			15.0		20.0		Sum	82.5	YES
Is this the right configuration?		NO, too few		NO, too many			YES		YES				

Table G.8: Configuration of FSK INDF1 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut	INDICATE Dimension of dried piece	INDICATE Number of pieces per charge	Kiln charge of 2x4s BF capacity of kiln	8 in^2 SSK Charge multiplier		BF per charge	% of Charge
	inch	inch						
MSU requires	24	23	25	31.9	2	=	63.89	22.5%
OSU requires	48	44	30	73.3	3	=	220.00	77.5%
					Total BF		283.89	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards	Extra Boards Required	Total Number of Boards Pulled From Each Packet
Packet 2x4x8s	0	0	20	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x10s	0	0	16	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x12s	1	4	12	46,848	30.0%	85.17	10.65	2.66	3	12	0	12
Packet 2x4x14s	1	2	10	27,328	17.5%	49.68	5.32	2.66	3	6	0	6
Packet 2x4x16s	1	3	10	46,848	30.0%	85.17	7.98	2.66	3	9	0	9
Packet 2x4x18s	1	2	8	35,136	22.5%	63.88	5.32	2.66	3	6	0	6
Packet 2x4x20s	0	0	8	0	0.0%	0.00	0.00	0.00	0	0	0	0
TOTAL ==>	4	11		156,160	100.00%	283.89	29.28			33		33

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples for each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x4x8s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x10s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x12s	30.0%	7.5	3.75	9.0	30.0%	30.0%	8.0	4.00	9.00	32.0%	30.0%	35.0	YES
Packet 2x4x14s	17.5%	4.0	2.00	5.0	16.0%	16.7%	4.0	2.00	5.00	16.0%	16.7%	19.0	YES
Packet 2x4x16s	30.0%	7.5	3.75	9.0	30.0%	30.0%	7.0	3.50	9.00	28.0%	30.0%	34.0	YES
Packet 2x4x18s	22.5%	6.0	3.00	7.0	24.0%	23.3%	6.0	3.00	7.00	24.0%	23.3%	27.0	YES
Packet 2x4x20s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		25.0		30.0			25.0		30.0		Sum	115.0	YES
Is this the right configuration?		YES		YES			YES		YES				

Table G.9: Configuration of FSK INDF2 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	Kiln charge of 2x4s BF capacity of kiln	SSK Charge multiplier 8 in^2		BF per charge	% of Charge
MSU requires	24	23	25	31.9	2	=	63.89	22.5%
OSU requires	48	44	30	73.3	3	=	220.00	77.5%
					Total BF		283.89	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards	Extra Boards Required	Total Number of Boards Pulled From Each Packet
Packet 2x4x8s	0	0	20	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x10s	1	2	16	19,520	12.5%	35.49	5.32	2.66	3	6	0	6
Packet 2x4x12s	1	3	12	35,136	22.5%	63.88	7.98	2.66	3	9	0	9
Packet 2x4x14s	1	1	10	13,664	8.8%	24.84	2.66	2.66	3	3	1	4
Packet 2x4x16s	1	2	10	31,232	20.0%	56.78	5.32	2.66	3	6	0	6
Packet 2x4x18s	1	1	8	17,568	11.3%	31.94	2.66	2.66	3	3	0	3
Packet 2x4x20s	1	2	8	39,040	25.0%	70.97	5.32	2.66	3	6	0	6
TOTAL ==>	6	11		156,160	100.00%	283.89	29.28			33		34

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples for each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTE Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x4x8s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x10s	12.5%	3.0	1.50	4.0	12.0%	13.1%	3.0	1.50	4.00	12.0%	13.3%	15.0	YES
Packet 2x4x12s	22.5%	6.0	3.00	7.0	24.0%	23.0%	6.0	3.00	7.00	24.0%	23.3%	27.0	YES
Packet 2x4x14s	8.8%	2.0	1.00	3.0	8.0%	9.8%	2.0	1.00	3.00	8.0%	10.0%	11.0	YES
Packet 2x4x16s	20.0%	5.0	2.50	6.0	20.0%	19.7%	5.0	2.50	6.00	20.0%	20.0%	23.0	YES
Packet 2x4x18s	11.3%	3.0	1.50	3.0	12.0%	9.8%	3.0	1.50	3.00	12.0%	10.0%	12.0	YES
Packet 2x4x20s	25.0%	6.0	3.00	7.5	24.0%	24.6%	6.0	3.00	7.00	24.0%	23.3%	27.0	YES
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		25.0		30.5			25.0		30.0		Sum	115.0	YES
Is this the right configuration?		YES		NO, too many			YES		YES				

Table G.10: Configuration of FSK INDF3 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut	INDICATE Dimension of dried piece	INDICATE Number of pieces per	Kiln charge of 2x4s BF capacity	8 in^2 SSK Charge multiplier		BF per charge	% of Charge
	inch	inch	charge	of kiln				
MSU requires	24	23	25	31.9	2	=	63.89	22.5%
OSU requires	48	44	30	73.3	3	=	220.00	77.5%
					Total BF		283.89	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards	Extra Boards Required	Total Number of Boards Pulled From Each Packet
Packet 2x4x8s	0	0	20	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x10s	1	2	16	19,520	12.5%	35.49	5.32	2.66	3	6	0	6
Packet 2x4x12s	1	2	12	23,424	15.0%	42.58	5.32	2.66	3	6	0	6
Packet 2x4x14s	1	1	10	13,664	8.8%	24.84	2.66	2.66	3	3	1	4
Packet 2x4x16s	1	3	10	46,848	30.0%	85.17	7.98	2.66	3	9	0	9
Packet 2x4x18s	1	3	8	52,704	33.8%	95.81	7.98	2.66	3	9	0	9
Packet 2x4x20s	0	0	8	0	0.0%	0.00	0.00	0.00	0	0	0	0
TOTAL ==>	5	11		156,160	100.00%	283.89	29.28			33		34

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples for each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x4x8s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x10s	12.5%	3.0	1.50	4.0	12.0%	13.1%	3.0	1.50	4.00	12.0%	13.3%	15.0	YES
Packet 2x4x12s	15.0%	4.0	2.00	4.5	16.0%	14.8%	4.0	2.00	4.00	16.0%	13.3%	16.0	YES
Packet 2x4x14s	8.8%	2.0	1.00	3.0	8.0%	9.8%	2.0	1.00	3.00	8.0%	10.0%	11.0	YES
Packet 2x4x16s	30.0%	7.5	3.75	9.0	30.0%	29.5%	8.0	4.00	9.00	32.0%	30.0%	35.0	YES
Packet 2x4x18s	33.8%	8.5	4.25	10.0	34.0%	32.8%	8.0	4.00	10.00	32.0%	33.3%	38.0	YES
Packet 2x4x20s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		25.0		30.5			25.0		30.0		Sum	115.0	YES
Is this the right configuration?		YES		NO, too many			YES		YES				

Table G.11: Configuration of FSK INDF5 and Lumber Sample Requirements For MSU and OSU.

Kiln charge of 2x6s 12 in^2
Kiln charge of 2x4s 8 in^2

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	BF capacity of kiln	SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	15	28.8	2	=	57.5	28.2%
OSU requires	48	44	20	73.3	2	=	146.7	71.8%
					Total BF		204.2	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards	Extra Boards Required	Total Number of Boards Pulled From Each Packet
Packet 2x6x8s	1	4	20	31,232	20.0%	40.83	5.10	1.28	2	8	0	8
Packet 2x6x10s	1	2	16	19,520	12.5%	25.52	2.55	1.28	2	4	0	4
Packet 2x4x20s	1	1	8	19,520	12.5%	25.52	1.91	1.91	2	2	0	2
Packet 2x6x14s	1	1	10	13,664	8.8%	17.86	1.28	1.28	2	2	0	2
Packet 2x6x16s	1	1	10	15,616	10.0%	20.42	1.28	1.28	2	2	0	2
Packet 2x6x18s	1	1	8	17,568	11.3%	22.97	1.28	1.28	2	2	0	2
Packet 2x6x20s	1	2	8	39,040	25.0%	51.04	2.55	1.28	2	4	0	4
TOTAL ==>	7	12		156,160	100.00%	204.1666667	15.95			24		24

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples for each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x6x8s	20.0%	3.0	1.50	4.0	18.2%	18.6%	3.0	1.5	4.0	20.0%	20.0%	11.0	YES
Packet 2x6x10s	12.5%	2.0	1.00	2.5	12.1%	11.6%	2.0	1.0	2.5	13.3%	12.5%	7.0	YES
Packet 2x4x20s	12.5%	3.0	1.50	4.0	18.2%	18.6%	2.0	1.0	2.5	13.3%	12.5%	7.0	YES
Packet 2x6x14s	8.8%	1.0	0.50	2.0	6.1%	9.3%	1.0	0.5	2.0	6.7%	10.0%	5.0	YES
Packet 2x6x16s	10.0%	1.5	0.75	2.0	9.1%	9.3%	1.0	0.5	2.0	6.7%	10.0%	5.0	YES
Packet 2x6x18s	11.3%	2.0	1.00	2.0	12.1%	9.3%	2.0	1.0	2.0	13.3%	10.0%	6.0	YES
Packet 2x6x20s	25.0%	4.0	2.00	5.0	24.2%	23.3%	4.0	2.0	5.0	26.7%	25.0%	14.0	YES
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		16.5		21.5			15.0		20.0		Sum	55.0	YES
Is this the right configuration?		NO, too many		NO, too many			YES		YES				

Table G.12: Configuration of FSK INDF6 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	Kiln charge of 2x4s BF capacity of kiln	8 in^2 SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	25	31.9	2	=	63.89	30.3%
OSU requires	48	44	30	73.3	2	=	146.67	69.7%
					Total BF		210.56	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards	Extra Boards Required	Total Number of Boards Pulled From Each Packet
Packet 2x4x8s	0	2	20	15,616	10.0%	21.06	3.95	1.97	2	4	0	4
Packet 2x4x10s	1	4	16	39,040	25.0%	52.64	7.90	1.97	2	8	1	9
Packet 2x4x12s	1	2	12	23,424	15.0%	31.58	3.95	1.97	2	4	1	5
Packet 2x4x14s	1	0	10	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x16s	1	0	10	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x18s	1	0	8	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x20s	0	4	8	78,080	50.0%	105.28	7.90	1.97	2	8	1	9
TOTAL ==>	5	12		156,160	100.00%	210.56	23.69			24		27

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples for each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTED Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x4x8s	10.0%	2.5	1.25	3.0	10.0%	10.0%	2.0	1.00	3.00	8.0%	10.0%	8.0	YES
Packet 2x4x10s	25.0%	6.0	3.00	7.5	24.0%	25.0%	6.0	3.00	7.50	24.0%	25.0%	21.0	YES
Packet 2x4x12s	15.0%	4.0	2.00	4.5	16.0%	15.0%	4.0	2.00	4.50	16.0%	15.0%	13.0	YES
Packet 2x4x14s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x16s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x18s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x20s	50.0%	12.5	6.25	15.0	50.0%	50.0%	13.0	6.50	15.00	52.0%	50.0%	43.0	YES
	100.0%				100.0%	100.0%				100.0%	100.0%		
Total boards		25.0		30.0			25.0		30.0		Sum	85.0	YES
Is this the right configuration?		YES		YES			YES		YES				

Table G.13: Configuration of FSK INDF7 and Lumber Sample Requirements For MSU and OSU.

	INDICATE Dimension of piece cut inch	INDICATE Dimension of dried piece inch	INDICATE Number of pieces per charge	Kiln charge of 2x4s BF capacity of kiln	8 In^2 SSK Charge multiplier		BF per charge	% of Charge
MSU requires	24	23	25	31.9	2	=	63.89	30.3%
OSU requires	48	44	30	73.3	2	=	146.67	69.7%
					Total BF		210.56	

	INDICATE Type of board is being dried YES = 1 NO = 0	INDICATE Number of packets in Charge	Maximum Number of Packets in the Charge	BF contribution from each type of packet	Percentage in charge	BF out of each TYPE of packet	Total number of boards required	Number of boards from each packet	Number of boards from each packet rounded	Rounded number of boards	Extra Boards Required	Total Number of Boards Pulled From Each Packet
Packet 2x4x8s	0	0	20	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x10s	1	4	16	39,040	25.0%	52.64	7.90	1.97	2	8	1	9
Packet 2x4x12s	1	4	12	46,848	30.0%	63.17	7.90	1.97	2	8	1	9
Packet 2x4x14s	0	0	10	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x16s	1	2	10	31,232	20.0%	42.11	3.95	1.97	2	4	1	5
Packet 2x4x18s	0	0	8	0	0.0%	0.00	0.00	0.00	0	0	0	0
Packet 2x4x20s	1	2	8	39,040	25.0%	52.64	3.95	1.97	2	4	1	5
TOTAL ==>	4	12		156,160	100.00%	210.56	23.69			24		28

	Percentage in charge	CALCULATED Number of samples for each MSU Charge using 24 inch pieces	CALCULATED Number of samples for each MSU Charge using 48 inch pieces	CALCULATED No. of samples for each OSU Charge 48 inch pieces	Calculated Percent MSU	Calculated Percent OSU	ADJUSTED Number of samples for each MSU Charge using 24 inch pieces	ADJUSTED Number of samples for each MSU Charge using 48 inch pieces	ADJUSTED No. of samples for each OSU Charge 48 inch pieces	ADJUSTED Percent MSU	ADJUSTE Percent OSU	ADJUSTED Number of 48 inch pieces needed	Have enough?
Packet 2x4x8s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x10s	25.0%	6.0	3.00	7.5	24.5%	25.0%	6.0	3.00	7.50	24.0%	25.0%	21.0	YES
Packet 2x4x12s	30.0%	7.5	3.75	9.0	30.6%	30.0%	8.0	4.00	9.00	32.0%	30.0%	26.0	YES
Packet 2x4x14s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x16s	20.0%	5.0	2.50	6.0	20.4%	20.0%	5.0	2.50	6.00	20.0%	20.0%	17.0	YES
Packet 2x4x18s	0.0%	0.0	0.00	0.0	0.0%	0.0%	0.0	0.00	0.00	0.0%	0.0%	0.0	
Packet 2x4x20s	25.0%	6.0	3.00	7.5	24.5%	25.0%	6.0	3.00	7.50	24.0%	25.0%	21.0	YES
	100.0%				100.0%	100.0%				100.0%	100.0%		
	Total boards	24.5		30.0			25.0		30.0		Sum	85.0	YES
Is this the right configuration?		NO, too few		YES			YES		YES				

APPENDIX H

STANDARD VOC SAMPLING PROTOCOL

STANDARD PROTOCOL FOR THE VOC CONCENTRATION MEASUREMENT METHOD FOR THE LUMBER KILN SUPPLEMENTAL ENVIRONMENTAL PROJECT

1. Introduction

This sampling method is written specifically for lumber kilns participating in the Lumber Kiln Emission Study being conducted by Georgia-Pacific Corporation (G-P) and the National Council for Air and Stream Improvement, Inc. (NCASI). The intent of this method is to establish a standard volatile organic compound (VOC) sampling protocol to reduce the variability in sampling methodologies used by the participants of this study.

This sampling protocol will address the equipment requirements, sampling methodology, and calculation procedures to yield a VOC mass emission rate from a lumber kiln drying southern pine. This protocol also includes methodology for determining the moisture content of the exhaust gas from the kiln (for this protocol only). Measurement methods for ambient temperature and barometric pressure will be traced to NIST standards. A measurement method for determining the exhaust flow rate has not been included in this document and must be approved by NCASI.

This method is a modification of the Environmental Protection Agency's (EPA) Method 25A-*Determination of Total Gaseous Organic Concentration Using A Flame Ionization Analyzer* (1). The modifications that appear in this protocol have been directly incorporated into the text of EPA Method 25A. The modifications are primarily intended to (1) specify equipment or operating parameters that are optional or loosely specified in Method 25A, (2) specify procedures for kiln testing, and (3) reduce the number of procedures, materials, and equipment that increase the cost of sampling yet result in minimum benefit.

The two major modifications included in this protocol are the requirement of a sample dilution system and the requirement to perform a total system leak check. The measurement system described in this protocol is intended to reduce the interference at the VOC analyzer caused by sampling high moisture gas streams, such as those exhausted from lumber kilns.

The primary modifications of Method 25A are:

(1) requirement of heated components, including a heated filter
(2) leak check procedure
(3) establish the types of and concentrations for the calibration gases
(4) requirement for dilution of the sample stream to a moisture content of 10 to 20% or less moisture (by volume)
(5) simplified three-point undiluted calibration procedure
(6) a two-point diluted calibration check
(7) field data sheet (see Appendix 1)

2. Applicability and Principle

2.1 **Applicability** - This method is designed to provide a measure of the total concentration of carbon atoms in the exhaust gas of a lumber kiln. This method, as well as EPA Method 25A, accurately measures alkanes, alkenes, and/or arenes in low moisture gases. The measurement of the compounds in these classes is typically based on instrument calibration with an alkane gas of known concentration. This method and Method 25A do not quantitatively measure fully-oxidized-carbon atoms such as the carbon atom in a carbonyl or carboxyl group or carbon atoms in which hydrogen is substituted by a halogen, amine, or hydroxyl group (2).

2.2 **Principle** - A diluted gas sample is extracted from the source through a heated probe, heated filter, heated sample line and, if necessary, additional heated components to a volatile organic compound (VOC) analyzer that utilizes a flame ionization detector (FID) for measurement of total organic compounds.

The results are to be reported in several ways:

- for each sampled time increment (e.g. per minute): pounds of VOC, expressed as carbon, per sampled time increment (e.g. lbs VOC as carbon/min) and thousand board feet of lumber dried (e.g. lbs VOC as carbon/MBF/min);
- for each hour lbs VOC as carbon/hr and lbs VOC as carbon/MBF/hr;
- for each 3-hour sample run lbs VOC as carbon/3-hr sample run and lbs VOC as carbon/MBF/3-hr sample run;
- for the entire kiln cycle lbs VOC as carbon/MBF/kiln cycle.

3. Definitions

3.1 **Measurement System** - The total equipment required for the determination of the concentration VOC as propane in the exhaust gas of a dry kiln.

3.2 **Moisture Content** - Moisture content is used to designate the amount of moisture in a gas being sampled. Specifically, the moisture content of a gas will be the standard volume of the water vapor divided by the combined standard volumes of the dry gas and water vapor. The moisture content is then expressed as the percent moisture by volume. This project will be concerned with the moisture content of the air at three locations: inside the kiln, the kiln exhaust gas, and the sample gas as it enters the VOC analyzer. Additional background information on moisture content is provided in Appendix 2 of this protocol.

3.3 **Calibration Gas** - A gas with a known total hydrocarbon (THC) concentration in an air matrix. Calibration gases in a nitrogen matrix shall not be used. As specified within this method, the quality of calibration gases will range from the "Certified" level to EPA Protocol No. 1 level.

3.4 **Organic "Free" Air or Zero Air**- Air which has a total hydrocarbon (THC) concentration equivalent to or less than 0.1 percent of the span value. Nitrogen may not be used as organic-free air or zero air.

3.5 **Exhaust Gas** - The gas exiting through the vents or stacks of a dry kiln that will be sampled to evaluate the mass emission rate of VOC as carbon.

3.6 **Sample Gas** - A slipstream of the exhaust gas that will contain a representative organic concentration to be measured by a VOC analyzer. The sample gas will enter the measurement system through the sample probe tip and be diluted with organic "free" air. This procedure will lower the moisture content of the sample gas to the appropriate level specified by this protocol.

3.7 **Span Value** - A review of data from full-scale southern pine kilns indicates that a span value of 3000 parts per million by volume (ppmv) VOC expressed as propane would provide a reasonable span value. Small-scale kiln operators may have data from past VOC testing on southern pine lumber which may be used to determine a target span value. If such data are to be used, then the span value shall be no less than the maximum average concentration for any 30 minute time period and shall be approved for use by NCASI.

3.8 **Zero Drift** - The difference in the measurement system's response to zero calibration gas before and after a stated period of operation during which no unscheduled maintenance, repair or adjustment took place.

3.9 **Mid Drift** - The difference in the measurement system's response to a mid level calibration gas before and after a stated period of operation during which no unscheduled maintenance, repair or adjustment took place.

3.10 **Span Drift** - The difference in the measurement system's response to the highest level calibration gas before and after a stated period of operation during which no unscheduled maintenance, repair or adjustment took place.

3.11 **Calibration Error** - The difference between the gas concentration indicated by the measurement system and the known concentration of the calibration gas.

3.12 **Sample Event** - For the purposes of this method, a sample event refers to the process of sampling over the entire duration of the lumber drying cycle. The sample event will be divided into discrete sample runs.

3.13 **Sample Run** – A sample run is a sample collection period preceded and followed by quality assurance checks as specified in Section 8. For the purposes of this method, a discrete sample run shall have a maximum time interval of 3 hours and a minimum time interval of one hour. NCASI recommends that the time period of the sample run correspond to the sampling crew's confidence in their instruments' ability to remain in calibration.

4. Measurement System

The configuration of the measurement system for this method will depend on the length of the heated sample line. Figure 1 shows the measurement system for facilities requiring a heated sample line that is greater than 50 feet in length. A simplified measurement system is shown in Figure 2 for facilities using a heated sample line that is 50 feet or less. The intent of these schematics are to provide the sampler with an idea of the main components involved with these two measurement systems. The actual configuration of the measurement system for each small-scale kiln may vary somewhat because of the different sampling

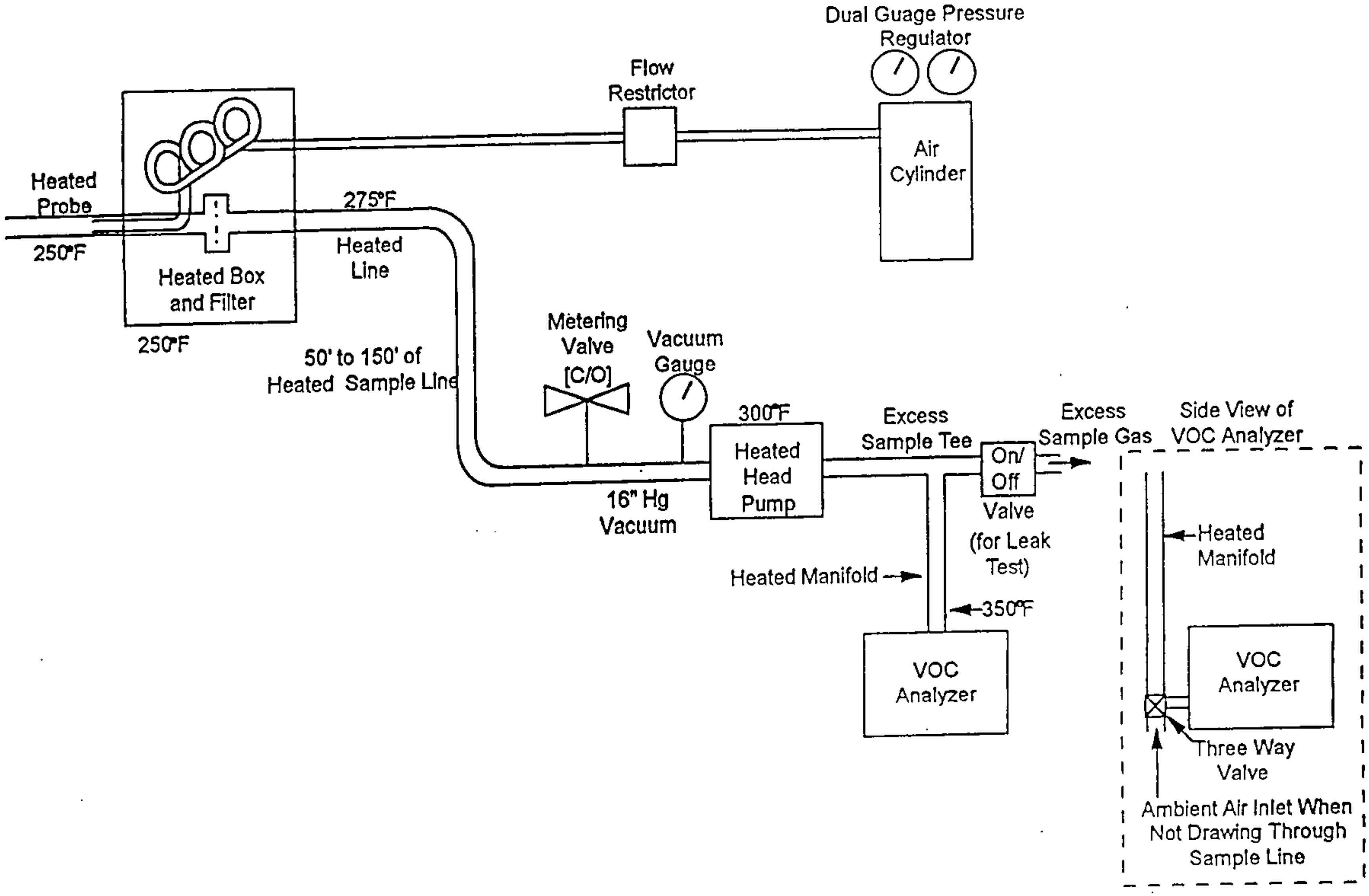


Figure 1. VOC Measurement System for Heated Sample Lines Greater than 50 ft.

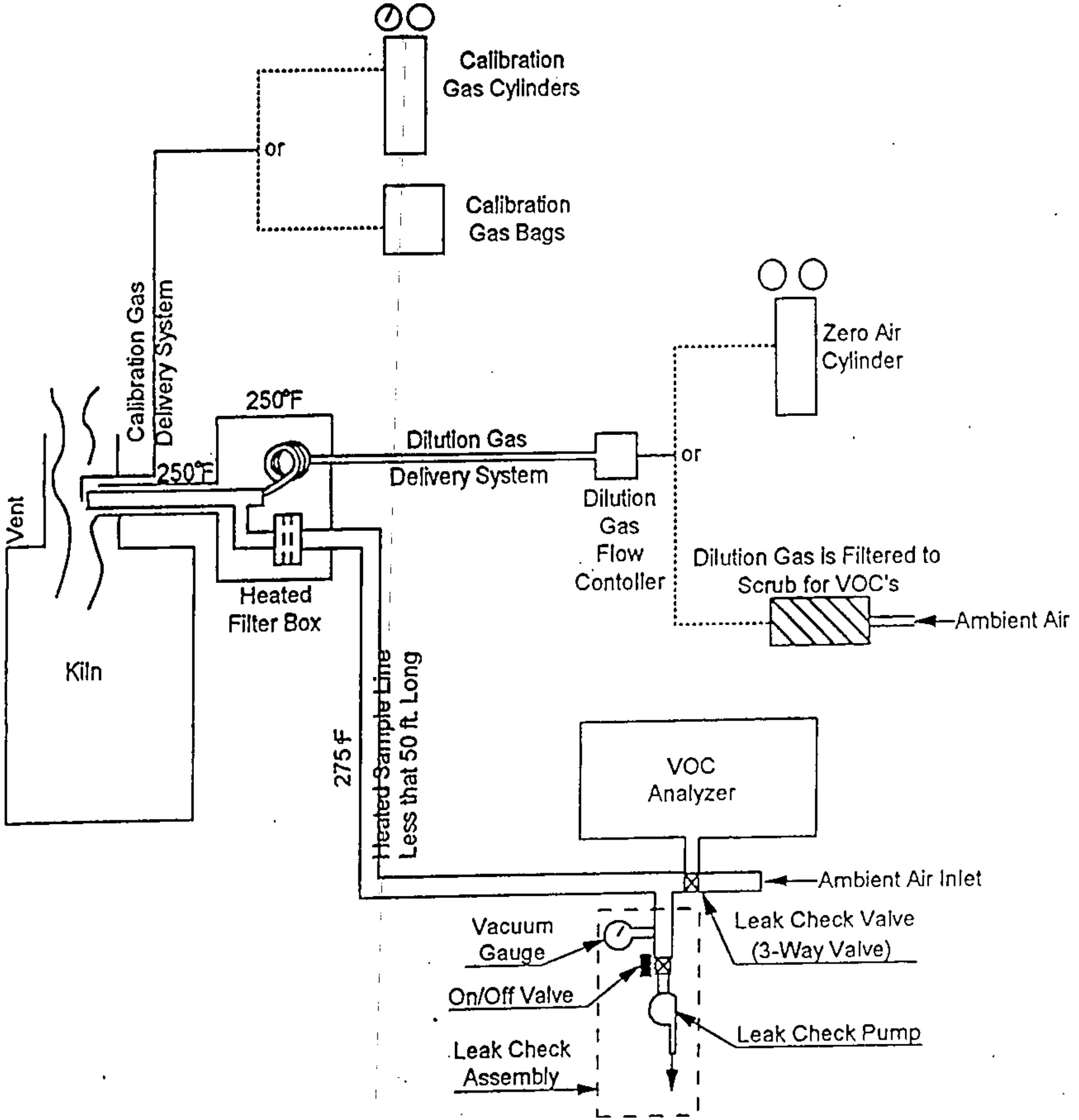


Figure 2. VOC Measurement System for Heated Sample Lines Less than 50 ft.

environments and types of kilns. Each participating facility shall inform NCASI of the proposed measurement system to be used in this study.

The essential components of the approved measurement system are described below beginning with the inlet to the system:

4.1 **Calibration Gas Delivery System** - Calibration gas shall be introduced at the sample probe tip of the measurement system. This optimum introduction location will ensure that the calibration gases are measured under the same conditions as the sample gas. Calibration gases may be introduced into the measurement system by calibration bags, from a compressed gas cylinder, or another method with approval from NCASI. The introduction of calibration gases shall be done with caution to ensure that additional pressure is not exerted on the measurement system. The two recommended calibration gas delivery systems shown in Figure 2 are described below:

4.1.1 **Calibration Bags** - The calibration bag shall attach to the sample probe in a leak free manner. The material of the calibration bags shall be made of Tedlar® or an equivalent material. NCASI has found that under certain conditions some calibration bag materials emit low levels of VOCs. Therefore, it is recommended that all calibration bags be cleaned and tested for contamination prior to use in order to achieve accurate concentration responses.

4.1.1.1 **Calibration Bag Cleaning Procedure** - The cleaning procedure involves inflating the calibration bag with zero gas or nitrogen gas and then evacuating the calibration bag. It is recommended that this procedure be repeated at least two times. The calibration bag will now be considered ready to be inflated with the appropriate calibration gas for either a contamination test or a calibration drift check.

4.1.1.2 **Calibration Bag Contamination Test** - To conduct the contamination test, fill the calibration bag with zero gas. With the VOC analyzer properly configured, zero the instrument to ambient air. Then obtain a response from the zero gas in the calibration bag and compare it to the VOC analyzer's response to ambient air. If the response for the calibration bag is higher than for ambient air, then the calibration gas bag is emitting low levels of VOCs and should not be used. If the response from the FID for the zero gas is equivalent or lower than for ambient air, then the calibration gas bag is deemed acceptable for use in this method.

4.1.2 **Calibration Gas From Compressed Cylinders** - Special care must be taken to avoid pressurizing the measurement system when using this option as a calibration gas delivery system. A majority of the manufacturers of VOC analyzers indicate that bias responses will result from measurement systems which are pressurized above ambient conditions. In general, this means that a "tee," or other configuration, will have to be placed on the probe tip to allow for the venting of excess calibration flow.

4.2 **Dilution Gas Delivery System** - The dilution gas delivery system shall be able to deliver organic "free" air to the measurement system. The purpose of the dilution system is to lower the percent moisture by volume of the gas being sampled. Two recommended dilution systems for kiln testing are shown in Figure 2. Refer to Appendix 1 for additional information regarding the dilution system.

A flow rate controller and a shut off valve shall be installed in the delivery line to regulate the amount of dilution air entering the measurement system. The flow controller will also serve as a visual aid during sampling to detect any changes in the flow rate of the system.

The dilution gas shall be heated to 250°F prior to mixing with the sample gas. Both Figures 1 and 2 show a method of preheating the dilution gas by coiling a section of the delivery line in the heated filter box. Ambient air may suffice for dilution gas if it can be filtered to meet the specifications of this method.

4.3 **Sample Probe** - Probe material shall be made of stainless steel, Teflon®, or another equivalent material approved by NCASI. The probe shall be a single opening type probe, a rake type probe, or of another design approved by NCASI. The sample probe shall be maintained at a temperature of 250°F (± 25°F) throughout both the calibration process and the sample event.

4.4 **Sample Filter Box** - The sample filter box contains the filter housing, the coil for preheating the dilution gas, a thermocouple, and a heater capable of reaching 250°F (± 25°F). The filter housing shall be constructed of stainless steel or an approved equivalent material. The inlet of the filter housing shall have a leak-free connection with the sample probe. The outlet of the filter housing shall have a leak-free connection with the heated sample line. The sample filter box shall be constructed of a durable material and insulated to maintain the filter housing and the coil used for sample dilution at a temperature of 250°F (± 25°F) during the calibration process and sample event.

4.5 **Particulate Filter** - A Teflon®, sintered stainless steel, or glass fiber filter must be used. The filter must be supported such that it does not tear and must be maintained at 250°F (± 25°F) during the calibration process and sample event.

4.6 **Heated Sample Line** - Teflon® tubing or stainless steel tubing must be used to transport the sample gas to the VOC analyzer. The sample line is required to be heated to an operational temperature of 275°F (± 25°F) to prevent condensation in the sample line during the calibration process and sample event.

4.7 **Heated Head Pump** - An optional heated external pump is only shown in Figure 1 for measurement systems with heated sample lines greater than 50 feet in length. Some VOC analyzers require the external heated head pump to maintain a constant sample pressure at the inlet to the VOC analyzer when the heated sample line is too long. This pump must have a heated head maintained at a temperature of 300°F (± 25°F) during the calibration process and sample event.

4.8 **Heated Excess Sample Tee and Manifold** - The sample-tee is simply a means of venting sample gas in excess of that required by the analyzer and is only shown in Figure 1. The heated manifold maintains the slip-stream sample not exhausted from the sample-tee at an elevated temperature. Both the excess sample-tee and the manifold shall be maintained at a temperature of 325°F (± 25°F) during the calibration process and sample event.

4.9 **Leak Check Assembly** - For measurement systems with heated sample line lengths of 50 feet or less, one method for leak checking the measurement system is shown in Figure 2. This Leak Check Assembly consists of a vacuum gauge capable of reading 20 in. Hg vacuum, an on/off valve, and a pump capable of drawing a 15 in. Hg vacuum. The pump in this configuration does not contact the sample gas entering the VOC analyzer. All other leak check methods for measurement systems with sample lines less than 50 ft. must be approved by NCASI.

4.10 **Leak Check Valve** – This 3-way valve connects the heated manifold to the inlet of the VOC analyzer. The purpose of this 3-way valve is to allow for the continued operation of the analyzer during the measurement system leak-check. The Leak Check Valve is shown in both Figures 1 and 2. During a leak check, the valve will be open to the ambient air side of the valve and closed to the heated line side of the valve. During sampling, the valve will be open to the heated line side of the valve and closed to the ambient air side of the valve.

4.11 **Volatile Organic Compound (VOC) Analyzer** - That portion of the system that contains the sensor for the organic content of the exhaust gas and will generate an output proportional to the total gas concentration in parts per million wet by volume. A flame ionization detector (FID) is used as the sensor.

4.12 **Data Recorder** - A data storage or recording system capable of storing or recording the response signals from a VOC analyzer. If a datalogger type system is used, the minimum data acquisition interval shall be one measurement value per minute. NCASI recommends the use of a chart recorder as a data backup system when the primary data recorder is a datalogger.

5. Calibration and Other Gases

5.1 **Fuel for the VOC Analyzer** - The fuel for the FID shall be hydrogen or hydrogen/ helium mixture as specified by the manufacturer.

5.2 **Zero Gas** – Shall be the calibration gas with the lowest level of THC, specifically a THC concentration less than 1.0 ppmv expressed as propane. Zero gas is used to establish a zero point for calibration and for kiln exhaust gas dilution.

The quality of the zero gas shall be at the Certified level or above as appropriate to establish a confident zero reference point for the measurement system. Nitrogen may not be used as zero air.

5.3 **Mid Gas** - The calibration of the measurement system will be done with a minimum of one calibration gas containing a concentration of propane in air equivalent to 30 to 50 percent of the applicable span value. If a span value of 3000 ppmv propane is used, then, at the minimum, one mid level gas concentration in the range of 1000 ppmv to 1500 ppmv propane shall be used.

The quality of the mid gas shall be at the Certified level or above. If a level of gas quality other than an EPA Protocol No. 1 gas is to be used, then the mid gas concentration shall be "named" by following the "naming" procedure in Appendix 3.

5.4 **Span Gas** - The calibration gas with a concentration of propane equivalent to the span value (see Section 3.7). The span gas shall be an EPA Protocol Gas in an air matrix.

The introduction of span gas to the measurement system is intended to provide the VOC analyzer with an upper limit point of reference. The peak sample gas concentrations expected during the sample event should ideally fall below the span gas concentration. Data will be considered invalid if the average of the peak sample concentrations over a 30 minute period exceeds the span gas concentration. The invalid data must be flagged in the report.

5.5 **Dilution Gas** – Organic "free" air with a THC concentration (expressed as propane) equivalent to or less than 0.1 percent of the span value. Dilution gas can be either zero air or ambient air that has been filtered to reduce the THC content to the specified limit. The dilution gas is used to dilute the sample stream to a maximum moisture content of 10 to 20 percent by volume.

6. Moisture Content Ratio

The purpose of this section is to define the parameters required to calculate the Moisture Content Ratio (MCR). The MCR will be used in Section 8 of this method to calculate the target sample flow rate and the target dilution flow rate. If the MCR is calculated to be less than 1.0, then the sample gas shall be diluted.

To calculate the MCR use the following equation:

$$MCR = \frac{MC\_L(\%)}{MC_{MAX}(\%)}$$

MC_{max} = The highest moisture content observed in the kiln exhaust gas during the drying of a representative southern pine lumber charge as ascertained by the wet bulb/dry bulb temperature method described in Appendix 2 of this protocol, by EPA Method 4, or an alternate method approved by NCASI.

MC_L = Moisture Content Limit is defined as the maximum allowable moisture content in the diluted sample gas reaching the VOC analyzer. Use the following values for MC_L corresponding to the type of VOC analyzer being used:

MC_L for TECO VOC analyzers = 10%
MC_L for JUM VOC analyzers = 20%
MC_L for all other analyzers = 10%

7. Preparation for the Sample Event

7.1 Sampling Locations

7.1.1 **Small-Scale Kilns**- Small-scale kilns may require modification in order to conduct VOC emission testing according to this protocol. Modifications may include a "stack" which incorporates well designed sampling ports. Because of this, a criteria for the selection of a sampling location(s) will not be provided in this method. The sample location for each small-scale kiln will be evaluated by NCASI. NCASI will also be assessing the means by which air flow rate, temperature, and moisture are measured.

7.1.2 **Large-Scale Kilns**- The large-scale kilns selected for participation in the GP/NCASI Lumber Kiln SEP will have the exhaust gases channeled to one or two emission points. These emission points will be stacks with sturdy access scaffolding and one or two sample ports. The sample location(s) will be at the sample port(s) of the stack(s).

7.2 **Setup** - Assemble the approved measurement system so that the sample probe is located at the sample location, and the VOC analyzer is located in an area where it will be secure from the elements.

7.3 **Frequency of Leak-Checks** - Measurement systems must have a means of conducting a leak–check within two hours of the start of the sample event and again at the termination of the sample event. A leak check procedure other than described below must be approved by NCASI. Leak-check procedures and leak-check results must be discussed in the sampling report.

7.4 **Temperature of Measurement System During Leak-Checks** – The leak-check procedure shall be conducted when all of the measurement system's components have reached their appropriate operating temperatures. The measurement system can alternatively be leak-checked when the system is "cold" and then followed with a final leak-check at "operating temperature." The leak-check shall not, however, be conducted when the system's components are warming up.

7.5 **Leak-Check Procedure** – A leak check is conducted to insure the integrity of the measurement system. This quality assurance procedure will be followed prior to the first and after the last sample run of the sample event. The following leak check procedure is for the measurement system shown in Figure 2. Use this procedure as a guide for all other measurement systems.

7.5.1 Turn the Leak Check Valve open to ambient air. This will enable the VOC analyzer to remain ignited and at the same time close off the outlet end of the heated sample conveyance components.

7.5.2 Close off all inlets to the measurement system at the heated filter box. The inlets could include the sample probe and the inlet ports for the ambient air, the dilution gas, and calibration gases.

7.5.3 For the measurement system described in Figure 1: Turn on the Leak Test Valve at the Excess Sample Tee. Turn on the external heated head pump and draw a 15 in. Hg vacuum on the heated sample line and heated filter box.

7.5.4 For the measurement system described in Figure 2: Turn on On/Off Valve within the Leak Check Assembly. Use the Leak Check Pump to draw a 15 in. Hg vacuum on the heated sample line and heated filter box.

7.5.5 When the vacuum gauge reads the appropriate drop in pressure, turn off the on/off valve and the pump. Note the beginning and ending readings on the vacuum gauge over a 2-minute period. The system will be considered leak free when the difference in pressure loss at 15 in. Hg is equal to or less than 1-inch of Hg.

7.5.6 If the change in pressure is greater than 1-inch Hg., then investigate the cause of the leak, secure it, and return to Section 7.5.1. Proceed to Section 7.5.7 when the leak check has been successfully completed.

7.5.7 Release the vacuum on the system. Check that all documentation has been completed. This will be considered the end of the leak check procedure and the measurement system will be ready for calibration.

8. Measurement System Calibration and Drift Checks

The performance of the measurement system is gauged by the calibration test. The calibration test compares a series of known gas concentrations (zero, mid, and span gases), in ppmv propane in air, to the corresponding relative concentration output (response) shown by the VOC analyzer. This calibration test is conducted prior to and after each sample run.

Due to the variability of measurement systems expected to be encountered, the following is a general discussion on the calibration process. Significant deviations from the calibration process outlined below must be evaluated and approved by NCASI on a case-by-case basis.

8.1 **Pre-Sample Run Calibration Checks** - The pre-sample run calibration checks verify that the performance of the measurement system is operating properly prior to sampling. The various components of the measurement system are required to be at their respective operating temperatures for calibration.

8.1.1 **Initial Adjustment of the VOC Analyzer and Data Recorder to Zero Gas** - Introduce the zero gas to the measurement system and allow the system time to respond and stabilize. For this section only, follow the manufacturer's recommended procedure for adjusting the VOC analyzer's output to read "zero ppm." Remove the zero gas and allow the measurement system to stabilize to ambient air. Record the ambient air response. Introduce zero gas and allow the measurement system to stabilize. The response to the ambient air should be greater than or equal to the response to the zero air. If this is not the case, check for contamination at the zero air source, the calibration gas delivery system, or the measurement system.

When the VOC analyzer is zeroed, follow the manufacturer's recommended procedure for adjusting the data recorder's output to read "zero ppm." This procedure will synchronize the data recorder(s) with the output of the VOC analyzer. After synchronization has been completed, the measurement system will be ready for the next calibration procedure.

8.1.2 **Initial Adjustment of the VOC analyzer and Data Recorder to Span Gas** - Introduce the span gas to the measurement system and allow the system time to respond and stabilize. For this section only, follow the manufacturer's recommended procedure for adjusting the VOC analyzer's output to read the known span gas concentration.

When the VOC analyzer is spanned, follow the manufacturer's recommended procedure for adjusting the data recorder's output to read the span gas concentration. This procedure will synchronize the data recorder with the VOC analyzer. After synchronization has been completed, the measurement system will be ready for the next calibration procedure. For chart recorders, adjust the recorder scale and note the span value next to the response on the chart paper.

8.2 **Begin Pre-Sample Run Drift Checks** - Begin the recording of calibration data on the data recorder and document the beginning of the pre-sample run drift checks. Record the following information:

Date
Start Time
Sampling Location
Kiln No. & BF
Sample Event No.
Sample Run No.
Data Recorder Session No. (if applicable)
Span Gas Concentration
Span Gas Matrix

8.2.1 **Pre-Sample Run Zero Drift Check** - Introduce the zero gas to the measurement system and allow the system time to respond and stabilize. Verify that the response from the VOC analyzer indicates zero ppmv to within ±3% of the known span gas concentration. If this is not the case, return to Section 8.1.1.

Document the response from the VOC analyzer and, if applicable, the data recorder. Proceed to the next calibration procedure.

8.2.2 **Pre-Sample Run Mid Drift Check** - Introduce the mid gas to the measurement system and allow the system time to respond and stabilize. Verify that the response from the VOC analyzer is within ±5% of the span gas concentration. If this is not the case, do not adjust the VOC analyzer; however, check that the mid gas concentration has been named correctly. If the mid gas concentration has been reported correctly, then re-check the responses to zero, span and mid gases, respectively. If any of responses are not reading the correctly, then return to Section 8.1.1. Note that this method requires only one mid gas calibration point. Additional mid gases may be used to attain additional calibration points.

Document the response from the VOC analyzer and, if applicable, the data recorder. Proceed to the next calibration procedure.

8.2.3 **Pre-Sample Run Span Drift Check (Pre-[span])** - Introduce the span gas to the measurement system and allow the system time to respond and stabilize. Verify that the output from the VOC analyzer indicates the span gas concentration is within ±3% of the known span gas concentration. If this is not the case, return to Section 8.1.1. Document the response from the VOC analyzer and, if applicable, the data recorder. Proceed to the next calibration procedure.

8.3 **Measurement System Flow Rates** - The measurement of all flow rates shall be done by a calibrated method directly traceable to an NIST Standard or an applicable EPA Method. All components of the measurement system should be at their respective operating temperatures.

8.3.1 **Pre-Sample Run Measurement of Total Flow Rate (Pre-TFR)** – The Pre-TFR for a measurement system is the flow rate regulated by the sample pump within the VOC analyzer, a flow restrictor, or a flow rate meter. The Pre-TFR is measured at the sample probe tip with the dilution system turned *off*. If a flow meter is used as a regular, then it should not be adjusted during the sample run after the Pre-TFR has been established. Measure and record the flow rate five consecutive times. The measurements should be reasonably precise, indicating that the measurement system has reached a stable flow rate. The Pre-TFR will be equivalent to the average of the five recorded flow rates.

8.3.2 **Pre-Sample Run Measurement of Sample Flow Rate (Pre-SFR)** – The Pre-SFR of the measurement system is the flow rate of the sample gas measured at the probe tip with the dilution system *on*. Follow the steps below to measure the correct Pre-SFR (for background information concerning the dilution system and instrument response bias due to moisture, refer to appendices of this protocol):

Step 1: Calculate the Target Dilution Flow Rate (Target DFR) by the following the equation:

$$\text{Target-DFR} = \text{Pre-TFR} \times (1 - \text{MCR})$$

Step 2: Adjust the flow regulator on the dilution system to read the Target-DFR or place an inline flow restrictor rated for this flow rate. Turn the dilution system on.

Step 3: Calculate the Target-Pre-SFR by the following equation:

$$\text{Target-Pre-SFR} = \text{Pre-TFR} \times \text{MCR}$$

Step 4: Measure the flow rate at the probe tip. Adjust the flow rate of the dilution gas until the flow rate at the probe tip is within 10% of the Target-Pre-SFR.

Step 5: Record five consecutive flow rate readings at the probe tip and calculate the average of these readings. If the average flow rate is still within 10% of the Target-Pre-SFR, then this averaged value shall be the Pre-SFR.

Step 6: Record the flow rate of the dilution gas. The flow rate controller should not be adjusted for the remainder of the sample run.

8.4 **Measurement of Diluted Span (Pre-[span_d])** - Calculate the diluted concentration of the span gas, [calcspan]_d, expected by the following equation:

$$[\text{calcspan}]\_\text{d} = \text{Pre} - [\text{span}] \times \frac{\text{Pre} - \text{SFR}}{\text{Pre} - \text{TFR}}$$

Where: Pre-[span] = the undiluted known span gas concentration
Pre-SFR = the actual flow rate measured at the probe tip with the dilution system turned ON.
Pre-TFR = the actual flow rate measured at the probe tip with the dilution system turned OFF.

Introduce the span gas to the measurement system with the dilution gas delivery system *on* and allow the system time to respond and stabilize. Verify that the response from the VOC analyzer indicates that the actual [calcspan]_d is within ±3% of the span gas concentration.

If the response from the VOC analyzer is not within the specified tolerance, return to Section 8.1.7 to verify that the system flow rates have been calculated and measured properly. If the VOC analyzer requires re-calibration, return to Section 8.1.

When the VOC analyzer indicates the appropriate response, document that response from both the VOC analyzer and data recorder. Proceed to the next calibration procedure.

8.5 **End of Pre-Sample Run Measurements** – The measurement system shall be considered ready when the percent difference between the flow and concentration ratios is less than or equal to 10%.

$$\text{ABS}\left[\frac{\text{flow ratio} - \text{conc. ratio}}{\text{AVE (flow ratio, conc. ratio)}}\right] \leq 10\%$$

Where: Flow Ratio = (Pre-SFR/Pre-TFR)
Conc. Ratio = (Pre-[span_d]/Pre-[span])

If the 10% criterion has been met, proceed to Section 9. Otherwise, return to Section 8.1.4.

8.6 **Post-Sample Run Drift Checks** – A determination of the measurement system's accuracy after a sample run is made by post-sample run checks. No adjustments to the VOC analyzer's output should be made during these drift checks.

The calibration gases are required to be introduced at the probe tip during the calibration checks. Removal of the probe and heated filter box from the sample port may be required for some measurement systems. Measurement systems with alternative calibration methods will be approved on a case-by-case basis.

8.6.1 **Post-Sample Run Diluted Span Drift Check (Post-[span_d])** - Introduce the span gas to the measurement system with the dilution gas delivery system ***on*** and allow the system time to respond and stabilize. Document the response from the VOC analyzer and data recorder, if applicable, to the diluted span gas concentration. Compare the response to the [calcspan]_d (±3% of [span]). Remove the span gas from the probe tip.

8.6.2 **Post-Sample Run Measurement of SFR (Post-SFR)** – With the dilution system ***on***, measure and record the flow rate at the probe tip five consecutive times. The average of these flow rates will be the Post-SFR. Also record the dilution flow rate as indicated by the flow rate controller.

8.6.3 **Post-Sample Run Measurement of TFR (Post-TFR)** – With the dilution system *off*, measure and record the flow rate at the probe tip five consecutive times. The average of these flow rates will be the Post-TFR.

8.6.4 **Post-Sample Run Span Drift Check (Post-[span])** - Introduce the span gas to the measurement system with the dilution gas delivery system *off* and allow the system time to respond and stabilize. Document the response from the VOC analyzer and data recorder, if applicable, to the span gas concentration. Compare the response to the known [span] (±3% of [span]). Remove the span gas from the probe tip.

8.6.5 **Post-Sample Run Mid Drift Check** - Introduce the mid gas to the measurement system with the dilution gas delivery system *off* and allow the system time to respond and stabilize. Document the response from the VOC analyzer and data recorder, if applicable. Compare the response to the [mid] (±5% of [span]). Remove the mid gas from the probe tip. Repeat this step for any additional mid gas concentrations.

8.6.6 **Post-Sample Run Zero Drift Check** - Introduce the zero gas to the measurement system with the dilution delivery system *off* and allow the system time to respond and stabilize. Document the response from the VOC analyzer and data recorder, if applicable, to the zero gas. Compare the response to a value equal to within ±3 percent of [span]. Remove the zero gas.

8.6.7 **Completion of Post-Sample Run Checks** - End the recording of data and document the completion of the post-sample run checks with the following information. Calculate the percent difference between the flow (Post-SFR/Post-TFR) and concentration ratios (Post-[span_d])/Post-[span]). Proceed to Section 9.5.

Date
End Time
Sampling Location
Kiln No. & BF

Sample Event No.
Sample Run No.
Data Recorder Session No. (if applicable)

Span Gas Concentration
Span Gas Matrix

9. Sample Run Measurement Procedures

9.1 **Pre-Sample Run Procedures** - This section shall be followed after all of the pre-sample run calibration, drift and ratio checks have been conducted and documented as outlined in Sections 8.1 through 8.5.

9.1.1 If applicable, place the sample probe in the port at the sampling location and secure, as necessary, to remain in place for the remainder of the sample run.

9.1.2 Verify that the source being sampled is operating correctly and ready to be sampled.

9.1.3 Verify that all of the components in the measurement system are at their appropriate operating temperatures.

9.2 **Begin Sample Run** - Begin the sampling run by starting all data recording devices. Note the starting time on the data recorder device (where appropriate) and field data sheet. The duration of a sample run is defined in Section 3.13 of this method.

Use the attached Field Data Sheet to record any relevant information during the sample run. At periodic intervals record the time, temperatures of the measurement system components, and the responses from the VOC analyzer, primary data recorder, and secondary data recorder (if applicable).

9.3 **End Sample Run** - End the sampling run by recording the time of completion on the Field Data Sheet and all applicable data recording devices.

9.4 **Post-Sample Run Procedures** - This section shall be followed when the sample run has been completed. Proceed to Section 8.6 for post-sample checks.

9.5 **Final Leak Check** - <u>If additional Sample Runs are to be conducted, then bypass this section and proceed to Section 9.6</u>.

The measurement system shall be leak-checked after the final sample run of the sample event has been completed.

9.5.1 Turn the Leak Check Valve open to ambient air. This will enable the VOC analyzer to remain ignited and at the same time close off the outlet end of the heated sample conveyance components.

9.5.2 Close off all inlets to the measurement system at the heated filter box. The inlets could include the sample probe or the inlet ports for the ambient air, the dilution gas, and calibration gases.

9.5.3 <u>For the measurement system described in Figure 1:</u> Turn on the Leak Test Valve at the Excess Sample Tee. Turn on the external heated head pump and draw a 15 in. Hg vacuum on the heated sample line and heated filter box.

9.5.4 For the measurement system described in Figure 2: Open the On/Off Valve within the Leak Check Assembly. Use this Leak Check Pump to draw a 15 in. Hg vacuum on the heated sample line and heated filter box.

9.5.5 When the vacuum gauge reads the appropriate drop in pressure, close the on/off valve and turn off the pump. Note the beginning and ending readings on the vacuum gauge over a 2-minute period. The system will be considered leak free when the difference in pressure loss at 15 in. Hg is equal to or less than 1-inch of Hg.

9.5.6 If the change in pressure is greater than 1-inch Hg., then investigate the cause of the leak, secure it, and return to Section 9.5.1. Proceed to Section 9.5.7 when the leak check has been successfully completed.

9.5.7 When the leak check has been successfully completed, release the vacuum on the system and check that all documentation has been updated. Proceed to Section 9.6 if an additional sample run is to be conducted. Otherwise, this will be the endpoint for this Sample Event and the mass and production emission rates should be calculated. Section 10 of this method provides guidance for these calculations.

9.6 Preparation To Begin The Next Sample Run

9.6.1 **Sample Run Drift Checks** - Perform the following sample run drift checks to determine whether the measurement system was operating within the drift limits during the sample run:

Zero Drift Limit: 3% of [span] ≥ absolute value (Pre-zero response - Post-zero response)

Mid Drift Limit: 5% of [span] ≥ absolute value (Pre-mid response - Post-mid response)

Span Drift Limit: 3% of [span] ≥ absolute value (Pre-span response - Post-span response)

Diluted Span Drift Limit: 3% of [span] ≥ absolute value (Pre-zero response- Post-zero response)

9.6.2 **Preparation for Next Sample Run** - Proceed to Section 8.1.1 to commence the quality assurance checks for the next sample run.

10. Mass Emission Rate and Production Based Emission Rate Calculation

In order to calculate a mass emission rate, the exhaust flow rate from the kiln must be determined. Generally, this entails concurrent measurements of velocity and temperature in the same duct in which the VOC concentration is measured. As discussed in Section 1, this method does not designate the method for determining the exhaust flow rate from the kiln. NCASI will be reviewing the methods used on a case-by-case basis.

This protocol does, however, provide a standard calculation procedure for determining the mass emission rate of VOCs from a small-scale kiln and a full-scale kiln. The information is located in the appendices of this protocol and the accompanying electronic files. This method will still require that each participant provide a description of the means by which the exhaust flow rate was determined (and corrected to standard conditions), and all calculations required for determining mass emission rates (e.g. lbs VOC/hour) and production based emission rates (e.g. lbs VOC/MBF).

11. Bibliography

(1) "Method 25A – Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer," *Federal Register*, Volume 48, No. 161, p. 37595 (August 18, 1983).

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(3) Pallady, P. H. and P.J. Henley, *Chemical Engineering*, McGraw-Hill, Inc. (October 29, 1984).

CALCULATION PROCEDURE FOR DETERMINING THE VOC MASS EMISSION RATE

RE: Explanation of the calculation process for the mass emission rate of VOC for the **Standard Protocol for the VOC Concentration Measurement Method** **ONLY**.

Introduction

The intent of this document is to provide a standard method for calculating the average mass emission rate of VOC as carbon per MBF over three kiln charges. Please note that the method of calculation described below does not apply to the calculation of mass emission rates for formaldehyde and methanol.

There will be two calculation methods described below, one for the small-scale kilns and one for the full-scale kilns. Obviously, the sampler will use only one of the two equations depending on the type of kiln sampled. The parameters that are to be measured to compute each equation will be defined in the following discussion.

For Small-Scale Kilns: The mass emission rate equation for small-scale kilns assumes that the inlet air flow rate is dry and is equivalent to the dry flow rate exhausted from the kiln. The basis for this assumption is that the kilns have small internal volumes and that the kilns are generally operated under a slight positive pressure. The general VOC mass emission rate equation for small-scale kiln samplers will be:

$$\frac{\begin{array}{c}\text{lbs VOC}\\ \text{as carbon}\end{array}}{\text{time interval}}[i] = \frac{IR_{[i]}}{10^{\wedge}6} \times \frac{\text{Pre[span]} + \text{Post[span]}}{\text{Pre[span\_d]} + \text{Post[span\_d]}} \times \frac{3\ \text{carbons}}{1\ \text{propane}} \times \text{dacfm}_{[i]} \times \frac{527.67}{\left(459.67 + T_{[i]}\right)} \times \frac{\left(\frac{P_{\text{Pre}} + P_{\text{Post}}}{2}\right)}{29.92\ \text{in Hg}} \times \frac{100}{\left(100 - MC_{\text{kiln}[i]}\right)} \times \frac{1\text{lbmole}}{385.6\text{scf}} \times \frac{12\ \text{lbcarbon}}{\text{lbmole}}$$

This general equation can be modified to accommodate the use of a mass flow controller to measure the kiln inlet flow rate. If a mass flow controller is used and the controller standardizes the flow rate measurement to 32°F and 1 atm., then the following modified equation can be used:

$$\frac{\begin{array}{c}\text{lbs VOC}\\ \text{as carbon}\end{array}}{\text{time interval}}[i] = \frac{IR_{[i]}}{10^{\wedge}6} \times \frac{\text{Pre[span]} + \text{Post[span]}}{\text{Pre[span\_d]} + \text{Post[span\_d]}} \times \frac{3\text{carbons}}{1\text{propane}} \times \text{dscfm}_{32°\text{F},1\text{atm}[i]} \times \frac{527.67R}{491.67R} \times \frac{100}{\left(100 - MC_{\text{kiln}[i]}\right)} \times \frac{1\text{lbmole}}{385.6\text{scf}} \times \frac{12\text{lbcarbon}}{\text{lbmole}}$$

For Full-Scale Kilns with Two Emission Sources: The mass emission rate equation for full-scale kilns is different from the equation used by the small-scale kilns because the moisture content of the exhaust gas does not appear in the equation. Furthermore, two different parameters are required to be measured, the actual kiln exhaust flow rate on a wet basis and the exhaust gas dry bulb temperature. The full-scale kiln mass emission rate equation is shown below:

$$\frac{\text{lbs VOC as carbon}}{\text{time interval}}[i] = \frac{IR_{[i]}}{10^{\wedge}6} \times \frac{\text{Pre[span]} + \text{Post[span]}}{\text{Pre[span\_d]} + \text{Post[span\_d]}} \times \frac{\text{3 carbons}}{\text{1 propane}} \times \text{wacfm}_{[i]} \times \frac{527.67}{\left(459.67 + T_{db[i]}\right)} \times \frac{\left(\frac{P_{Pre} + P_{Post}}{2}\right)}{\text{29.92in Hg}} \times \frac{\text{1lbmole}}{\text{385.6scf}} \times \frac{\text{12lbcarbon}}{\text{lbmole}}$$

Theory

One of the main objectives of this SEP is to get a better estimate of the exhaust gas flow rate from a lumber kiln because this flow rate directly influences the mass emission rate. Samplers should not measure the kiln's flow rate prior to the Sample Run to obtain a representative flow rate to be used over the entire calculation process. In using one average flow rate, there would be no account for the periods of variable flow rate and changing mass emission rates. Therefore, the small-scale kiln operators participating in this study will be required to continuously measure the dry flow rate into their kilns. The full-scale kiln samplers, on the other hand, will be required to measure wet exhaust flow rate from the kiln using the shortest reasonable measurement intervals.

The flow rate measurements will then be combined with the VOC concentration measurements to yield the mass emission rate of VOC as carbon per thousand board feet (MBF) in a cost effective and simplified manner. This objective will be accomplished, in part, by following the calculation methodology presented in this attachment.

For a typical southern pine drying schedule, the dry kiln will operate in such a manner as to maintain a consistent relative humidity (RH) inside the kiln to facilitate the transfer of the moisture in the green lumber to the hot air passing over the lumber. In the dry kiln community, the amount of moisture in the air is referred to as RH, and moisture content is used to define the amount of moisture in the lumber. In the air sampling community, however, moisture content is typically used to designate the amount of moisture in a gas being sampled. Specifically, the moisture content of a gas will be the standard volume of the water vapor divided by the combined standard volumes of the dry gas and water vapor. The moisture content is then expressed as the percent moisture content by volume. This protocol will be addressing the moisture content of sample gas stream originating from inside the small-scale kilns and from the full-scale kiln exhaust gas.

The moisture content of the sample gas stream can affect the calculation of an accurate mass emission rate for VOCs because it can vary from 10% to as high as 50% during a typical drying cycle. The research conducted at NCASI indicates that sample gases containing high levels of moisture tend to bias the responses generated by certain VOC analyzers. To minimize this bias, the standard VOC protocol has incorporated a dilution system that uses dry, organic "free" air to bring the moisture content of a sampled gas stream to an acceptable level. By operating the dilution system to handle the highest expected moisture content, the sample gas stream will not cause a significant bias in the VOC analyzer's response. This is an important point that the sampler should recognize. For a sample gas with a fixed wet VOC concentration, the analyzer's response should remain the same when the moisture content of the sample gas decreases from the highest recorded level and the calculated dilution ratio remains the same. This will be the case because the response is on a wet volume basis.

To calculate the mass emission rate of VOCs from the lumber kiln, the diluted analyzer response will be "adjusted" to the undiluted concentration of the kiln exhaust gas by using a dilution ratio. The source gas concentration will then be combined with the kiln's wet exhaust flow rate to obtain the wet mass emission rate. By basing the mass emission rate on a wet basis, the changes in the moisture content of the exhaust gas can be neglected as long as the calculations are done with both the measured wet undiluted VOC concentration and the wet exhaust gas flow rate.

The standard conditions for this calculation method have been established to be 68°F and 1 atmosphere (atm). As previously mentioned, some small-scale kiln samplers use mass flow controllers to measure the inlet air to the kiln. The equation provided for this situation assumes that the measurements yielded by mass flow controllers are standardized to 32°F and 1 atm. If this is not the case, then the equation provided will require modification.

The method for measuring the wet exhaust flow rate from the full-scale kilns will be reviewed by NCASI for approval. Ideally, the kiln exhaust flow rate should be recorded at the same time as the VOC concentration. The standard methods available for measuring this parameter from an exhaust stack, however, are limited by the flow rate measurement options and the frequency of which these measurements can be taken.

Definitions

Exhaust Gas - The gas exiting from the dry kiln either through a vent or stack that will be evaluated for the mass emission rate of VOC as carbon. As related to small-scale kilns, the moisture laden gas inside the kiln will assume to represent the exhaust gas leaving the kiln.

Sample Gas - A slipstream of the exhaust gas that will contain a representative organic concentration to be measured by a VOC analyzer. The sample gas will also contain the same amount of moisture vapor as the exhaust gas. The sample gas will enter the measurement system through the sample probe tip and be diluted with organic "free" air to limit its moisture content.

$MC_{kiln[i]}$ - The percent moisture content by volume of the exhaust gas at time [i] or over a sampled period. This parameter may be calculated from the wet/dry bulb method provided in this protocol, by EPA Method 4, or by an alternate method approved by NCASI.

MC_L - The Moisture Content Limit for various types of analyzers. For this project, a MC_L refers to the maximum allowable moisture content in the sample air that reaches the flame ionization detector (FID) within the analyzer. For example, if a JUM analyzer is to be used in this project, then the value of the MC_L shall be 20% moisture by volume at the inlet to the analyzer in order not to create a significant moisture bias in this analyzer's response. For all other types of analyzers, the MC_L shall be 10% moisture by volume at the inlet to the analyzer.

MC_{max} -	The highest percent moisture content in the exhaust gas achieved while drying a representative charge of southern pine lumber at a particular kiln. Two wet/dry bulb profiles from a steam kiln (Figure 1) and a direct-fired kiln (Figure 2) have been included to help with the explanation of this term. Although both of these profiles are not technically the moisture profiles for the exhaust gas from the kiln, they can illustrate the meaning of MC_{max}. For example, the wet/dry bulb profile in Figure 1 shows that the moisture content of the kiln gas has a MC_{max} equivalent to 40% as indicated by the four sample points. Similarly, Figure 2 has a MC_{max} of 44% as indicated by the six sample points on that diagram. For both small-and full-scale kilns, MC_{max} shall be determined prior to the sampling effort. The MC_{max} shall be based on the wet/dry bulb profile of the kiln schedule.
MCR -	The Moisture Content Ratio. This ratio compares the MC_L to the MC_{max} and will be used to determine the appropriate dilution of the sample gas.

Measured Parameters

Sample Lumber for Full-Scale and Small-Scale Kilns

For this SEP, NCASI will be sampling six direct-fired and six indirect-fired full-scale lumber kiln charges. NCASI will extract from each full-scale kiln charge enough lumber to make at least one charge for each small-scale kiln. NCASI will implement measures to provide statistically equivalent lumber samples to each of the small-scale kilns.

Small-Scale Kilns

Inlet parameters for small-scale kilns with mass flow controllers: The only inlet parameter to be measured will be the flow rate. The sample interval for the inlet flow rate shall be determined by NCASI based on the capability of the sampler's data acquisition system.

"Outlet" parameters for small-scale kilns: The two "outlet" parameters will not be measured at the outlet of the kiln, instead, the two parameters will be measured inside the kiln. The two parameters will be the internal kiln moisture content, by volume, and VOC concentration. Both parameters will be continuously monitored and recorded at the same time as the inlet parameters.

Ambient parameters for small-scale kilns: The two ambient parameters that will be measured are the ambient temperature and barometric pressure.

FIGURE 1: STEAM KILN MOISTURE PROFILE

Kiln No. 2 Run: 17 CONSTANT WB 8/4 - TRIAL 2
Start Time: Thu May 19 05:56:39 1994.   Finish Time: Fri May 20 03:24:56 1994
Auto Shutdown: MC 18.40 Mult 1.60   TDAL 11.50 Stm Usage 301,856

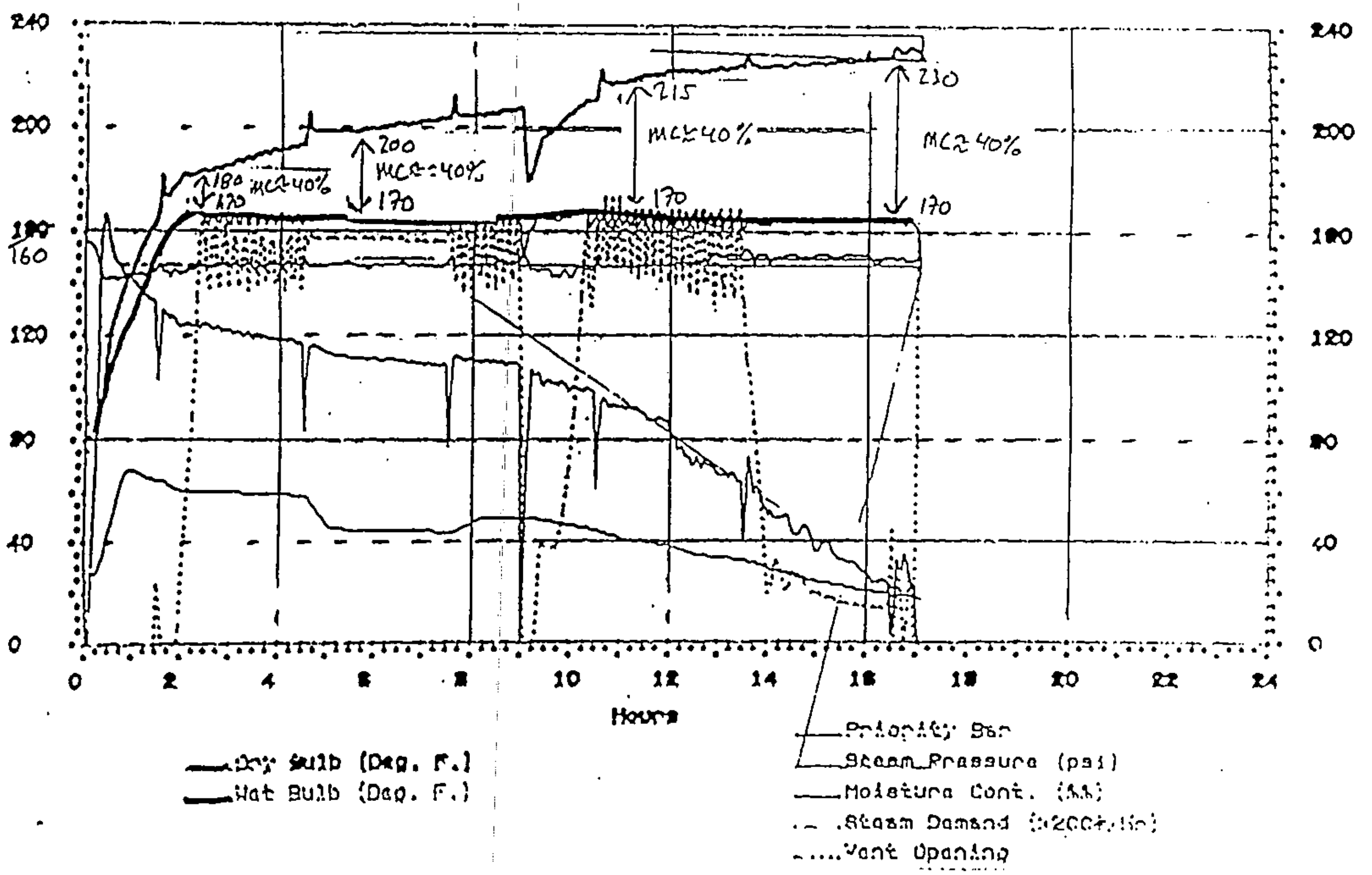
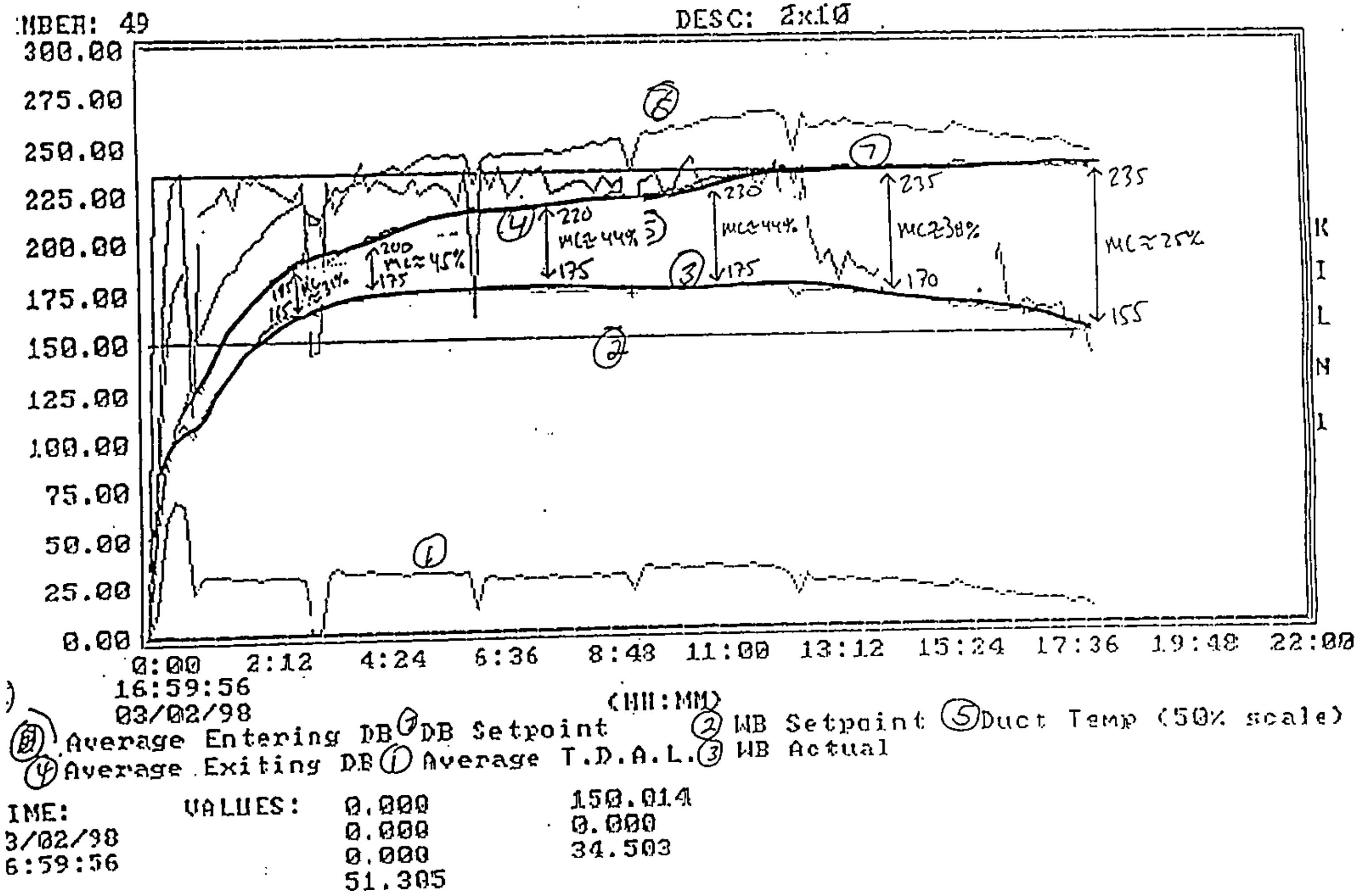


FIGURE 2: DIREZT FIRED KILN MOISTURE PROFILE



Full-Scale Kilns

Outlet parameters for full-scale kilns: The three exhaust gas parameters that will be recorded are the wet actual flow rate, the dry bulb temperature, and the VOC concentration. Ideally, all three of these parameters should be recorded at the same time to accurately monitor changes in exhaust gas, however, this may not be possible due to the limitations of collecting the flow rate data. At the minimum, the VOC concentration and dry bulb temperature of the exhaust gas will be recorded every minute. The recording interval of the wet flow rate will depend on the measurement method used.

Ambient parameters for full-scale kilns: The two ambient parameters that will be measured are the ambient temperature and barometric pressure. The measurement of these two parameters will be taken at the beginning of each Sample Run and at the end of each Sample Run.

Calculation of Moisture Content by Volume

For Small-Scale Kilns: The small-scale kilns will calculate the moisture content, by volume, of the gas inside the kilns from the wet and dry bulb temperatures by the following two steps:

Step 1: Calculate the Partial Pressure of Water Vapor Below The Saturation Point

Overall Equation (derived from equation referenced below[1]):

$$PP_{wv} = \left[P_c \times 10^{K_w \times (1 - T_c/T_w)} - \left\{ 0.000367 \left[1 + \left(\frac{t_w - 32}{1{,}571} \right) \right] \times P_{amb} \times (t_d - t_w) \right\} \right] \times \left(\frac{1\,\text{inch Hg}}{25.4\,\text{mm Hg}} \right)$$

Where:
PP_{wv} = Partial pressure of water vapor below the saturation point, in Hg
P_c = The critical pressure of water, 166,818 mm Hg
T_c = The critical temperature of water, 1,165.67°R
T_w = Wet-bulb temperature, °R
t_w = Wet-bulb temperature, °F
t_d = Dry-bulb temperature, °F
P_{amb} = Ambient pressure, mm Hg
K_w = Temperature dependent parameter, dimensionless equation shown below:

$$K_w = (-8.833E-10) \times T_w^{\,3} + (3.072E-06) \times T_w^{\,2} - (3.469E-03) \times T_w + 4.39553$$

---

[1] Pallady, P. H. and P.J. Henley, *Chemical Engineering*, McGraw-Hill, Inc. (October 29, 1984, p. 117).

Step 2: Calculate the Percent Moisture Content, by Volume

$$\%MC = \left(\frac{PP_{ww}}{P_{amb}} \right) \times 100$$

For Full-Scale Kilns: The determination of the moisture content of the exhaust gas from the full-scale kiln stacks will depend on the type of method used. If the wet/dry bulb temperatures are recorded simultaneously with the VOC measurement, then the moisture content will be calculated by the same method described for the small-scale kilns. If EPA Method 4 is used, then the moisture content of the exhaust gas will be determined on an hourly basis. All other methods will be reviewed for approval by NCASI.

Calculation of the Dilution Ratio

A dilution ratio will be used to "adjust" the wet diluted VOC response at the analyzer to the wet undiluted VOC concentration in the source gas. A dilution ratio for each Sample Run will be calculated and applied to the VOC data recorded over that time period.

Calculate the dilution ratio by the following three steps: (1) compute the ratios described in Sections 8.5 (Pre-) and 8.6.7 (Post-) of this Protocol, (2) determine the average of the ratios from step 1, and (3) compute the reciprocal of calculated average.

The dilution ratio can also be determined by a one step computation:

$$\frac{(\text{Pre[span]} + \text{Post[span]})}{(\text{Pre[span\_d]} + \text{Post[span\_d]})}$$

Calculation of the Mass Emission Rate Per Sampled Increment for Small-Scale Kilns

Step 1: The conversion of the measured wet diluted VOC instrument response ($IR_{[i]}$) to the calculated undiluted wet stack concentration, $SC_{[i]}$

The VOC analyzer will generate a response in terms of propane for the wet diluted sample gas entering the VOC analyzer. This response should be considered to have no moisture interference because the sample gas will be at or less than the analyzer's MC_L. The response, however, will be a diluted reading at the analyzer. The undiluted response for the source gas can be calculated by using the dilution ratio. Furthermore, the response shall be converted from a propane reading to a carbon reading by the ratio of 3 carbon atoms to one propane molecule. The calculation for this step is shown below:

$$SC_{[i](wet)} = IR_{[i]\,(wet,\,propane)} \times \frac{(\text{Pre[span]} + \text{Post[span]})}{(\text{Pre[span\_d]} + \text{Post[span\_d]})} \times \frac{3\ \text{carbons}}{1\ \text{propane}}$$

Step 2: The conversion of the measured inlet air flow rate to a standard wet exhaust flow rate for each incremental sampling period

This calculation procedure will assume that the inlet air is dry and the flow rate is measured in standard (32°F, 1 atm.) cubic feet per minute ($\text{dscfm}_{32°F[i]}$). This standard dry flow rate will be converted to the standard conditions as defined by this protocol. The "exhaust" flow rate from the small-scale kilns will be made up of the dry inlet air plus the moisture vapor released by the lumber. The calculations are shown below:

$$\text{wscfm}_{[i]} = \text{dscfm}_{32°F[i]} \times \frac{527.67\,\text{R}}{491.67\,\text{R}} \times \frac{100}{100 - \text{MC}_{\text{kiln}[i]}(\%)}$$

Step 3: Mass emission rate of VOCs as carbon per sample increment

Convert the undiluted wet stack concentration ($\text{SC}_{[i]}$) and wet standard flow rate ($\text{wscfm}_{[i]}$) to pounds of VOCs as carbon per incremental sampling period [i] by the equation shown below:

$$\frac{\text{lbs VOC as carbon}}{\text{time interval}}[i] = \frac{\text{SC}_{[i](\text{step 1})}}{10^{\wedge}6} \times \text{wscfm}_{[i](\text{step 2})} \times \frac{1\text{lbmole}}{385.6\text{scf}} \times \frac{12\text{lbcarbon}}{\text{lbmole}}$$

The following equation is a one step simplified formula for small-scale kilns that summarizes the previously explained steps:

$$\frac{\text{lbs VOC as carbon}}{\text{time interval}}[i] = \frac{\text{IR}_{[i]}}{10^{\wedge}6} \times \frac{\text{Pre[span]} + \text{Post[span]}}{\text{Pre[span\_d]} + \text{Post[span\_d]}} \times \frac{3\,\text{carbons}}{1\,\text{propane}} \times \text{dscfm}_{32°\text{F},1\text{atm}[i]} \times \frac{527.67\,R}{491.67\,R} \times \frac{100}{\left(100 - \text{MC}_{\text{kiln}[i]}\right)} \times \frac{1\text{lbmole}}{385.6\text{scf}} \times \frac{12\text{lbcarbon}}{\text{lbmole}}$$

Calculation of the Mass Emission Rate Per Sampled Increment for Full-Scale Kilns

Step 1: The conversion of the measured wet diluted VOC instrument response ($\text{IR}_{[i]}$) to the calculated undiluted wet stack concentration, $\text{SC}_{[i]}$

The VOC analyzer will generate a response in terms of propane for the wet diluted sample gas entering the VOC analyzer. This response should be considered to have no moisture interference because the sample gas will be at or less than the analyzer's MC_L. The response, however, will be a diluted reading at the analyzer. The undiluted response for the source gas can be calculated by using the dilution ratio. Furthermore, the response is converted from a propane reading to a carbon reading by the ratio of 3 carbon atoms to one propane molecule. The calculation for this step is shown below:

$$\text{SC}_{[i](\text{wet})} = \text{IR}_{[i](\text{wet, propane})} \times \frac{\text{Pre[span]} + \text{Post[span]}}{\text{Pre[span\_d]} + \text{Post[span\_d]}} \times \frac{3\,\text{carbons}}{1\,\text{propane}}$$

Step 2: The conversion of the measured wet actual flow rate ($\text{wacfm}_{[i]}$) to standard wet flow rate ($\text{wscfm}_{[i]}$) over an incremental sampling period

The measured flow rate is standardized to allow for the data to be compared with the data from the small-scale kilns participating in this study. The type of equation used to generate the actual wet flow rate will depend on the flow rate measurement method approved by NCASI. Similarly, the recorded time interval for this parameter will also depend on the measurement method.

The calculation shown below assumes that the sampler is able to record the actual wet flow rate at the same time interval as the VOC concentration and the dry-bulb temperature of the exhaust gas. The average barometric pressure measured before and after the Sample Run at the site has been also included in this equation:

$$\text{wscfm}_{[i]} = \text{wacfm}_{[i]} \times \frac{527.67}{459.67 + T_{\text{db}[i]}} \times \frac{\left(\frac{P_{\text{Pre}} + P_{\text{Post}}}{2}\right)}{29.92\text{ in Hg}}$$

Step 3: Mass emission rate of VOC as carbon per sample increment

The conversion of the undiluted wet stack concentration ($\text{SC}_{[i]}$) and wet standard flow rate ($\text{wscfm}_{[i]}$) to pounds of VOC as carbon per sample increment [i] is shown below.

$$\frac{\text{lbs VOC as carbon}}{\text{time interval}}[i] = \frac{\text{SC}_{[i](\text{step 1})}}{10\text{^}6} \times \text{wscfm}_{[i](\text{step 2})} \times \frac{1\text{lbmole}}{385.6\text{scf}} \times \frac{12\text{lbcarbon}}{\text{lbmole}}$$

The one step simplified formula for full-scale kilns is shown below:

$$\frac{\text{lbs VOC as carbon}}{\text{time interval}}[i] = \frac{\text{IR}_{[i]}}{10\text{^}6} \times \frac{\text{Pre[span]} + \text{Post[span]}}{\text{Pre[span\_d]} + \text{Post[span\_d]}} \times \frac{3\text{ carbons}}{1\text{ propane}} \times \text{wacfm}_{[i]} \times \frac{527.67}{\left(459.67 + T_{[i]}\right)} \times \frac{\left(\frac{P_{\text{Pre}} + P_{\text{Post}}}{2}\right)}{29.92\text{in Hg}} \times \frac{1\text{lbmole}}{385.6\text{scf}} \times \frac{12\text{lbcarbon}}{\text{lbmole}}$$

Calculation method for filling in missing data points and calibration periods

This section will cover two methods that will be used to fill in data that are not recorded during the course of an 18 to 24 hour Sampling Event conducted at either the small- or full-scale kilns. The averaging method will cover the standard way to fill in random missing data points not recorded. The linear interpolation method will address filling in data for the calibration periods and for time periods due to technical or equipment problems. These methods will only be applied to the measured parameters discussed previously in this document. The mass emission rates will then be calculated from the filled in parameters.

Table 1 has been included to provide an example of how this method should work. The data in bold, italic font identifies the data point(s) that have been calculated as a result of using one of the methods discussed in this section.

Averaging Method: During the process of reviewing the measured data, there may be single blank data points encountered periodically where the data logger failed to record a value. Table 1 shows two examples of missing VOC concentration data points that have been filled in. These data points occur at the time intervals of 13:27 and 14:08. Each of these data points was previously blank, and the data shown were filled in by calculating the average of the concentration value above and below the previously blank data point. The calculated concentration was then highlighted by using a bold and italic font. The mass emission rate was then calculated from this averaged VOC concentration value.

Linear Interpolation Method: This method will be applied to fill in data that were not recorded during calibration periods at the end of each 3-Sample Run or due to equipment malfunctions. Note that only one of the two different procedures described below will be used when applying the Linear Interpolation Method. The choice of which procedure to apply will depend on the characteristic trend of the recorded data.

Step 1: For both types of procedures, the first step will be to determine the number of data points that will require interpolation. Table 1 shows an example of a calibration period starting at 13:32 and ending at 13:52. For this example, the calibration period has 21 data points to fill.

Step 2: Choosing the correct interpolation procedure will depend on whether the trend of the data is clearly increasing or decreasing at the end of the Sample Run and continues, with the same trend, into the next Sample Run (Procedure 1). Procedure 2 will be applied to data trends that do not fit Procedure 1.

Procedure 1: For a trend that displays an increasing or decreasing trend use the following equation to interpolate between data points:

$$\text{data value}_{(n)} = \text{data value}_{(n-1)} + \frac{C2 - C1}{(\text{calibration time interval} + 1)}$$

The value of the constant C1 will be the last recorded data point of the ending Sample Run. For example, in Table 1, C1 would be the value at 13:31 in columns 8 or 9. Similarly, the constant C2 would be the first recorded data point of the starting Sample Run (13:53, column 8 or 9). Note that C1 and C2 will need to be absolute referenced (for example: A23) for the interpolation equation to properly compute the values.

The interpolation equation will then replace the blank data spaces. In Table 1, the data would be interpolated over the range from 13:32 to 13:52.

Table 1: Example Data Set for the Calculation of Calibration Data Points

1	2	3	4	5	6	7	8	9
Time	**Wet Bulb** Deg. F	**Dry Bulb** Deg. F	**Ambient** Deg. F	**Original STD @ F 32 Air Flow** dslm	**Original STD @ F 32 Air Flow** dscfm	**Dry STD @ 68 F Inlet Air Flow** dscfm	**VOCs** PPM	**Dilution Ratio**
13:20	163	193	72	52.00	1.84	1.97	84.8	4.15
13:21	164	193	72	52.00	1.84	1.97	81.1	4.15
13:22	164	193	72	52.00	1.84	1.97	84.9	4.15
13:23	164	193	72	52.00	1.84	1.97	85.0	4.15
13:24	163	194	72	52.00	1.84	1.97	84.0	4.15
13:25	163	194	72	52.00	1.84	1.97	55.9	4.15
13:26	163	194	72	52.00	1.84	1.97	65.5	4.15
13:27	164	194	72	52.00	1.84	1.97	74.3	4.15
13:28	164	194	72	52.00	1.84	1.97	83.1	4.15
13:29	164	194	72	52.00	1.84	1.97	83.0	4.15
13:30	164	194	72	52.00	1.84	1.97	83.0	4.15
13:31	164	194	72	52.00	1.84	1.97	82.1	4.15
13:32	164	194	72	52.00	1.84	1.97	*78.4*	*4.15*
13:33	164	194	72	52.00	1.84	1.97	*78.8*	*4.13*
13:34	164	194	72	52.00	1.84	1.97	*79.2*	*4.11*
13:35	164	194	72	52.00	1.84	1.97	*79.6*	*4.08*
13:36	164	194	72	52.00	1.84	1.97	*80.0*	*4.06*
13:37	164	194	72	52.00	1.84	1.97	*80.5*	*4.04*
13:38	164	195	72	52.00	1.84	1.97	*80.9*	*4.02*
13:39	164	195	72	52.00	1.84	1.97	*81.3*	*4.00*
13:40	164	195	72	52.00	1.84	1.97	*81.7*	*3.98*
13:41	164	195	72	52.00	1.84	1.97	*82.2*	*3.96*
13:42	164	195	72	52.00	1.84	1.97	*82.6*	*3.93*
13:43	164	195	72	52.00	1.84	1.97	*83.0*	*3.91*
13:44	164	195	72	52.00	1.84	1.97	*83.4*	*3.89*
13:45	164	195	72	52.00	1.84	1.97	*83.8*	*3.87*
13:46	164	195	72	52.00	1.84	1.97	*84.3*	*3.85*
13:47	164	195	72	52.00	1.84	1.97	*84.7*	*3.83*
13:48	164	195	72	52.00	1.84	1.97	*85.1*	*3.81*
13:49	164	195	72	52.00	1.84	1.97	*85.5*	*3.79*
13:50	164	196	72	60.00	2.12	2.27	*86.0*	*3.76*
13:51	164	196	72	60.00	2.12	2.27	*86.4*	*3.74*
13:52	164	196	72	60.00	2.12	2.27	*86.8*	*3.72*
13:53	164	196	72	52.00	1.84	1.97	94.9	3.72
13:54	164	196	72	52.00	1.84	1.97	93.9	3.72
13:55	164	196	72	52.00	1.84	1.97	91.9	3.72
13:56	164	196	72	52.00	1.84	1.97	89.0	3.72
13:57	164	196	72	52.00	1.84	1.97	89.0	3.72
13:58	164	196	72	52.00	1.84	1.97	89.9	3.72
13:59	164	196	72	60.00	2.12	2.27	84.9	3.72
14:00	164	196	72	60.00	2.12	2.27	81.1	3.72
14:01	164	196	72	52.00	1.84	1.97	78.2	3.72
14:02	164	196	72	52.00	1.84	1.97	75.2	3.72
14:03	164	196	72	52.00	1.84	1.97	81.1	3.72
14:04	164	197	72	52.00	1.84	1.97	80.1	3.72
14:05	164	197	72	60.00	2.12	2.27	74.2	3.72
14:06	164	197	72	60.00	2.12	2.27	71.4	3.72
14:07	164	197	72	60.00	2.12	2.27	68.3	3.72
14:08	164	197	72	60.00	2.12	2.27	*61.4*	3.72
14:09	164	197	72	52.00	1.84	1.97	48.1	3.72

Procedure 2: For data trends that do not fit Procedure 1, such as the data trend shown in Table 1. The principle for Procedure 2 is similar to Procedure 1 in that the blank data values are still linearly interpolated, but the constants C1 and C2 are determined differently.

Divide the value determined by Step 1 in half to determine the interval over which the recorded data will be averaged to compute C1 and C2. For the data in Table 1, the average of the last 11 ending Sample Run data points (13:21 to 13:31) would be computed to determine C1. Similarly, C2 would be an average over the initial 10 data points (13:53 to 14:02) for the following Sample Run. C1 and C2 would be placed in the first (13:32) and last (13:52) blank data points of the calibration period. Interpolation of the remaining blank data points (13:33 to 13:51) would be computed by the interpolation equation shown below:

$$\text{data value}_{(n)} = \text{data value}_{(n-1)} + \frac{\text{C2} - \text{C1}}{(\text{calibration time interval} - 1)}$$

Calculation of Hourly, Sample Run, and Sample Event VOC Mass Emission Rates

NCASI will be providing each sampler with a spreadsheet that will be formatted to generate the mass emission rate of VOC in terms of hourly, Sample Run and Sample Event. A brief outline follows that will describe the process for generating these numbers.

Hourly Mass Emission Rates: The measured and filled in data described above will be referenced and organized into hourly segments of time within one of the spreadsheets provided. From the measured data, two mass emission rates will be calculated. First, the "lbs of VOC as carbon per sample time increment" will be calculated by the manner described in this protocol. Then, the "mass emission rate per MBF per sampled time increment" will be calculated. These two sets of numbers will be summed over each sampled hour of the event.

Sample Run Mass Emission Rates: The two sets of mass emission rates calculated on an hourly basis will then be summed to generate results for each three hour Sample Run. The Sample Run results will be calculated on the same spreadsheet as the hourly mass emission rate data.

Sample Event Mass Emission Rate: Only the mass emission rate per MBF for the entire Sample Event will be calculated from the summation of the three hour Sample Run values. This calculation will be done on a separate dedicated spreadsheet.

APPENDIX 1 **FIELD SHEET FOR THE VOC ANALYZER**

Sample Event No.
Sample Run No.
DR Session No.
Date of Run
Time (at this moment)

Kiln Operator* 1.
2.

Sampling Crew* 1.
2.
3.

*Please note additional Operators/Crew in comments section

Kiln Reference No.:

Sample Location:

Kiln Capacity: BF

Number of 2X4's in Charge:

Kiln Operating Temperature: F / C

Type Of:
VOC Analyzer:

MC_L = %

Data Recorder(s): 1.
2.

Calibration Gas Concentrations In ppmv Propane In Air

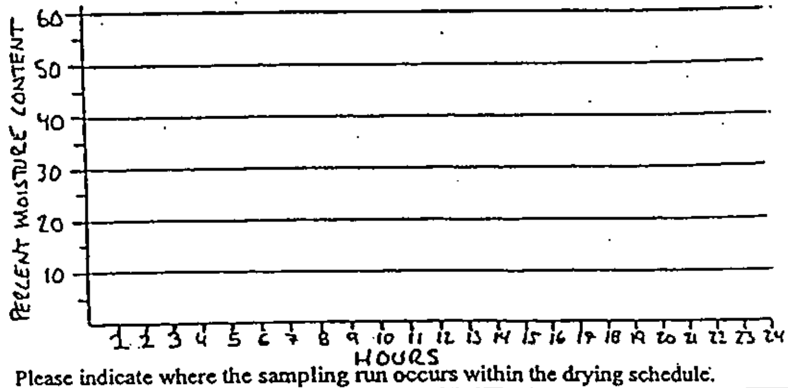
Type of Gas		
Span	ppmv [span]	
"Named" Mid	ppmv [mid]	
"Named" Mid (2)	ppmv [mid_2]	if applicable
"Named" Mid (3)	ppmv [mid_3]	if applicable

Moisture Schedule Chart

MC_L:

MCmax:

MCR:



Please indicate where the sampling run occurs within the drying schedule.

Measurement System Leak Check

Pre-Sampling Event	in Hg/2 min at (indicate time)
Post-Sampling Event	in Hg/2 min at (indicate time)

Comments:

Page 1. Turn to opposite side for Page 2.

DATA FOR PRE-SAMPLE RUN

Pre-Ambient Pressure and Temperature = | (units?)

MCmax (or obs) = ____ % MCR = ____	Observed Readings			Pot settings on the VOC Instrument
	VOC Analyzer Response	Data Recorder Response	Within range? Yes or No	
[zero] w/in ± 3% x [span]?				
[mid] w/in ± 5% x [mid]?				
[span] w/in ± 3% x [span]?				

Average of the 5 measurements below for Pre-TFR = (units?)

1. 2. 3. 4. 5.

Calculate: Target-DFR = Pre-TFR x (1 - MCR) = ____ (units?)

Observed Dilution Flow Rate (DFR) = (units?)

Calculate: Target-SFR = Pre-TFR x MCR = ____ (units?)

Average of the 5 measurements below for Pre-SFR = (units?)

1. 2. 3. 4. 5.

Calculate: [calcspan]_d = [span] x (Pre-SFR/Pre-TFR) = ____ (units?)

Pre[span]_d ± 3% x [span]			

MCR = ____ =? PreSFR / PreTFR = ____ =? Pre[span]_d / Pre[span] = ____

Actual Percent MC of Diluted Sample: MCmax * Pre[span]_d / Pre[span] = ____ %

SAMPLE RUN No. ___ **Start Time:** ____ **End Time:** ____

DATA FOR POST-SAMPLE RUN

Post-Ambient Pressure and Temperature = | (units?)

Observed Post-[span]_d			

Average of the 5 measurements below for Post-SFR = (units?)

1. 2. 3. 4. 5.

Observed Post-Dilution Flow Rate (Post-DFR) = (units?)

Average of the 5 measurements below for Post-TFR = (units?)

1. 2. 3. 4. 5.

[span] w/in ± 3% x [span]?				
[mid] w/in ± 5% x [mid]?				
[zero] w/in ± 3% x [span]?				

MCR = ____ =? PostSFR/PostTFR = ____ =? Post[span]_d / Post[span] = ____

Actual Percent MC of Diluted Sample: MCmax * Post[span]_d / Post[span] = ____ %

End time for Calibration Checks: ____ Date: ____

Comments: ____

PROCEDURE FOR "NAMING" GASES
For Section 5 - Calibration and Other Gases

The operator of the measurement system is required to be thoroughly familiar with the VOC Sampling Protocol prior to performing this procedure. This procedure requires that the measurement system be assembled in an approved manner and heated to the appropriate operating temperatures.

In an effort to minimize the cost burden of procuring calibration gases used to calibrate the measurement system, NCASI will allow kiln samplers to "name" the mid gas concentration(s). The "naming" process is essentially a two point calibration curve, with a known span gas as the highest point of the curve and the zero gas as the lowest point.

In order to obtain a confident "name" (concentration) for a mid gas, NCASI will require kiln sampler's to purchase an EPA Protocol No. 1 span gas. The span gas concentration required is outlined in the VOC Sampling Protocol, Section 3.3. The operator should be able to purchase this level of calibration gas within the cost range of $190 to $300 for 150 cubic feet of gas. The mid gas to be "named" can be purchased at a level of Certified or above. The mid gas concentration to purchase is outlined in the VOC Sampling Protocol, Section 5.3. The operator should be able to purchase a Certified level of calibration gas within the cost range of $80 to $100 for 150 cubic feet of gas.

Naming Procedure:

(1) Prior to naming a mid level gas, the measurement system should be at the proper operating temperature and the VOC analyzer shall be zeroed and spanned in accordance with Sections 8.3.2, and 8.3.3 (a data recorder is not required for this procedure).

(2) A minimum of five "naming" runs must be conducted.

- The first naming run shall be conducted by recording the VOC analyzer's response to the mid gas introduced into the measurement system as outlined in Section 8.2.
- The four subsequent naming runs shall follow the same procedure,
  (1) Zero and span the measurement instrument and
  (2) Record the response from the VOC analyzer.
- The average of the observed five mid gas concentrations will be the new mid gas concentration.

(3) The "named" concentration will then supersede the "certified" mid gas concentration as identified by the vender of the gas.

APPENDIX I

STANDARD FORMALDEHYDE AND METHANOL SAMPLING PROTOCOL

FINAL

NCASI CHILLED IMPINGER METHOD (MODIFIED) TO BE USED AT SMALL-SCALE KILNS TO MEASURE FORMALDEHYDE AND METHANOL

1. INTRODUCTION

The modified method described below has been derived from the NCASI "Chilled Impinger Method As Used At Wood Products Mill To Measure Formaldehyde, Methanol, and Phenol." Changes in this method are minor and primarily are incorporated to eliminate the use of a heated probe and heated filter which are considered unnecessary for measurement of lumber kiln emissions.

Although this sampling method is reasonably simple, expertise in field measurement of source gas flow rates, general field sampling techniques, sample handling and preparation, spectrophotometry, and gas chromatography is still required to obtain accurate results from this method.

A field data sheet has been provided at the end of this sample method.

2. PRINCIPLE AND APPLICABILITY

2.1 Principle. The source gas is drawn through two midget impingers, each containing chilled organic free water. Formaldehyde and methanol are absorbed by the water. For analysis of methanol, the water from the impingers is analyzed by direct injection into a gas chromatograph equipped with a flame ionization detector (GC/FID). The retention time for methanol is compared with a known standard containing the same compound. The methanol concentration is calculated from a calibration curve obtained from analysis of the standard solution. The formaldehyde concentration in the impinger solution is determined by the acetylacetone procedure. This procedure involves the reaction of acetylacetone with formaldehyde to produce a colored derivative which is measured by colorimetric analysis.

2.2 Applicability. This method is applicable to the analysis of formaldehyde and methanol.

3. RANGE AND SENSITIVITY

3.1 Range. The range of this method varies with the analyte, but in general, the lower limit is in the 0.3 ppmv (in air) range and the upper limit is in the percent range.

3.2 Sensitivity. The sensitivity limit for each compound corresponds to the practical limit of quantitation (PLQ). It is compound specific, but is generally in the 0.4 to 0.8 ppmv (in air) range.

3.3 Factors Affecting the PLQ. The amount of water in the impingers (plus rinse water) and the amount of sample gas collected both affect the PLQ. If a sample flow rate of 200 mL/min is used for three hours and the total volume of water in the impingers plus rinse is 50 mL, then concentrations in the source emission vent of 0.8 and 0.6 ppmv, respectively, for formaldehyde and methanol yield concentrations of 0.7 and 0.6 μg/mL in the aqueous phase. These concentrations are easily quantified by the analytical methods described in Section 9.

4. PRECISION AND ACCURACY

4.1 Precision. EPA Method 301 validation studies have resulted in precision values in the range of 1 to 12 percent, depending on the analyte and emission source.

4.2 Accuracy. EPA Method 301 studies have resulted in bias correction factors of 0.98 to 1.03, depending on the analyte and emission source.

5. INTERFERENCES

5.1 Coelutants. Compounds present in the source gas can coelute with the analytes of interest during the chromatographic analysis. These types of interferences can be reduced by appropriate choice of GC columns, chromatographic conditions and detectors.

5.2 Other Aldehydes and Ketones. The presence of acetaldehyde, amines, polymers of formaldehyde, periodate, and sulfites <u>can</u> cause interferences with the acetylacetone procedure which is used for the determination of the formaldehyde concentration.

6. APPARATUS

6.1 Sampling

6.1.1 <u>Sample Probe</u>. The non-heated sample probe is constructed of ¼ inch OD Teflon® or stainless steel tubing. The probe should be placed near the center of the stack or duct. As an alternative, the sample probe may be heated. The operating temperature for the heated sample probe shall be maintained at 250°F (±25°F).

6.1.2 <u>Optional Heated Filter Box</u>. When the optional heated sample probe is used, it shall be connected to a heated box containing a glass fiber or Teflon filter. The filter housing and connections may be Teflon or stainless steel. A thermocouple connected to or within the filter housing is used to maintain the filter temperature at 250°F (± 25°F).

6.1.3 Sample Line. The non-heated sample line is constructed of Teflon® or stainless steel tubing. The sample line shall be connected to the non-heated probe in a leak-free manner. When the heated probe/filter box combination is used, the sample line shall be connected to the outlet side of the filter box in a leak-free manner. The sample line is used to convey the exhaust gas sample from the sample probe to the first impinger.

6.1.4 Midget Impingers. Two midget impingers are required for sampling.

6.1.5 Flow Control Device. A critical orifice is used for flow control.

6.1.6 Vacuum Pump. Pump capacity must be sufficient to obtain critical conditions at the orifice.

6.1.7 Flow Measurement Device. A bubble meter, or comparable flow measurement device, traceable to a NIST Standard or EPA Method, is used to check the sample flow rate at the sample probe tip. Alternatively, a calibrated dry gas meter could be used.

6.2 Analysis

6.2.1 Gas Chromatograph. A gas chromatograph with appropriate columns, detectors and data acquisition system is required for sample analysis. Section 9 provides the specific details concerning the GC equipment.

6.2.2 Spectrophotometer. A spectrophotometer is required for the formaldehyde analysis.

7. REAGENTS

7.1 Sampling

7.1.1 Water. Organic free water is used in both of the impingers as the capture solution, as well as for rinsing the sampling line and impingers at the completion of the sample run.

7.1.2 Ice. Ice is packed around the impingers during sampling.

7.2 Analysis

7.2.1 Calibration Standards. Reagent grade compounds are required for the preparation of calibration standards.

8. SAMPLE COLLECTION

8.1 Number of Sample Runs. Sampling will be conducted over the complete kiln drying cycle. The drying cycle will be divided into distinct sample runs. according to the kiln schedule. Each sample run will have a maximum duration of 3 hours. The number of sample runs will depend on the length of the kiln cycle and the turn-around-time between samples. For each sample run, the formaldehyde/methanol field sheet (Attachment 1) is required to be completed.

8.2 Preparation of Sampling Train. Figure 8-1 shows the schematic for the non-heated sampling train. The sampling train consists of a non-heated probe, a non-heated sample line, two midget impingers in series immersed in an ice bath, a rotameter, a critical orifice, and a sample pump. Figure 8-2 shows the schematic for the heated sample train. The additional components are the heated sample probe and filter box. The two impingers each contain approximately 20 mL of de-ionized (DI) water. For sources with very high amounts of moisture (>40%), a third dry impinger, used as the first train impinger, may be necessary as a water dropout. For sources with moderate amounts of moisture (15 to 40% by volume), the first impinger can be filled with just enough water to cover the bottom of the impinger stem and then allowed to fill with water condensed from the source gas. The critical orifice should allow collection of about 200 mL/min of dry air.

8.3 System Leak-Check. The entire sample train is leak checked before each sample run. If the heated sample train is used, a leak check shall be done at the systems operating temperature. The leak check is conducted by exerting a vacuum equivalent to 20 inches of mercury on all components between, and including, the probe tip and the impinger train. An unacceptable leak check results from the loss of one inch or more of vacuum (measured as inches of mercury) in a two minute period.

8.4 Measurement of Sample Flow Rate. Sample flow rate for the entire system is measured five times prior to and after each sample run (if bubble tube meters or equivalent devices are used). The average flow rate from these measurements are required to be around 200 mL/min (±50 mL/min) and shall be used to calculate the sample volume. The rotameter is checked and recorded at least once every hour during sample collection to ensure that the sample flow rate is consistent. Rotameter readings are not used to calculate sample volume. Ambient temperature measurements are made prior to and after each sample, so that the measured sample flow rate can be converted to standard conditions and the moisture content of the measured sample flow can be determined (assume moisture saturation of ambient air within the bubble tube).

8.5 Measurement of Source Gas Flow Rate. Source gas flow rate is determined by EPA methods 1-4 or equivalent methods.

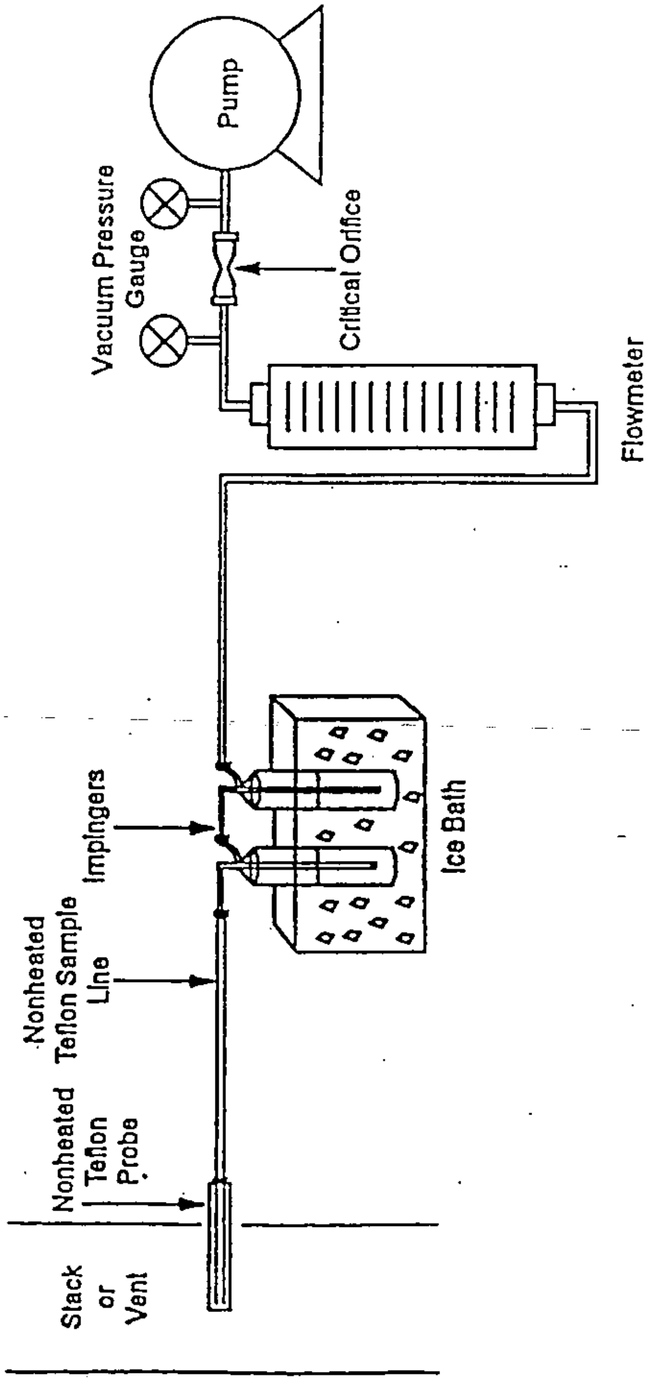


Figure 8. [illegible]on-heated NCASI Chilled Impinger Method Modified to be Used at [illegible] Scale Kilns to Measure Formaldehyde and Methanol

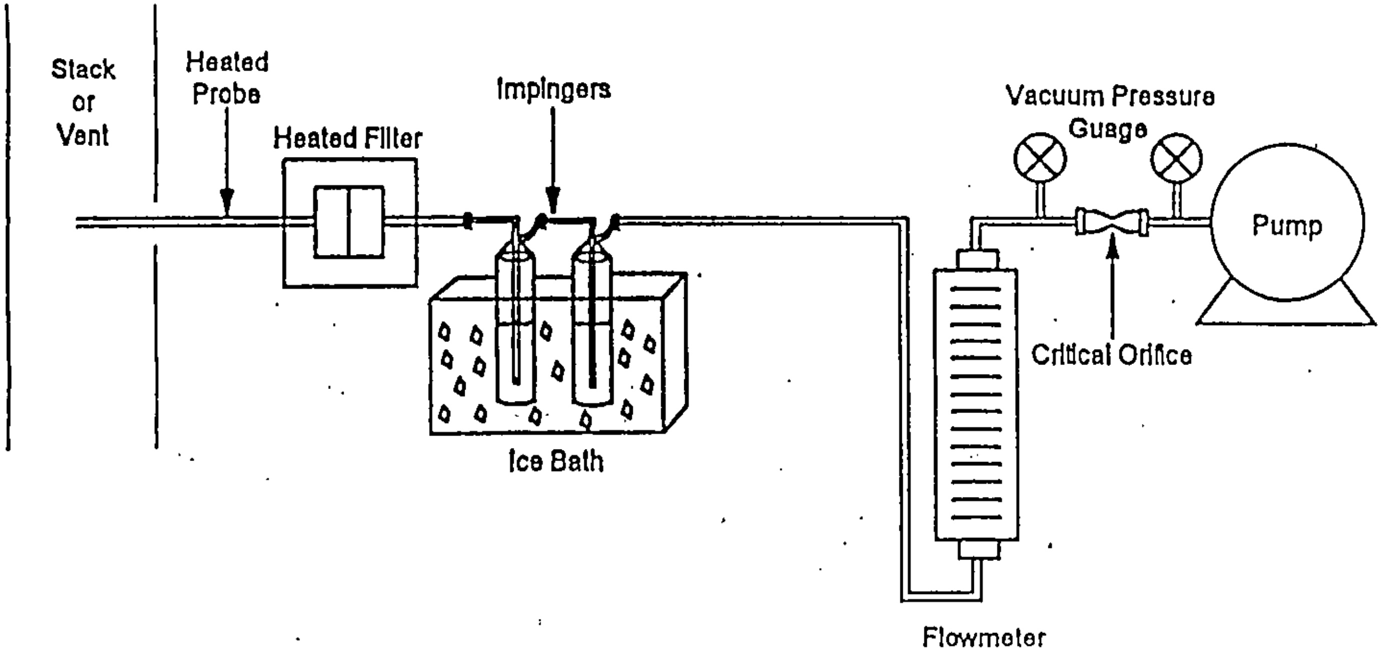


Figure 8-2. Heated NCASI Chilled Impinger Method as Used at Wood Products Mills to Measure Formaldehyde, Methanol, and Phenol

8.6 Sample Collection. Samples are collected with the probe set securely in the port at the sampling location and placed perpendicular to the source gas stream flow. The sample pump will draw sample gas from the exhaust gas stream exiting the kiln. During the sample run the sample gas will pass through the water in the impingers. The sample gas captured by the condensed moisture within the sample line will be drained and/or rinsed into the impingers.

8.7 Sample Transfer and Storage. After a sample run is complete, remove the probe from the sample port and drain any condensed water in the sample line into the first impinger. Follow this by the addition of a small amount of organic free water to rinse the sample line (approximately 5 mL). Turn off the sample pump and pour the contents of both impingers into an inert sample bottle. Rinse the impingers with a small amount of water and add this impinger rinse to the sample bottle. The sample bottle shall be kept chilled in ice, or refrigerated at approximately 4°C until analyzed. Prior to analysis the mass or volume of the impinger catch plus the rinse must be determined.

9. SAMPLE ANALYSIS

9.1 Chromatography System. For the analysis of methanol, a gas chromatograph (GC) system equipped with a flame ionization detector (FID) is required. The oven and column of the GC should be capable of separating methanol from other volatile water soluble compounds such as acetone, acetaldehyde, MEK, etc. An aliquot from the sample bottle is transferred to an autosampler vial (or directly injected into the GC). One microliter of sample from the autosampler vial is introduced by direct aqueous splitless injection into the GC/FID. The type of gas chromatograph model used at NCASI to conduct laboratory analysis for methanol is a Hewlett Packard 5890 Series II. The type of column used to separate the methanol from the other organic compounds within the GC is a J&W DB-624 fused silica capillary column. The internal diameter of the column is 0.53 mm and the length is 30 meters. The film thickness of the column is 3 micrometers. The GC and column described in this section was mentioned to provide assistance and is not mandated by this method. Laboratories may choose their own equipment provided that quality assurance procedures are followed.

9.2 Methanol Analysis. For the methanol analysis, a cryogenic cooling system is used to separate methanol from other water soluble compounds. An initial oven temperature of 10°C is held for 4 minutes, then the temperature is increased at a rate of 10°C per minute to 50°C and held for two minutes. From this point, the oven temperature is increased at a rate of 50°C per minute until a temperature of 200°C is reached and held for three minutes. The GC oven schedule described in this section was mentioned to provide assistance, other GCs may have different oven schedules.

9.4 Calibration. Stock solutions of formaldehydes and methanol shall be made. Calibration standards are then made from these stock solutions. Concentrations can range from 1,000 ppm to 0.4 ppm, depending on the concentration expected in the samples. Calibration curves are constructed and used to determine the concentration of analyte in the sample. Note that formalin typically is "fixed" with methanol and this must be considered if a mixed stock solution is made.

9.5 Impinger Catch Analysis. Before analysis, the volume of the impinger catch plus rinse is measured (or the volume of solution in each sample bottle is measured). For analysis, aliquots are acquired from the sample bottle. An internal standard (ethyl acetate) can be added, if desired. The impinger samples can be stored for up to 20 days at 4°C.

9.6 Determination of Formaldehyde. The concentration of formaldehyde present in the impinger sample is determined through the use of the acetylacetone procedure. This method involves the addition of an acetylacetone reagent to an aliquot of the sample. The formaldehyde in the sample reacts with acetylacetone in the presence of ammonium acetate to form the adduct diacetyldihydrolutidine (DDL) which has a yellow color. The intensity of the color formed is measured spectrophotometrically (@412 nm) and from this result the concentration of formaldehyde is calculated. This method is only good for formaldehyde concentrations of 0.2 to 7.5 ppm (in the liquid phase). Thus, a series of dilutions may need to be conducted (samples must be diluted prior to addition of acetylacetone - see section 9.6.3).

9.6.1 Reagent. The acetylacetone reagent is made by dissolving 15.4 g of ammonium acetate in about 50 mL of water in a 100 mL volumetric flask. To this solution, 0.20 mL of acetylacetone is added, along with 0.30 mL of glacial acetic acid. The solution is mixed thoroughly and then diluted to 100 mL with organic free water. The solution can be stored in a brown glass bottle in the refrigerator, and is stable for at least two weeks.

9.6.2 Calibration. A stock solution of 10 ppm formaldehyde is made. A series of calibration standards are made from the stock solutions by adding 0, 0.1, 0.3, 0.7, 1.0, and 1.5 mL (corresponding to 0, 1.0, 3.0, 7.0, 10.0, and 15.0 µg formaldehyde, respectively) to a screw-capped vial. The volume is adjusted to 2.0 mL with organic free water. Two mL of the acetylacetone reagent are added, and the procedure described below is used on these samples. A calibration curve is then constructed.

9.6.3 Analysis. A 2.0 mL aliquot of the impinger catch is transferred to a screw-capped vial. Two mL of the acetylacetone reagent are added and the solution is mixed thoroughly. Once mixed, the vial is placed in a water bath (or heating block) at 60°C for 10 minutes. Once the vials are cooled to room temperature, the solution is transferred to a cuvette and the absorbance is measured at 412 nm. The spectrophotometer is zeroed with water, and a method blank is analyzed with each set of samples. The amount of formaldehyde present is determined by comparison to a calibration curve. If the sample response is out of the calibration curve range, the sample muse be diluted and reanalyzed. Dilute the sample <u>before</u> the addition of the acetylacetone reagent, and repeat the full procedure.

10. QUALITY CONTROL

10.1 Calibration. Laboratory calibration curves are constructed from a four point curve, and such that it contains points near the quantitation limit for the analyte, and points above the expected concentration. Results are calculated from the appropriate region of the curve, and if necessary in low concentration samples, from a point-to-point calibration curve. Calibration checks are performed with each set of samples. The results of the check standard must be within 10% of the theoretical value to be acceptable.

10.2 Field Blanks. At least one field blank shall be collected at the sample location for each source tested. A sample bottle is filled, or partially filled, with the same organic free water used to fill the impingers and rinse the train. The field blanks are analyzed along with the impinger contents and the results reported. Laboratory blanks provide a check on field blanks and a means of determining the source of contamination (should any be determined). For this reason, laboratory blanks also are suggested.

10.3 Field Spike Recovery. A separate sample run must be conducted to determine spike recovery of the sample train. This run may be conducted prior to or following the kiln sampling.

A field spike is introduced into the first impinger or (through the sample probe for heated probes) to determine recovery of formaldehyde and methanol. Temperature, flow rate, and sample time should be identical to the actual sample runs. Care must be taken to prevent introduction of ambient formaldehyde and methanol during this procedure. If a single spike run is conducted, the mass of each analyte introduced should be <u>targeted</u> to be ± 50% of the mass expected to be captured in an actual sample run. Alternatively, both "low" and "high" spike solutions can be used on two separate spike recovery runs to bracket the expected capture from the source. Field spike recovery results must be reported. A criterion for field spike recovery of 70% to 130% is used to determine the validity of the sampling effort.

APPENDIX I **FIELD SHEET FOR FORMALDEHYDE AND METHANOL**

Sample Event No.	
FM Sample Run No.	
Date of Run	
The Time Right Now	

Kiln Operator* 1. ____________

Sampling Crew* 1. ____________

2. ____________

3. ____________

4. ____________

*Please note additional Operators/Crew in comments section

Sample Location: ____________

____

Kiln Reference No.: ______

Kiln Capacity: ______ BF

Number of 2X4's in Charge: ______

PRE-SAMPLE RUN DATA

	(units)	Imp ID		(units)
Dry Impinger wt. ==>			Wet Impinger wt. ==>	
Dry Impinger wt. ==>			Wet Impinger wt. ==>	
Dry Impinger wt. ==>			Wet Impinger wt. ==>	

Measurement System Leak Check: ____________ in Hg/2 min

Barometric Pressure Prior to Run: ____________ (units?)

Ambient Temperature Pre-Sampling Run: ____________ (units?)

Average of 5 measurements for Pre-Sample Flow (Pre-SF) = ☐ (indicate units)

1.	2.	3.	4.	5.

START TIME FOR RUN No. ___ TIME: ______

Observed Rotometer Delivery Rate = 1st hour		(indicate units)
2nd hour		(indicate units)
3rd hour		(indicate units)

POST-SAMPLE RUN DATA

END TIME FOR RUN No. ___ TIME: ______

Average of 5 measurements for Post-Sample Flow (Post-SF) = ☐ (indicate units)

1.	2.	3.	4.	5.

DOES PRE-SF = POST-SF? YES NO

CONTINUED ON OTHER SIDE

POST-SAMPLE RUN DATA

	(units)	Imp ID
Dry Impinger wt. ==>		
Dry Impinger wt. ==>		
Dry Impinger wt. ==>		

Ambient Temperature Post-Sampling Run: ______ (units?)

Barometric Pressure Post-Sampling Run: ______ (units?)

SAMPLE BOTTLE ID CODE: ______

Note any amount of impinger water losted during sample transfer ______ (units?)

Comments: ______

APPENDIX J

FUGITIVE STACK DATA ASSESSMENT

Table J.1. Fugitive Stack Data Assessment for FSK DF1, Sample Run 1

Client:	NCASI	Project Number:	10027-001-002
Location:	Idabel, OK	Operator:	Short/Roberts/Purser
Source:	Kiln Outlet	Sample ID:	Cycle 1
Date:	20 May 1999	Calibration:	1

Time	THC		O2		CO2		Delta P Press		Static Press		Dry Temp		
	mv	ppm	mv	%	mv	%	mv	"H2O	mv	"H2O	mv	°F	
Starting time 18:41													
18:42	325	74	553	14.4	234	6.1	91	0.00	177	0.00	211	210	2
18:43	339	79	552	14.4	233	6.0	90	0.00	176	0.00	210	210	2
18:44	353	83	552	14.4	234	6.1	92	0.00	176	0.00	210	210	2
18:45	354	83	551	14.3	234	6.0	93	0.00	175	0.00	210	210	2
18:46	361	86	553	14.4	231	6.0	95	0.00	174	0.00	210	210	2
18:47	363	86	553	14.4	230	5.9	95	0.00	182	0.00	210	210	2
18:48	362	86	551	14.3	233	6.0	93	0.00	178	0.00	210	210	2
The first 15 min. of data is from the stack that is not venting													
18:49	364	87	547	14.2	238	6.1	92	0.00	179	0.00	210	210	2
18:50	367	88	547	14.2	238	6.2	93	0.00	178	0.00	210	210	2
18:51	363	86	547	14.2	238	6.2	94	0.00	180	0.00	211	211	2
18:52	360	86	548	14.3	236	6.1	94	0.00	180	0.00	211	211	2
18:53	355	84	548	14.3	238	6.2	95	0.00	179	0.00	211	211	
18:54	354	84	548	14.3	237	6.1	98	0.00	183	0.00	211	211	2
18:55	349	82	548	14.3	237	6.1	96	0.00	182	0.00	211	211	2
18:56	348	82	547	14.3	239	6.2	97	0.00	187	0.00	211	211	21
18:57	346	81	547	14.2	240	6.2	96	0.00	187	0.00	212	212	2
18:58	351	83	547	14.2	240	6.2	100	0.00	180	0.00	212	212	21
18:59	353	83	545	14.2	241	6.2	100	0.00	182	0.00	212	212	21
19:00	356	84	546	14.2	241	6.2	99	0.00	176	0.00	212	212	21
19:01	354	83	545	14.2	242	6.2	89	0.00	179	0.00	212	212	2
Changing stacks													
19:02	90	15	602	15.7	195	5.0	396	0.08	103	0.00	184	184	1
19:03	286	61	683	17.8	103	2.6	862	0.19	0	0.00	177	177	17
19:04	252	50	559	14.6	226	5.8	687	0.15	0	0.00	187	187	1
19:05	262	53	554	14.4	232	6.0	683	0.15	0	0.00	190	190	1
19:06	296	64	552	14.4	235	6.1	676	0.15	0	0.00	192	192	1
19:07	321	73	550	14.3	237	6.1	654	0.14	0	0.00	192	192	1
19:08	338	78	550	14.3	237	6.1	641	0.14	0	0.00	192	192	1
19:09	352	83	553	14.4	234	6.0	632	0.14	0	0.00	192	192	1
19:10	363	86	561	14.6	225	5.8	648	0.14	0	0.00	192	192	1
19:11	365	87	568	14.8	218	5.6	649	0.14	0	0.00	191	191	1

Table J.1. (cont'd) Fugitive Stack Data Assessment for FSK DF1, Sample Run 1

Client: **NCASI**
Location: **Idabel, OK**
Source: **Kiln Outlet**
Date: **20 May 1999**

Project Number: **10027-001-002**
Operator: **Short/Roberts/Purser**
Sample ID: **Cycle 1**
Calibration: **1**

Time	Wet Temp	
	mv	°F
Starting time 18:41		
18:42	208	208
18:43	208	208
18:44	208	208
18:45	208	208
18:46	207	207
18:47	207	207
18:48	208	208
The first 15 min. of data is from the stack that is not venting		
18:49	208	208
18:50	208	208
18:51	208	208
18:52	209	209
18:53	209	209
18:54	209	209
18:55	209	209
18:56	210	210
18:57	209	209
18:58	210	210
18:59	210	210
19:00	210	210
19:01	200	200
Changing stacks		
19:02	135	135
19:03	175	175
19:04	186	186
19:05	188	188
19:06	189	189
19:07	190	190
19:08	189	189
19:09	189	189
19:10	189	189
19:11	188	188

Table J.2. Fugitive Stack Data Assessment for FSK DF1, Sample Run 3

Client: **NCASI**
Location: **Idabel, OK**
Source: **Kiln Outlet**
~~alibration: 1~~

Project Number: **10027-001-002**
Operator: **Short/Roberts/Purser**
Date: **20 May 1999**

Time	THC		O2		CO2		Delta P Press		Static Press		Dry Temp		W
	mv	ppm	mv	%	mv	%	mv	"H2O	mv	"H2O	mv	°F	m
Starting time 22:12													
Sampling from low-flow stack for first 15 min													
22:13	598	164	561	14.6	232	6.0	117	0.01	180	0.00	182	182	21
22:14	591	161	559	14.6	232	6.0	123	0.01	178	0.00	198	198	21
22:15	591	161	558	14.5	233	6.0	143	0.01	176	0.00	207	207	21
22:16	588	160	558	14.5	231	6.0	152	0.02	173	0.00	211	211	21
22:17	572	155	558	14.5	230	5.9	96	0.00	180	0.00	214	214	21
22:18	579	157	556	14.5	232	6.0	91	0.00	182	0.00	215	215	21
22:19	580	158	555	14.5	232	6.0	88	0.00	178	0.00	216	216	21
22:20	531	142	557	14.5	228	5.9	92	0.00	181	0.00	216	216	21
22:21	511	135	557	14.5	230	5.9	95	0.00	177	0.00	216	216	21
22:22	513	136	557	14.5	230	5.9	112	0.01	177	0.00	217	217	21
22:23	521	138	557	14.5	229	5.9	127	0.01	175	0.00	217	217	21
22:24	523	139	556	14.5	230	5.9	142	0.01	173	0.00	218	218	2
22:25	527	141	556	14.5	231	6.0	144	0.01	174	0.00	218	218	
22:26	529	141	555	14.5	232	6.0	148	0.02	174	0.00	219	219	21
22:27	535	143	553	14.4	235	6.1	146	0.01	175	0.00	219	219	21
22:28	505	133	553	14.4	235	6.1	146	0.01	175	0.00	219	219	21
22:29	361	86	559	14.6	233	6.0	46	0.00	200	0.00	214	214	17
22:30	42	8	745	19.4	58	1.5	336	0.07	160	0.00	178	178	12
22:31	422	106	622	16.2	161	4.1	498	0.10	122	0.00	175	175	1
22:32	441	112	562	14.6	226	5.8	495	0.10	117	0.00	181	181	1
22:33	468	121	561	14.6	226	5.8	509	0.11	112	0.00	185	185	1
22:34	493	129	561	14.6	226	5.8	493	0.10	121	0.00	191	191	1
22:35	516	137	559	14.6	226	5.8	523	0.11	112	0.00	197	197	1
22:36	522	139	559	14.5	225	5.8	509	0.11	114	0.00	199	199	1
22:37	528	141	558	14.5	225	5.8	515	0.11	113	0.00	200	200	1
22:38	527	140	558	14.5	224	5.8	506	0.10	116	0.00	200	200	17
22:39	548	147	558	14.5	224	5.8	507	0.10	112	0.00	200	200	17
22:40	524	139	557	14.5	225	5.8	513	0.11	109	0.00	200	200	1
22:41	508	134	559	14.6	225	5.8	512	0.11	116	0.00	201	201	1
22:42	520	138	560	14.6	224	5.8	503	0.10	117	0.00	201	201	1
** Previous data was with dilution air turned off **													
22:43	285	61	560	14.6	224	5.8	496	0.10	123	0.00	201	201	1

** Note that dilution Ratio for data from 22:43 to end of Run is 2.18.

Table J.2. (cont'd) Fugitive Stack Data Assessment for FSK DF1, Sample Run 3

.ient: **NCASI**
Location: **Idabel, OK**
Source: **Kiln Outlet**
~~alibration: 1~~

Project Number: **10027-001-002**
Operator: **Short/Roberts/Purser**
Date: **20 May 1999**

Time	Wet Temp mv	°F
Starting time 22:12		
Sampling from low-flow stack for first 15 min		
22:13	213	213
22:14	214	214
22:15	214	214
22:16	215	215
22:17	214	214
22:18	214	214
22:19	214	214
22:20	214	214
22:21	213	213
22:22	214	214
22:23	214	214
22:24	215	215
22:25	215	215
22:26	216	216
22:27	216	216
22:28	216	216
22:29	170	170
22:30	128	128
22:31	163	163
22:32	165	165
22:33	166	166
22:34	167	167
22:35	168	168
22:36	168	168
22:37	169	169
22:38	170	170
22:39	173	173
22:40	181	181
22:41	191	191
22:42	195	195
Previous data was with dilution air turned off		
22:43	197	197

Table J.2. (cont'd) Fugitive Stack Data Assessment for FSK DF1, Sample Run 3

*NOTE THC data
IS Diluted.
Mutiply by 2.18 for
Undiluted Values

lient: **NCASI**
ation: **Idabel, OK**
urce: **Kiln Outlet**
~~ation: 1~~

Project Number: **10027-001-002**
Operator: **Short/Roberts/Purser**
Date: **20 May 1999**

Time	THC		O2		CO2		Delta P Press		Static Press		Dry Temp		W
	mv	ppm	mv	%	mv	%	mv	"H2O	mv	"H2O	mv	°F	m
22:44	207	35	560	14.6	225	5.8	504	0.10	126	0.00	202	202	19
22:45	214	37	562	14.6	224	5.8	513	0.11	124	0.00	201	201	19
22:46	220	39	562	14.6	223	5.8	496	0.10	124	0.00	201	201	19
22:47	227	42	563	14.7	223	5.8	500	0.10	130	0.00	202	202	19
22:48	230	43	563	14.7	224	5.8	510	0.11	128	0.00	202	202	19
22:49	234	44	564	14.7	223	5.8	516	0.11	129	0.00	202	202	19
22:50	237	45	566	14.8	220	5.7	514	0.11	128	0.00	202	202	19
22:51	238	45	566	14.8	219	5.7	512	0.11	128	0.00	202	202	19
22:52	246	48	564	14.7	221	5.7	501	0.10	128	0.00	202	202	19
22:53	248	49	563	14.7	221	5.7	491	0.10	128	0.00	202	202	19
22:54	255	51	561	14.6	221	5.7	493	0.10	127	0.00	202	202	19
22:55	258	52	560	14.6	221	5.7	503	0.10	123	0.00	202	202	19
22:56	261	53	559	14.6	222	5.7	512	0.11	122	0.00	202	202	19
22:57	264	54	559	14.6	222	5.7	510	0.11	122	0.00	201	201	19
22:58	264	54	560	14.6	223	5.8	506	0.10	123	0.00	202	202	
22:59	263	54	560	14.6	223	5.8	510	0.11	121	0.00	202	202	19
23:00	263	54	561	14.6	223	5.8	502	0.10	118	0.00	202	202	19
23:01	262	53	560	14.6	222	5.7	505	0.10	118	0.00	202	202	19
23:02	262	53	560	14.6	224	5.8	527	0.11	116	0.00	202	202	19
23:03	261	53	563	14.7	222	5.7	504	0.10	121	0.00	202	202	20
23:04	260	53	563	14.7	222	5.7	497	0.10	126	0.00	203	203	20
23:05	262	53	560	14.6	225	5.8	516	0.11	124	0.00	203	203	20
23:06	264	54	560	14.6	225	5.8	509	0.10	123	0.00	203	203	20
23:07	264	54	561	14.6	223	5.8	506	0.10	121	0.00	203	203	20
23:08	267	55	563	14.7	221	5.7	498	0.10	122	0.00	203	203	20
23:09	268	55	563	14.7	221	5.7	501	0.10	119	0.00	203	203	20
23:10	268	55	564	14.7	220	5.7	498	0.10	121	0.00	203	203	20
23:11	267	55	564	14.7	220	5.7	502	0.10	119	0.00	203	203	20
23:12	265	54	565	14.7	221	5.7	498	0.10	118	0.00	203	203	20
23:13	264	54	566	14.7	220	5.7	499	0.10	121	0.00	203	203	20
23:14	262	53	566	14.7	222	5.7	492	0.10	124	0.00	203	203	20
23:15	256	51	566	14.7	221	5.7	487	0.10	127	0.00	204	204	20
23:16	254	51	565	14.7	222	5.7	485	0.10	126	0.00	204	204	20
23:17	255	51	562	14.7	225	5.8	488	0.10	122	0.00	204	204	20

Table J.2. (cont'd) Fugitive Stack Data Assessment for FSK DF1, Sample Run 3

.ent:	**NCASI**	Project Number:	**10027-001-002**
Location:	**Idabel, OK**	Operator:	**Short/Roberts/Purser**
Source:	**Kiln Outlet**	Date:	**20 May 1999**

~~libration: 1~~

Time	Wet Temp mv	Wet Temp °F
22:44	197	197
22:45	198	198
22:46	198	198
22:47	198	198
22:48	199	199
22:49	199	199
22:50	199	199
22:51	199	199
22:52	199	199
22:53	199	199
22:54	199	199
22:55	199	199
22:56	199	199
22:57	198	198
22:58	199	199
22:59	199	199
23:00	199	199
23:01	199	199
23:02	199	199
23:03	200	200
23:04	200	200
23:05	200	200
23:06	200	200
23:07	200	200
23:08	200	200
23:09	200	200
23:10	200	200
23:11	200	200
23:12	200	200
23:13	200	200
23:14	201	201
23:15	201	201
23:16	201	201
23:17	201	201

Table J.3. Percent Difference Between the Venting Stack Data and the Fugitive Stack Data

Summary for: Kiln Charge FSK DF4

Sample run number	Sampled interval (minutes)	Average % difference % O2	Average % difference % CO2	Average % difference T_db	Average % difference T_wb	Average % difference VOC
Run 1	0:39	-2.11%	7.00%	-15.89%	-0.71%	-27.05%
Run 2	0:29	-0.11%	-0.93%	-10.79%	-3.18%	4.93%
Run 4	0:29	1.00%	-9.89%	-12.47%	6.30%	9.49%
Run 5	0:59	0.29%	9.35%	0.31%	12.44%	-12.57%

Summary for: Kiln Charge FSK DF5

Sample run number	Sampled interval (minutes)	Average % difference % O2	Average % difference % CO2	Average % difference T_db	Average % difference T_wb	Average % difference VOC
Run 1	0:39	-3.10%	-11.97%	-13.65%	9.35%	-14.63%
Run 2	0:59	3.96%	2.25%	-10.53%	11.03%	1.89%
Run 3	0:59	-6.46%	3.25%	-11.08%	2.98%	-10.72%
Run 4	0:59	7.66%	-9.88%	-13.11%	-7.48%	-4.15%
Run 5	0:59	-12.63%	-6.43%	-1.75%	-3.55%	-3.57%

Summary for: Kiln Charge FSK DF6

Sample run number	Sampled interval (minutes)	Average % difference % O2	Average % difference % CO2	Average % difference T_db	Average % difference T_wb	Average % difference VOC
Run 1	0:59	-15.79%	45.36%	3.39%	10.23%	34.53%
Run 2	0:59	6.97%	0.27%	-11.83%	-1.24%	16.26%
Run 3	0:59	-6.49%	-7.17%	-13.62%	-1.76%	-39.37%
Run 4	0:59	9.38%	-11.00%	-14.92%	-5.80%	-7.95%
Run 5	0:59	-5.34%	-9.97%	-10.00%	-3.14%	-152.15%

APPENDIX K

SQUARE ROOT OF DELTA-P VALUES AND ANOVA TESTS

Table K.1: Average SQRT(delta-P) Values for Kiln Charges FSK DF1 through DF3

Average SQRT(Delta-P) Values for Kiln Charge FSK DF1

EAST STACK:				WEST STACK:			
Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)	Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
13:02	0.4741						
13:55	0.4724						
		16:45	0.2102	16:54	0.5086		
18:25	0.4367					18:25	0.2588
20:53	0.4864					20:58	0.1672
		22:05	0.2084	21:46	0.5051		
0:30	0.4094					0:35	0.2071
		3:30	0.2031	3:30	0.4784		
6:30	0.3244					6:30	0.1430
Average1 =	0.4558	Average =	0.2072	Average =	0.4974	Average1 =	0.2110
Average2 =	0.4339					Average1 =	0.1940

Average SQRT(Delta-P) Values for Kiln Charge FSK DF2

EAST STACK:				WEST STACK:			
Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)	Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
13:41	0.4881	16:48	0.2502	16:52	0.4800	13:30	0.1524
20:00	0.5182	21:32	0.1950	21:25	0.4391	19:56	0.1980
0:30	0.4774	3:38	0.1833	3:30	0.5127	0:35	0.2047
Average =	0.4946	Average =	0.2095	Average =	0.4773	Average =	0.1850

Average SQRT(Delta-P) Values for Kiln Charge FSK DF3

EAST STACK:				WEST STACK:			
Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)	Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
13:36	0.4768	15:46	0.1268	15:50	0.4635	13:31	0.1941
18:14	0.4241	21:15	0.2336	21:06	0.4983	18:16	0.1686
0:02	0.4372	3:20	0.1976	3:06	0.4970	0:13	0.1971
Average =	0.4460	Average =	0.1860	Average =	0.4863	Average =	0.1866

Table K.2: Average SQRT(delta-P) Values for Kiln Charges FSK DF4 through DF6

Average SQRT(Delta-P) Values for Kiln Charge FSK DF4

EAST STACK:

Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
16:40	0.5276		
		17:59	0.1281
22:05	0.5422		
23:20	0.5318		
		0:25	0.2100
		1:40	0.1701
3:00	0.5452		
4:30	0.5504		
Average =	0.5394	Average1 =	0.1901

WEST STACK:

Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
		16:45	0.1000
17:52	0.4946		
19:05	0.5957		
		21:52	0.1943
		23:10	0.1945
0:15	0.5561		
1:50	0.5173		
		2:55	0.1722
		4:25	0.1771
Average1 =	0.5409	Average =	0.1845

Average SQRT(Delta-P) Values for Kiln Charge FSK DF5

EAST STACK:

Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
16:37	0.5300		
18:10	0.5314		
		19:15	0.2329
		20:45	0.1414
22:38	0.5253		
23:45	0.5428		
		0:50	0.2185
		2:15	0.2320
4:15	0.5143		
5:30	0.2505		
Average1 =	0.4824	Average =	0.2062
Average2 =	0.5288		

WEST STACK:

Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
		16:45	0.1597
		18:15	0.2011
19:07	0.4084		
20:50	0.5447		
		22:35	0.1583
		23:50	0.1730
0:50	0.5386		
2:20	0.5415		
		4:20	0.1699
		5:35	0.1954
Average1	0.5083		0.1762
Average2	0.5416		

Average SQRT(Delta-P) Values for Kiln Charge FSK DF6

EAST STACK:

Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
15:35	0.5833		
16:50	0.5762		
		18:15	0.1569
		19:45	0.2115
20:50	0.5643		
22:20	0.5529		
		23:20	0.1949
		1:05	0.2002
2:20	0.5267		
4:00	0.5064		
Average =	0.5516	Average =	0.1937

WEST STACK:

Time:	Venting sqrt(delta-P)	Time:	Fugitive sqrt(delta-P)
		15:40	0.2310
		16:55	0.1711
18:10	0.5145		
19:50	0.4925		
		20:45	0.1886
		22:15	0.1787
23:25	0.5427		
1:10	0.5411		
		2:25	0.1722
		4:05	0.1487
Average1	0.5216	Average =	0.1817

Table K.3: Analysis of Variance for the Average Pitot Tube Delta-P Values From FSK DF1 through DF3

SQRT (Delta-P) Measurements	EAST STACK			WEST STACK		
	DF 1	DF 2	DF 3	DF 1	DF 2	DF 3
Run 1	0.4741 0.4724	0.4881	0.4768			
Run 2				0.5086	0.4800	0.4635
Run 3	0.4367	0.5182	0.4241			
Run 4				0.5051	0.4391	0.4983
Run 5	0.4864	0.4774	0.4372			
Run 6				0.4784	0.5127	0.4970
Number of samples:	4	3	3	3	3	3
Mean Readings =	0.4674	0.4946	0.4460	0.4974	0.4773	0.4863
Totals, T =	1.8696	1.4837	1.3381	1.4921	1.4318	1.4588

Number of different sample sets, k = 6
Number of different sample points, n = 19

Overall Total, sum_T = 9.0741
Overall mean, y_bar = 0.4782 <===
Sum of squares, sum_y^2 = 4.3471

TSS = sum of squares - (sum of totals)^2/n = 0.0134883
SST = sum of (Totals^2/n_I) - (sum of totals)^2/n = 0.0056723
SSE = TSS - SST = 0.0078161

Analysis of Variance ==>. F = 1.8869

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00567227	5	0.00113445	1.886872459	0.1651708	3.0254341
Within Groups	0.00781606	13	0.00060124			
Total	0.01348834	18				

Table K.4: Analysis of Variance for the Average Pitot Tube Delta-P Values From FSK DF4 through DF6

SQRT (Delta-P) Venting Measurements	WEST STACK DF 4	WEST STACK DF 5	WEST STACK DF 6	EAST STACK DF 4	EAST STACK DF 5	EAST STACK DF 6
Run 1				0.5276	0.5300 0.5314	0.5833 0.5762
Run 2	0.4946 0.5957	0.4084 0.5447	0.5145 0.4925			
Run 3				0.5422 0.5318	0.5253 0.5428	0.5643 0.5529
Run 4	*0.5561* 0.5173	*0.5386* 0.5415	*0.5427* 0.5411			
Run 5				0.5452 0.5504	0.5143	0.5267 0.5064
Run 6			0.5171			

							TOTAL
SUM y =	2.16	2.03	2.61	2.70	2.64	3.31	15.46
Mean Readings =	0.5409	0.5083	0.5216	0.5394	0.5288	0.5516	0.5330 <===
Mean difference #1 =	0.00006	0.00061	0.00013	0.00004	0.00002	0.00035	0.00
Number of samples:	4	4	5	5	5	6	29.00
	1.176	*1.047*	*1.362*	*1.455383*	*1.398429*	*1.830220*	*8.27*
Mean difference #2 =	0.00592	0.0133	0.0017	0.000360	0.0004	0.0044	0.0262
Mean difference #3 =	0.00025	0.00243	0.00065	0.00021	0.00009	0.00209	0.0057

number of groupings, k = 6

p = 6

size of pop. for equally sized groups, n = 4.0000

n = 29.00

TABLE 1: Based on an equal number of samples in each group

Source of variance	Sum of Squares SS	Degrees of freedom v	Mean square MS
Between samples(1):	0.0058 (SSTr)	5.00	0.0012 (MSTr)
Within samples(2):	0.0262 (SSE)	18.00	0.0015 (MSE)
Totals	0.0321		

F_calc = MSTr/MSE = 0.8020

TABLE 2: Based on an unequal number of samples in each group

Source of variance	Sum of Squares SS	Degrees of freedom v	Mean square MS
Between samples(1):	0.0057 (SSTr)	5.00	0.0011 (MSTr)
Within samples(2):	0.0262 (SSE)	23.00	0.0011 (MSE)
Totals	0.0319		

F_calc = MSTr/MSE = 1.0037

Compare F for alpha = 0.05 ==> F_0.05 = 3.13. Therefore check to see F_0.05 > F_calc:

RESULTS

No Significant Difference for Either Case

SUMMARY Anova: Single Factor

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	4	2.164	0.5409	0.001975
Column 2	4	2.033	0.5083	0.004445
Column 3	5	2.608	0.5216	0.000436
Column 4	5	2.697	0.5394	0.000090
Column 5	5	2.644	0.5288	0.000107
Column 6	6	3.310	0.5516	0.000887

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0057222	5	0.00114444	1.0036688	0.437794706	2.6400002
Within Groups	0.0262259	23	0.00114026			
Total	0.0319481	28				

Table K.5: Average SQRT(delta-P) Values for Kiln Charges INDF1 through INDF7

Average SQRT(Delta-P) Values for Kiln Charge INDF1

Run #	Time:	sqrt(delta-P)		Run #	Time:	sqrt(delta-P)
1	17:00	0.2469		5	5:47	0.2579
1	19:01	0.2574		5	7:30	0.2495
2	20:10	0.2496		6	9:00	0.2519
2	22:00	0.2595		6	10:04	0.2375
3	23:20	0.2655		7	13:02	0.2430
3	1:06	0.2631		8	15:30	0.2488
4	2:30	0.2475		9	17:00	0.2497
4	4:25	0.2615				

Average SQRT(Delta-P) Values for Kiln Charge INDF2

Run #	Time:	sqrt(delta-P)		Run #	Time:	sqrt(delta-P)
1	21:55	0.3481		5	10:00	0.3407
1	0:06	0.3407		5	12:00	0.3480
1	0:16	0.3406		6	14:00	0.3479
2	2:27	0.3443		7	17:00	0.3339
2	2:37	0.3597		8	20:03	0.3356
3	5:20	0.4240		9	21:55	0.3280
4	6:48	0.3993				
4	8:00	0.3814				

Average SQRT(Delta-P) Values for Kiln Charge INDF3

Run #	Time:	sqrt(delta-P)		Run #	Time:	sqrt(delta-P)
1	23:45	0.3256		5	13:50	0.2951
1	2:00	0.3142		6	16:00	0.3274
2	2:30	0.3035		7	17:30	0.3301
2	4:20	0.2958		7	20:00	0.3183
3	5:50	0.3089		8	22:10	0.3226
4	8:30	0.3121		9	0:15	0.3258
4	9:20	0.3068		9	2:45	0.3218
5	11:30	0.3246				

Average SQRT(Delta-P) Values for Kiln Charge INDF5

Run #	Time:	sqrt(delta-P)		Run #	Time:	sqrt(delta-P)
1	15:30	0.3517		6	7:30	0.3354
1	17:30	0.3484		6	9:25	0.3078
2	19:30	0.3134		7	11:50	0.3067
3	21:30	0.3217				
3	23:30	0.3163		8	13:30	0.3028
4	1:30	0.3118		8	15:30	0.3074
5	3:45	0.3318				
5	5:30	0.3239				

Average SQRT(Delta-P) Values for Kiln Charge INDF6

Run #	Time:	sqrt(delta-P)		Run #	Time:	sqrt(delta-P)
1	18:30	0.3316		6	9:45	0.3286
1	20:30	0.3214		6	11:30	0.3190
2	22:30	0.3188		7	12:40	0.3199
3	1:30	0.3164				
4	3:30	0.3289		8	14:50	0.3161
4	5:30	0.3245		8	16:40	0.3268
5	6:30	0.3265				
5	8:30	0.3222				

Average SQRT(Delta-P) Values for Kiln Charge INDF7

Run #	Time:	sqrt(delta-P)		Run #	Time:	sqrt(delta-P)
1	20:15	0.3379		6	11:00	0.3618
1	22:15	0.3282		6	13:15	0.3551
2	0:15	0.3336		7	14:45	0.3580
3	2:15	0.3188		7	16:30	0.3186
3	4:15	0.3057		8	18:15	0.3258
4	6:15	0.3147				
5	8:20	0.3584				
5	9:45	0.3586				

Table K.6: Analysis of Variance for the Average SQRT(Delta-P) Values From FSK INDF1-INDF3 & INDF5-INDF7

SQRT (Delta-P) Venting Measurements	IDF1	IDF2	IDF3	IDF5	IDF6	IDF7
Run 1	0.2469 0.2574	0.3481 0.3407 0.3406	0.3256 0.3142	0.3517 0.3484	0.3316 0.3214	0.3379 0.3282
Run 2	0.2496 0.2595	0.3443 0.3597	0.3035 0.2958	0.3134	0.3188	0.3336
Run 3	0.2655 0.2631	0.4240	0.3089	0.3217 0.3163	0.3164	0.3188 0.3057
Run 4	0.2475 0.2615	0.3993 0.3814	0.3121 0.3068	0.3118	0.3289 0.3245	0.3147
Run 5	0.2579 0.2495	0.3407 0.3480	0.3246 0.2951	0.3318 0.3239	0.3265 0.3222	0.3584 0.3586
Run 6	0.2519 0.2375	0.3479	0.3274	0.3354 0.3078	0.3286 0.3190	0.3618 0.3551
Run 7	0.2430	0.3339	0.3301 0.3183	0.3067	0.3199	0.3580 0.3186
Run 8	0.2488	0.3356	0.3226	0.3028 0.3074	0.3161 0.3268	0.3258
Run 9**	0.2497	0.3280	0.3258 0.3218			
**NOTE:	(1 hour)	(1 hour)	(5 hours)	(45 minutes)	(53 minutes)	(1 hour)

							TOTAL	
SUM y =	3.79	4.97	4.73	4.18	4.20	4.38	22.46	
Mean Readings =	0.2526	0.3552	0.3155	0.3215	0.3231	0.3366	0.3304	<===
Mean difference #1 =	0.00604	0.00061	0.00022	0.00008	0.00005	0.00004	0.0010	
Number of samples:	15	14	15	13	13	13	68.00	
sum of squares of all y's	0.958	1.776	1.495	1.347	1.358	1.477	7.45	
Mean difference #2 =	0.0009	0.0099	0.0018	0.0031	0.0003	0.0047	0.0198	
Mean difference #3 =	0.0906	0.0086	0.0033	0.0010	0.0007	0.0005	0.0141	

number of groupings, k = 5

p = 5

size of pop. for equally sized groups, n = 13.0000

n = 68.00

TABLE 1: Based on an equal number of samples in each group

Source of variance	Sum of Squares SS	Degrees of freedom v	Mean square MS
Between samples(1):	0.0137 (SSTr)	4.00	0.0034 (MSTr)
Within samples(2):	0.0198 (SSE)	60.00	0.0003 (MSE)
Totals	0.0334		

F_calc = MSTr/MSE = 10.3736

TABLE 2: Based on an unequal number of samples in each group

Source of variance	Sum of Squares SS	Degrees of freedom v	Mean square MS
Between samples(1):	0.0141 (SSTr)	4.00	0.00353 (MSTr)
Within samples(2):	0.0198 (SSE)	63.00	0.00031 (MSE)
Totals	0.0339		

F_calc = MSTr/MSE = 11.2536

Compare F for alpha = 0.05 ==> 2.5300

Therefore check to see F_0.05 > F_calc:

RESULTS

Shows significant difference for both cases

SUMMARY — Anova: Single Factor for columns B thru f

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	14	4.97	0.3552	0.00076
Column 2	15	4.73	0.3155	0.00013
Column 3	13	4.18	0.3215	0.00026
Column 4	13	4.20	0.3231	0.00003
Column 5	13	4.38	0.3366	0.00039

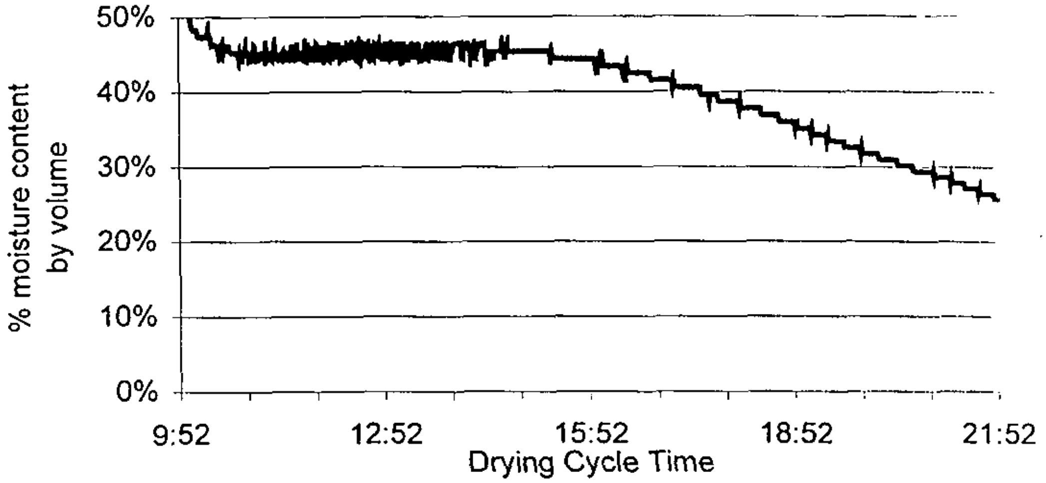
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0141	4	0.00353	11.25	5.95E-07	2.52
Within Groups	0.0198	63	0.00031			
Total	0.0338842	67				

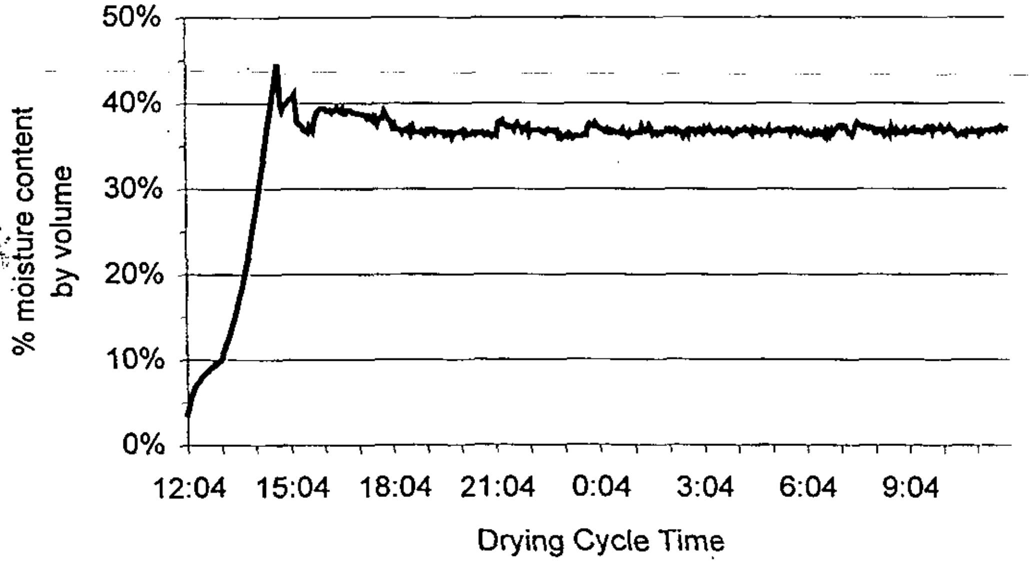
APPENDIX L

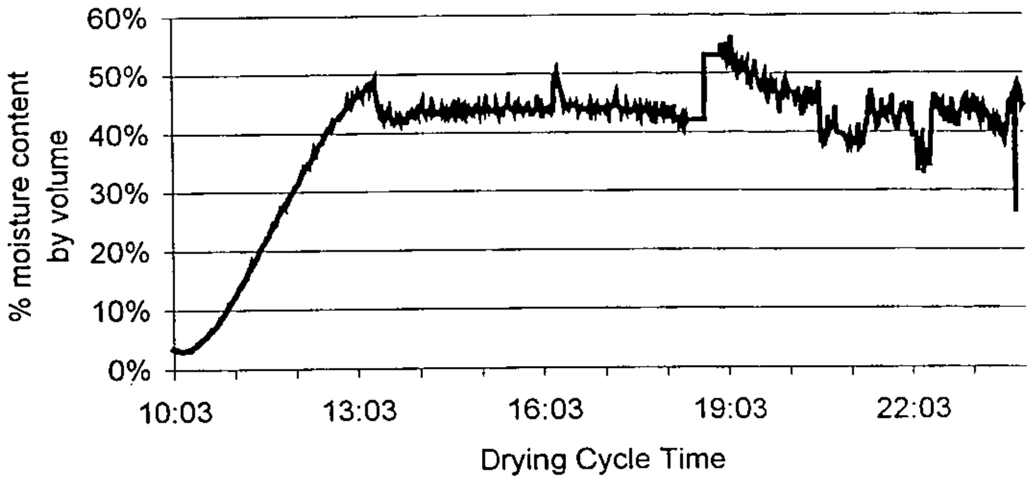
VARIABILITY STUDY PERCENT MOISTURE CONTENT PROFILES FOR KILN EXHAUST

Variability Study MSU 2b
%Moisture Content of Kiln Exhuast
By Wet/Dry Bulb Temperature Method

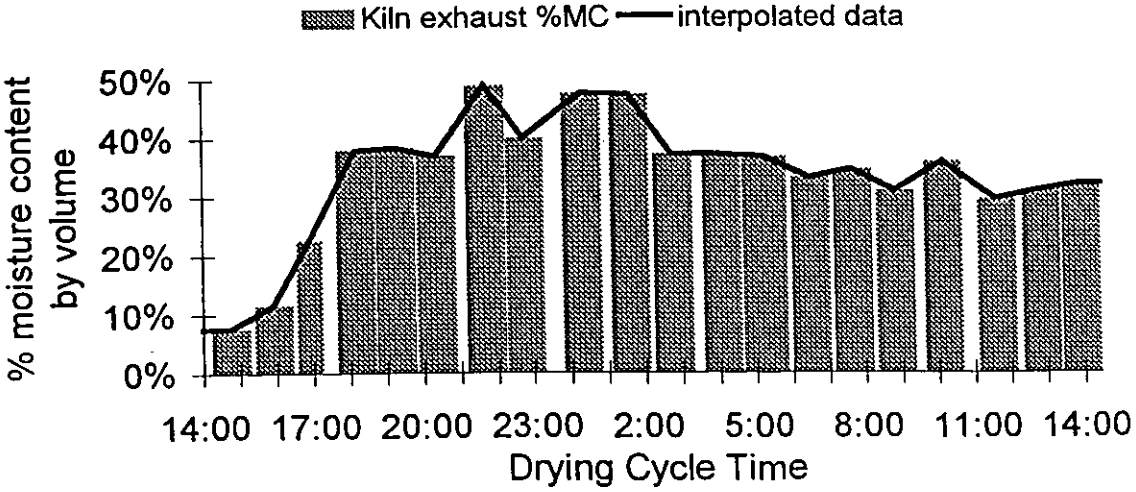


Variability Study OSU 5a
% Moisture Content of Kiln Exhaust Gas
By Wet/Dry Bulb Temperature Method





Variability Study Horizon Engineering 1b
% Moisture of Kiln Exhaust Gas By
Wet/Dry Bulb Temperature Method



Variability Study Charge NCSU/DEECO 3
%Moisture Content of Kiln Exhaust
By Moisture Train Method

APPENDIX M

EXAMPLE OF THE DETERMINATION OF THE MOISTURE CONTENT LEVELS AT THE FULL-SCALE KILNS (SECTION 5.5.1.4)

Table M.1 shows an interval of data from the direct-fired kiln. At 19:03, the moisture train value of 33% was chosen for the corrected %MC. The next corrected %MC data point chosen from the two measurement method results was at 22:10. The corrected %MC values between 19:03 and 22:10 were interpolated. Note that at 19:40 and 20:38, the moisture train provided results of 40% MC and 2% MC, respectively, but the wet/dry bulb data remained around 34%. Then at 21:50, the moisture train data returned to 33% once again. A decision was made not to include those anomalies because the wet/bulb data appeared to indicate no major process disruptions.

Table M.2, from the steam kiln data set, has been included to demonstrate how the wet/dry bulb data can also be affected by measurement system anomalies. The interpolated period for the corrected data in this table was from 04:49 to 05:59. Note the range in wet/dry bulb temperatures for the inlet side of the heat exchanger. Furthermore, the data over the same time period for the outlet side is consistently lower than the moisture train data collected.

Table M.1

Kiln Charge FSK DF2

Time	Venting Stack		%Diff between WB/DB & Moisture Train	%MC used for flow rates		DB Temp. used for flow rates	WD Temp for plots
	WB/DB %MC	Moisture Train %MC					
19:02	32.6%	33%	-1%	33.1%		189	161
19:03	33.5%	33%	1%	33.1%	*	189	162
19:04	32.6%	33%	-1%	33.1%		188	161
19:05	32.7%	33%	-1%	33.1%		187	161
19:06	33.5%	33%	1%	33.1%		187	162
19:07	33.5%	33%	1%	33.1%		187	162
19:08	33.5%	33%	1%	33.1%		187	162
19:09	33.5%	33%	1%	33.1%		187	162
19:10	33.5%	33%	1%	33.1%		187	162
19:11	33.5%	33%	1%	33.1%		188	162
19:12	33.5%	33%	1%	33.1%		188	162
19:13	33.5%	33%	1%	33.1%		189	162
19:14	33.4%	33%	1%	33.1%		191	162
19:15	33.3%	33%	1%	33.1%		192	162
19:16	33.3%	33%	1%	33.1%		192	162
19:17	33.3%	33%	1%	33.1%		193	162
19:18	33.3%	33%	1%	33.1%		192	162
19:19	34.2%	33%	3%	33.1%		191	163
19:20	34.2%	33%	3%	33.1%		192	163
19:21	34.2%	33%	3%	33.1%		192	163
19:22	34.2%	33%	3%	33.1%		193	163
19:23	34.2%	33%	3%	33.1%		193	163
19:24	34.1%			33.1%		194	163
19:25	34.2%			33.1%		193	163
19:26	34.2%			33.1%		193	163
19:27	33.3%			33.1%		192	162
19:28	34.2%			33.1%		193	163
19:29	33.3%			33.1%		193	162
19:30	33.3%			33.1%		192	162
19:31	32.5%			33.1%		192	161
19:32	33.3%			33.1%		193	162
19:33	32.5%			33.1%		193	161
19:34	33.3%			33.1%		193	162
19:35	32.5%			33.0%		193	161
19:36	33.3%			33.0%		193	162
19:37	32.5%			33.0%		193	161
19:38	32.5%			33.0%		193	161
19:39	33.3%			33.0%		193	162
19:40	33.3%	40%	-18%	33.0%		192	162
19:41	33.4%	40%	-18%	33.0%		191	162
19:42	33.4%	40%	-18%	33.0%		191	162
19:43	33.4%	40%	-18%	33.0%		191	162
19:44	33.4%	40%	-18%	33.0%		191	162
19:45	33.4%	40%	-18%	33.0%		191	162
19:46	33.3%	40%	-18%	33.0%		192	162
19:47	34.2%	40%	-15%	33.0%		192	163
19:48	34.2%	40%	-16%	33.0%		193	163
19:49	33.3%	40%	-18%	33.0%		192	162
19:50	33.3%	40%	-18%	33.0%		192	162
19:51	34.3%	40%	-15%	33.0%		191	163
19:52	34.3%	40%	-15%	33.0%		191	163
19:53	33.4%	40%	-18%	33.0%		191	162
19:54	34.3%	40%	-15%	33.0%		191	163
19:55	34.3%	40%	-15%	33.0%		191	163
19:56	34.3%	40%	-15%	33.0%		190	163
19:57	34.3%	40%	-15%	33.0%		191	163
19:58	34.2%	40%	-15%	33.0%		192	163

Table M.1

Kiln Charge FSK DF2

Time	Venting Stack WB/DB %MC	Venting Stack Moisture Train %MC	%Diff between WB/DB & Moisture Train	%MC used for flow rates	DB Temp. used for flow rates	WD Temp for plots
19:59	34.2%	40%	-16%	33.0%	193	163
20:00	34.1%	40%	-16%	33.0%	194	163
20:01	34.1%	40%	-16%	33.0%	194	163
20:02	35.1%	40%	-13%	33.0%	192	164
20:03	35.1%	40%	-13%	33.0%	191	164
20:04	35.1%	40%	-13%	33.0%	192	164
20:05	35.0%	40%	-13%	33.0%	194	164
20:06	34.1%	40%	-16%	33.0%	194	163
20:07	34.1%	40%	-16%	33.0%	195	163
20:08	34.1%	40%	-16%	33.0%	195	163
20:09	34.1%	40%	-16%	33.0%	195	163
20:10	34.2%	40%	-15%	33.0%	192	163
20:11	34.2%	40%	-15%	33.0%	192	163
20:12	34.2%	40%	-15%	33.0%	192	163
20:13	33.4%	40%	-18%	33.0%	192	162
20:14	33.3%	40%	-18%	33.0%	193	162
20:15	33.2%	40%	-18%	33.0%	195	162
20:16	33.2%	40%	-18%	33.0%	195	162
20:17	33.2%	40%	-18%	33.0%	195	162
20:18	33.2%	40%	-18%	33.0%	195	162
20:19	33.2%	40%	-18%	33.0%	196	162
20:20	34.1%	40%	-16%	33.0%	194	163
20:21	34.2%			33.0%	193	163
20:22	34.2%			33.0%	193	163
20:23	34.2%			33.0%	193	163
20:24	34.1%			33.0%	194	163
20:25	34.1%			33.0%	195	163
20:26	35.1%			33.0%	193	164
20:27	34.3%			33.0%	191	163
20:28	35.1%			33.0%	192	164
20:29	34.1%			33.0%	195	163
20:30	35.0%			33.0%	195	164
20:31	34.1%			33.0%	196	163
20:32	34.1%			33.0%	196	163
20:33	34.1%			33.0%	196	163
20:34	34.1%			33.0%	196	163
20:35	34.1%			33.0%	196	163
20:36	34.1%			33.0%	196	163
20:37	33.2%			33.0%	196	162
20:38	34.1%	2%	175%	33.0%	196	163
20:39	33.2%	2%	175%	33.0%	196	162
20:40	33.2%	2%	175%	33.0%	196	162
20:41	33.2%	2%	175%	33.0%	196	162
20:42	33.2%	2%	175%	33.0%	195	162
20:43	33.2%	2%	175%	33.0%	195	162
20:44	34.1%	2%	176%	33.0%	195	163
20:45	33.2%	2%	175%	33.0%	196	162
20:46	34.1%	2%	176%	33.0%	195	163
20:47	33.2%	2%	175%	32.9%	195	162
20:48	34.1%	2%	176%	32.9%	195	163
20:49	34.1%	2%	175%	32.9%	196	163
20:50	34.1%	2%	176%	32.9%	195	163
20:51	34.1%	2%	176%	32.9%	194	163
20:52	33.3%	2%	175%	32.9%	194	162
20:53	33.3%	2%	175%	32.9%	194	162
20:54	33.3%	2%	175%	32.9%	194	162
20:55	32.5%	2%	174%	32.9%	193	161

Table M.1

Kiln Charge FSK DF2

	Venting Stack		%Diff between WB/DB & Moisture Train	%MC used for flow rates	DB Temp. used for flow rates	WD Temp for plots
Time	WB/DB %MC	Moisture Train %MC				
20:56	32.5%	2%	174%	32.9%	192	161
20:57	32.5%	2%	174%	32.9%	192	161
20:58	31.7%	2%	174%	32.9%	192	160
20:59	31.7%	2%	174%	32.9%	192	160
21:00	31.7%	2%	174%	32.9%	192	160
21:01	31.7%	2%	174%	32.9%	191	160
21:02	31.7%	2%	174%	32.9%	192	160
21:03	30.9%	2%	173%	32.9%	192	159
21:04	30.9%	2%	173%	32.9%	192	159
21:05	31.6%	2%	174%	32.9%	193	160
21:06	31.6%	2%	174%	32.9%	193	160
21:07	31.6%	2%	174%	32.9%	194	160
21:08	32.5%	2%	174%	32.9%	193	161
21:09	32.5%			32.9%	193	161
21:10	32.5%			32.9%	193	161
21:11	32.5%			32.9%	193	161
21:12	31.6%			32.9%	193	160
21:13				32.9%	193	160
21:14				32.9%	194	160
21:15				32.9%	194	160
21:16				32.9%	194	160
21:17				32.9%	194	161
21:18				32.9%	195	161
21:19				32.9%	195	161
21:20				32.9%	195	161
21:21				32.9%	195	161
21:22				32.9%	196	161
21:23				32.9%	196	161
21:24				32.9%	196	161
21:25				32.9%	196	162
21:26				32.9%	197	162
21:27				32.9%	197	162
21:28				32.9%	197	162
21:29				32.9%	198	162
21:30				32.9%	198	162
21:31				32.9%	198	162
21:32				32.9%	198	162
21:33				32.9%	199	162
21:34				32.9%	199	163
21:35				32.9%	199	163
21:36				32.9%	199	163
21:37				32.9%	200	163
21:38				32.9%	200	163
21:39				32.9%	200	163
21:40				32.9%	200	163
21:41				32.9%	201	163
21:42				32.9%	201	164
21:43				32.9%	201	164
21:44				32.9%	201	164
21:45				32.9%	202	164
21:46	34.7%			32.9%	202	164
21:47	34.7%			32.9%	202	164
21:48	34.7%			32.9%	202	164
21:49	34.7%			32.9%	203	164
21:50	34.7%	33%	5%	32.9%	203	164
21:51	34.7%	33%	5%	32.9%	203	164
21:52	35.6%	33%	8%	32.9%	203	165

Table M.1

Kiln Charge FSK DF2

	Venting Stack		%Diff between WB/DB & Moisture Train	%MC used for flow rates		DB Temp. used for flow rates	WD Temp for plots
Time	WB/DB %MC	Moisture Train %MC					
21:53	34.7%	33%	5%	32.9%		203	164
21:54	34.7%	33%	5%	32.9%		203	164
21:55	34.7%	33%	5%	32.9%		203	164
21:56	34.7%	33%	6%	32.9%		202	164
21:57	34.7%	33%	5%	32.9%		203	164
21:58	34.7%	33%	5%	32.9%		203	164
21:59	34.7%	33%	6%	32.9%		202	164
22:00	34.7%	33%	6%	32.8%		202	164
22:01	33.8%	33%	3%	32.8%		202	163
22:02	34.7%	33%	6%	32.8%		202	164
22:03	35.6%	33%	8%	32.8%		202	165
22:04	34.7%	33%	6%	32.8%		201	164
22:05	34.7%	33%	6%	32.8%		201	164
22:06	34.7%	33%	6%	32.8%		202	164
22:07	34.7%	33%	6%	32.8%		202	164
22:08	35.6%	33%	8%	32.8%		201	165
22:09	33.9%	33%	3%	32.8%		201	163
22:10	33.9%	33%	3%	32.8%	*	200	163
22:11	33.9%	33%	3%	32.9%		200	163
22:12	33.9%	33%	3%	32.9%		200	163

Table M.2

Kiln Charge FSK INDF3

	Inlet side of heat exchanger		Outlet side of heat exchanger		WB/DB %Diff between locations	% Difference Between WB/DB and moisture train		Corrected Inlet %MC used for flow rates	Corrected Outlet %MC used for flow rates	Corrected Inlet		Corrected Outlet	
Time	WB/DB %MC	Moisture train %MC	WB/DB %MC	Moisture train %MC		Inlet	Outlet			WB Temp. used for Graphs	DB Temp. used for Graphs	WB Temp. used for Graphs	DB Temp. used for flow rates
4:47	83.7%	74%	41.4%	65%	68%	12.5%	-44.4%	73.4%	64.8%	199	224	171	179
4:48	1669.4%	74%	40.3%	65%	191%	183.1%	-46.7%	73.6%	64.9%	200	223	170	180
4:49	72.1%	74%	41.3%	65%	54%	-2.4%	-44.5%	73.8%	65.0%	200	223	171	180
4:50	75.8%	74%	39.3%	65%	63%	2.7%	-49.2%	73.8%	65.1%	199	223	169	182
4:51	79.7%	74%	42.2%	65%	61%	7.7%	-42.4%	73.9%	65.3%	200	223	172	182
4:52	78.9%	74%	38.3%	65%	69%	6.7%	-51.5%	73.9%	65.5%	200	223	168	182
4:53	77.8%	74%	42.2%	65%	59%	5.2%	-42.4%	73.9%	65.6%	200	222	172	182
4:54	77.4%	74%	42.2%	65%	59%	4.8%	-42.4%	74.0%	65.8%	200	222	172	182
4:55	77.5%	74%	42.2%	65%	59%	4.8%	-42.4%	74.0%	66.0%	200	222	172	182
4:56	78.8%	74%	43.3%	65%	58%	6.6%	-40.1%	74.0%	66.1%	200	222	173	182
4:57	83.0%	74%	42.3%	65%	65%	11.7%	-42.2%	74.1%	66.3%	200	222	172	180
4:58	78.3%	74%	43.3%	65%	58%	5.9%	-40.1%	74.1%	66.5%	200	222	173	182
4:59	78.3%	74%	41.2%	65%	62%	5.9%	-44.7%	74.1%	66.7%	200	221	171	182
5:00	77.7%	74%	42.2%	65%	59%	5.2%	-42.4%	74.2%	66.8%	200	221	172	182
5:01	77.5%	74%	39.3%	65%	65%	4.9%	-49.2%	74.2%	67.0%	200	221	169	182
5:02	77.5%	74%	40.3%	65%	63%	4.9%	-47.0%	74.3%	67.2%	200	221	170	182
5:03	77.6%	74%	40.3%	65%	63%	5.0%	-46.9%	74.3%	67.3%	200	220	170	182
5:04	#######	74%	43.3%	65%	200%	199.9%	-40.1%	74.3%	67.5%	200	222	173	182
5:05	522.0%	74%	41.2%	65%	171%	150.5%	-44.7%	74.4%	67.7%	200	222	171	183
5:06	530.6%	74%	41.2%	65%	171%	151.2%	-44.7%	74.4%	67.8%	200	222	171	183
5:07	530.6%	74%	43.2%	65%	170%	151.2%	-40.2%	74.4%	68.0%	200	222	173	183
5:08	530.5%	74%	44.3%	65%	169%	151.1%	-37.9%	74.5%	68.2%	200	223	174	183
5:09	530.5%	74%	44.3%	65%	169%	151.1%	-37.9%	74.5%	68.3%	200	223	174	183
5:10	#######	74%	42.2%	65%	199%	198.4%	-42.5%	74.5%	68.5%	200	221	172	183
5:11	385.2%	74%	39.2%	65%	163%	135.7%	-49.3%	74.6%	68.7%	200	221	169	183
5:12	264.3%	74%	40.2%	65%	147%	112.7%	-47.0%	74.6%	68.9%	200	221	170	183
5:13	533.1%	74%	41.2%	65%	171%	151.4%	-44.7%	74.6%	69.0%	200	221	171	183
5:14	533.8%	74%	41.2%	65%	171%	151.4%	-44.8%	74.7%	69.2%	200	221	171	184
5:15	453.2%	74%	45.3%	65%	164%	144.0%	-35.6%	74.7%	69.4%	200	221	175	183
5:16	-83.9%	74%	41.2%	65%	586%	3115.4%	-44.8%	74.7%	69.5%	200	220	171	183
5:17	-83.9%	74%	43.2%	65%	625%	3117.1%	-40.2%	74.8%	69.7%	200	220	173	183
5:18	-39.3%	74%	43.2%	65%	-4173%	-655.0%	-40.2%	74.8%	69.9%	200	220	173	183
5:19	77.6%	74%	44.3%	65%	55%	5.0%	-37.9%	74.8%	70.0%	200	220	174	183
5:20	77.5%	74%	43.2%	65%	57%	4.9%	-40.2%	74.9%	70.2%	200	222	173	183
5:21	79.2%		39.3%		67%			74.9%	70.4%	201	222	169	183
5:22	79.2%		43.2%		59%			74.9%	70.6%	201	222	173	183
5:23	79.2%		40.2%		65%			75.0%	70.7%	201	222	170	183
5:24	80.8%		41.1%		65%			75.0%	70.9%	202	224	171	185
5:25								75.0%	71.1%	202	223	174	185
5:26								75.1%	71.2%	201	223	178	185
5:27	79.1%		52.0%		41%			75.1%	71.4%	201	222	181	185
5:28	81.6%		48.5%		51%			75.1%	71.6%	202	222	178	185
5:29	81.1%		49.7%		48%			75.2%	71.7%	202	222	179	184
5:30	86.8%	76%	49.7%	77%	54%	13.0%	-42.9%	75.2%	71.9%	202	222	179	185
5:31	83.4%	76%	48.5%	77%	53%	9.0%	-45.1%	75.2%	72.1%	202	222	178	185
5:32	85.2%	76%	47.5%	77%	57%	11.2%	-47.3%	75.3%	72.3%	201	222	177	184
5:33	83.4%	76%	44.2%	77%	61%	9.0%	-53.9%	75.3%	72.4%	201	222	174	184
5:34	63.9%	76%	47.4%	77%	30%	-17.5%	-47.4%	75.4%	72.6%	201	223	177	185
5:35	-83.9%	76%	49.7%	77%	782%	4164.8%	-42.8%	75.4%	72.8%	200	223	179	184
5:36	-82.3%	76%	48.5%	77%	775%	5192.0%	-45.1%	75.4%	72.9%	201	223	178	185
5:37	-82.4%	76%	46.3%	77%	713%	5159.0%	-49.6%	75.5%	73.1%	201	223	176	186
5:38	-82.4%	76%	49.7%	77%	808%	5159.0%	-42.9%	75.5%	73.3%	201	223	179	185
5:39	46.4%	76%	50.9%	77%	-9%	-48.6%	-40.7%	75.5%	73.4%	201	223	180	185
5:40	83.0%	76%	47.4%	77%	55%	8.5%	-47.3%	75.6%	73.6%	202	223	177	185
5:41	80.8%	76%	46.3%	77%	54%	5.8%	-49.6%	75.6%	73.8%	202	223	176	185
5:42	80.8%	76%	49.7%	77%	48%	5.9%	-42.9%	75.6%	74.0%	202	223	179	185
5:43	80.8%	76%	48.6%	77%	50%	5.9%	-45.1%	75.7%	74.1%	202	223	178	185
5:44	79.1%	76%	46.4%	77%	52%	3.7%	-49.5%	75.7%	74.3%	201	223	176	184
5:45	79.1%	76%	45.3%	77%	54%	3.7%	-51.7%	75.7%	74.5%	201	223	175	184
5:46	79.1%	76%	45.2%	77%	54%	3.7%	-51.8%	75.8%	74.6%	201	223	175	185
5:47	79.1%	76%	49.7%	77%	46%	3.7%	-42.9%	75.8%	74.8%	201	223	179	185
5:48	79.1%	76%	46.4%	77%	52%	3.7%	-49.5%	75.8%	75.0%	201	223	176	184
5:49	79.1%	76%	46.4%	77%	52%	3.8%	-49.5%	75.9%	75.1%	201	222	176	184
5:50	79.1%	76%	48.6%	77%	48%	3.7%	-45.1%	75.9%	75.3%	201	223	178	185
5:51	79.1%	76%	48.5%	77%	48%	3.7%	-45.1%	75.9%	75.5%	201	223	178	185
5:52	77.4%	76%	45.3%	77%	52%	1.6%	-51.7%	76.0%	75.7%	200	223	175	184
5:53	79.1%	76%	46.3%	77%	52%	3.7%	-49.5%	76.0%	75.8%	201	223	176	185
5:54	79.1%	76%	43.2%	77%	59%	3.7%	-56.1%	76.0%	76.0%	201	223	173	184
5:55	79.1%	76%	44.2%	77%	57%	3.7%	-54.0%	76.1%	76.2%	201	223	174	185
5:56	79.1%	76%	48.6%	77%	48%	3.7%	-45.1%	76.1%	76.3%	201	223	178	184
5:57	79.1%	76%	48.6%	77%	48%	3.7%	-45.0%	76.1%	76.5%	201	223	178	184
5:58	79.1%	76%	47.4%	77%	50%	3.7%	-47.3%	76.2%	76.7%	201	223	177	185
5:59	80.8%	76%	46.3%	77%	54%	5.9%	-49.5%	76.2%	76.8%	202	223	176	185

APPENDIX N

EXAMPLE FOR CALCULATING THE FORMALDEHYDE AND METHANOL CONCENTRATION PARAMETERS (SECTION 5.5.2)

APPENDIX N

EXAMPLE FOR CALCULATING THE FORMALDEHYDE AND METHANOL CONCENTRATION PARAMETERS (SECTION 5.5.2)

The example below calculates the formaldehyde and methanol concentrations for the first sample run of FSK INDF3. The data used in this example are shown in Tables N.1 and N.2.

1. The field data for run S3N1 were entered at the top portion of Table N.1.
2. The total dry sample volume collected for this sample run was calculated to be 61.67 dsL.
3. The amount of water collected in the impingers at the end of S3N1 was 74.1 mL.
4. The laboratory analysis of the impinger water for formaldehyde and methanol yielded 0.56 ppm and 14.19 ppm, respectively.
5. Table N.2 shows that the reported canister concentration of methanol, 60 ppbv-wet, was converted to a mass, 5.0 μg.
6. The canister mass value for methanol was imported into Table N.1.
7. Then the canister and impinger mass values were combined to yield 1056 μg, the total mass captured of methanol for S3N1.
8. Equation 13 was then used to calculate the resulting kiln gas concentrations for formaldehyde, 0.54 ppmvd, and methanol,12.85 ppmvd.

Table N.1

Kiln Charge FSK INDF3

HAPs Sample Run	S3 N1	S3D1
Start time	23:25	23:25
End time	2:26	2:26
FSK Run Time, minutes	181	181
initial flow (mL/min)	365	367
final flow (mL/min)	364	369
average flow (mL/min)	**365**	**368**
sample volume (waL)	**65.97**	**66.61**
Pre-amb temp (F)	82	84
Post-amb temp (F)	78	78
Pre-barometric (in. Hg)	29.64	29.58
Post-barometric (in. Hg)	29.63	29.58
Total volume collected, wsL	**63.89**	**64.27**
Kw	3.28	3.28
Pw, in Hg	1.04	1.08
Total volume collected, dsL	**61.67**	**61.95**
pre imp. Weight (g)	21.40	21.70
post imp weight (g)	95.50	92.30
Final impinger volume, mL	**74.1**	**70.6**
field spike volume, mL		

LABORATORY	NCASI	
Analyte	formaldehyde	30
Sample ID:	S3 N1	S3D1
Reported imp. conc., ug/mL	0.56	0.50
Lab imp. duplicate, ug/mL	0.56	
%difference Lab dup	0.0%	
field imp.spike conc., ug/mL		
Captured impinger mass, ug	41	35
field imp. spike mass, ug		
Impinger mass, ug	41	35
Captured canister mass, ug		
Total mass, ug	**41**	**35**
Kiln gas conc., ppmv	0.54	0.46
	%diff. =	16.60%

LABORATORY	NCASI	
Analyte	methanol	32.04
Sample ID:	S3 N1	S3D1
Reported imp. conc., ug/mL	14.19	13.35
Lab imp. duplicate, ug/mL		
%difference Lab dup		
field imp.spike conc., ug/mL		
Captured impinger mass, ug	1051	943
field imp. spike mass, ug		
Impinger mass, ug	1051	943
Captured canister mass, ug	5.02	8.67
Total mass, ug	**1056**	**951**
Kiln gas conc., ppmv	12.85	11.52
	%diff. =	10.96%

Table N.2

Canister Run Number:	**S3N1**			
% Moisture in canister =	0.78%			
Initial Lab canister Pressure, in Hg. =	25.32	at	538.67	R
Final Lab Canister Pressure, in. Hg =	25.32	at	538.67	R
Dilution Factor = P_N2/Psample*Tsample/TN2 =	1			
Mass Correction Factor =	12.6			
gmol to Liters at 68F =	24.01			
Nominal can volume =	6	Liters		

Analytes of interest:	Molecular Weights	Concentration Diluted with N2	Concentration Diluted with N2	Concentration Undiluted without N2	Standard Volume of analyte in can	Uncorrected Mass of analyte in can	Corrected Mass of analyte in can
	g/gmole	ppbv-wet	ppbv-dry	ppbv-dry	L	ug	ug
ACETALDEHYDE	44.05	1288	1298	1298	6.46E-06	11.834	**149.2**
ACETONE	58.08	581	586	586	2.92E-06	7.046	**88.8**
ACROLEIN	56.06	61	62	62	3.08E-07	0.719	**9.1**
BENZENE	78.11	BDL	N/A	N/A	N/A	N/A	**BDL**
M,P-XYLENE	106.16	BDL	N/A	N/A	N/A	N/A	**BDL**
METHANOL	32	60	60	60	2.99E-07	0.398	**5.0**
METHYL ETHYL KETONE (MEK)	72.11	BDL	N/A	N/A	N/A	N/A	**BDL**
METHYL ISOBUTYL KETONE	100.16	BDL	N/A	N/A	N/A	N/A	**BDL**
O-XYLENE	106.16	BDL	N/A	N/A	N/A	N/A	**BDL**
PHENOL	94.11	BDL	N/A	N/A	N/A	N/A	**BDL**
PROPIONALDEHYDE	58.08	BDL	N/A	N/A	N/A	N/A	**BDL**
STYRENE	104.14	BDL	N/A	N/A	N/A	N/A	**BDL**
TOLUENE	92.13	BDL	N/A	N/A	N/A	N/A	**BDL**
		ppmv-wet					
ALPHA-PINENE	136.23	48.14	48.52	49	2.41E-04	1368	**17249**
BETA-PINENE	136.23	21.33	21.49	21.5	1.07E-04	606	**7641**

*NOTE: BDL = Below Detection Limit   N/A = not applicable

Table N.3

Kiln Charge FSK INDF3

Print this table to reference run times

Kiln Charge FSK INDF3

Run #	Start	End	Duration	Average Flow rate dscfm
S3 N1	23:25	2:26	181	2,184
S3 N2	2:26	5:26	180	1,229
S3 N3	5:26	8:25	179	749
S3 N4	8:26	11:25	179	927
S3 N5	11:26	14:25	179	1,022
S3 N6	14:26	17:25	179	837
S3 N7	17:26	20:25	179	788
S3 N8	20:25	23:25	180	992
S3 N9	23:33	2:25	172	1,265
S3 N10	2:34	4:19	105	1,318

Table N.4

Kiln Charge FSK INDF3
Averaged Mass Emission Rates

CHANGE RERENCE
MBF = 156.1

Sample Run	Flow rate dscfm	formaldehyde in kiln gas ppmv	NCASI formaldehyde mass emission rate Lbs/MBF per minute for each sample run	methanol in kiln gas ppmv	NCASI methanol mass emission rate Lbs/MBF per minute for each sample run
S3 N1	2,184	0.54	5.87E-07	12.85	1.49E-05
S3 N2	1,229	7.56	4.63E-06	84.09	5.50E-05
S3 N3	749	14.42	5.39E-06	177.14	7.07E-05
S3 N4	927	20.54	9.49E-06	239.28	1.18E-04
S3 N5	1,022	19.83	1.01E-05	270.07	1.47E-04
S3 N6	837	23.95	9.99E-06	342.11	1.52E-04
S3 N7	788	31.27	1.23E-05	537.69	2.26E-04
S3 N8	992	28.28	1.40E-05	448.31	2.37E-04
S3 N9	1,265	28.13	1.77E-05	387.52	2.61E-04
S3 N10	1,318	45.59	2.99E-05	435.18	3.05E-04

APPENDIX O

EXAMPLE OF THE TERMINATION POINT OF THE MEASURED DATA SET (SECTION 5.5.2.1)

APPENDIX O

EXAMPLE OF THE TERMINATION POINT OF THE MEASURED DATA SET (SECTION 5.5.2.1)

In order to provide a better understanding of how the standard %Wood-MC method was implemented, the %Wood-MC data for MSU DF2 have been presented below as an example.

Drying Cycle Start Time:	07:34
Drying Cycle End Time:	21:20
Weight of Kiln Charge, Green:	105 lb
Weight of Kiln Charge, Kiln-dry:	70 lb
Weight of Kiln Charge, Oven-dry:	64 lb

Step 1: Table O.1 shows that the $\%MC_{exh}$ (from the kiln gas) at the end of the drying cycle (21:20) was calculated to be 32.5%. From sample data, the 21:20 incremental value for the absolute humidity was calculated to be 0.299 lb of water per lb of dry gas.

Step 2: The amount of water exhausted from the kiln over the interval from 21:19 to 21:20 was determined from the absolute humidity and the dry standard flow rate. The 21:20 incremental value was calculated to be 0.051 lb of water.

Step 3: Since 21:20 was the end of the actual drying cycle, the unadjusted cumulative water weight was the same as the incremental value, 0.051 lb of water. Note that the unadjusted cumulative water value for 21:19, however, was 0.102 lb of water.

Step 4: The charge weight for 21:20 corresponded to the kiln-dry weight as reported (70.0 lb) by MSU for this charge. The charge weight for each of the previous data points was determined by adding the cumulative water weight to the 70 lb. For example, at 21:19 the charge weight was estimated as 70.10 lb.

Step 5: Equation 18 was then used to determine the $\%Wood\text{-}MC_{dry}$ of the charge for each minute of the drying cycle.

Step 6: Calculation models often require correction factors to adjust predicted results to the actual results attempting to be modeled. For this case, the data in the cumulative water weight column was adjusted by a correction factor in order to match the calculated green charge weight with the reported green charge weight at the start of the drying cycle.

Table O.2 shows that the unadjusted green charge weight was calculated to be 115.12 lb for MSU DF2. The difference between the reported green charge weight, 106 lb, and the calculated green charge weight, 115.12 lb, indicates that the %Wood-MC method added too much water back into the weight of the charge. Therefore, an adjustment of –0.01001 lb of water was made to the cumulative water weight data set. With this adjustment applied, the %Wood-MC data at 06:44 (Table O.3) began to decrease because the calculated amount of water leaving the kiln was below 0.01001 lb at this point. Therefore, the correction factor was not applied to the cumulative water data above 06:45. Thus, the resulting calculated green charge weight at the start of the drying cycle (shown in Table O.4 at 04:35) compared favorably with the reported green charge weight of 106 lb.

Step 7: The termination point for MSU DF2 was determined to be at 20:34 as shown in Table O.5. First, 15% was located in %Wood-MC data column. For this charge, 15% was calculated at 19:58. Then a decision had to be made between terminating the charge at 19:34, when the %Wood-MC was at 16.7%, or 20:34, when the charge was calculated to be at 12.5%Wood-MC.

As previously mentioned, the kiln-dry %Wood-MC was estimated to be 15% for the FSK DF2 test charge. For this case, therefore, the small-scale kiln DF2 sample charges should be terminated at or below the 15%Wood-MC level. Thus, the decision was made to terminate MSU DFW at 20:34.

The purpose for terminating the Phase II sample charge data at an even hour data point was to simplify the mass emission rate integration procedure by maintaining the integrated data in hourly blocks of time.

Table O.1

Date	Time	%MC kiln air (V/V)	Absolute Humidity lbH2O/lbdry air	Amount of water exhausted lbs	cumulative water exhausted lbs	Phase 2 Charge weight lbs	Phase 2 Wood %MC dry basis
07-01-99	20:34	33.4%	0.31133	0.05318	2.446	72.45	13.2%
07-01-99	20:35	33.4%	0.31133	0.05318	2.393	72.39	13.1%
07-01-99	20:36	33.4%	0.31133	0.05318	2.339	72.34	13.0%
07-01-99	20:37	33.4%	0.31133	0.05318	2.286	72.29	12.9%
07-01-99	20:38	33.4%	0.31133	0.05318	2.233	72.23	12.9%
07-01-99	20:39	33.4%	0.31133	0.05318	2.180	72.18	12.8%
07-01-99	20:40	33.4%	0.31133	0.05318	2.127	72.13	12.7%
07-01-99	20:41	33.4%	0.31133	0.05318	2.074	72.07	12.6%
07-01-99	20:42	33.4%	0.31133	0.05318	2.020	72.02	12.5%
07-01-99	20:43	33.4%	0.31133	0.05318	1.967	71.97	12.4%
07-01-99	20:44	33.4%	0.31133	0.05318	1.914	71.91	12.4%
07-01-99	20:45	33.4%	0.31133	0.05318	1.861	71.86	12.3%
07-01-99	20:46	33.4%	0.31133	0.05318	1.808	71.81	12.2%
07-01-99	20:47	33.4%	0.31133	0.05318	1.754	71.75	12.1%
07-01-99	20:48	33.4%	0.31133	0.05318	1.701	71.70	12.0%
07-01-99	20:49	33.4%	0.31133	0.05318	1.648	71.65	12.0%
07-01-99	20:50	33.4%	0.31133	0.05318	1.595	71.59	11.9%
07-01-99	20:51	33.4%	0.31133	0.05318	1.542	71.54	11.8%
07-01-99	20:52	33.4%	0.31133	0.05318	1.489	71.49	11.7%
07-01-99	20:53	33.4%	0.31133	0.05318	1.435	71.44	11.6%
07-01-99	20:54	33.4%	0.31133	0.05318	1.382	71.38	11.5%
07-01-99	20:55	32.5%	0.29921	0.05111	1.329	71.33	11.5%
07-01-99	20:56	32.5%	0.29921	0.05111	1.278	71.28	11.4%
07-01-99	20:57	32.5%	0.29921	0.05111	1.227	71.23	11.3%
07-01-99	20:58	32.5%	0.29921	0.05111	1.176	71.18	11.2%
07-01-99	20:59	32.5%	0.29921	0.05111	1.125	71.12	11.1%
07-01-99	21:00	32.5%	0.29921	0.05111	1.073	71.07	11.1%
07-01-99	21:01	32.5%	0.29921	0.05111	1.022	71.02	11.0%
07-01-99	21:02	32.5%	0.29921	0.05111	0.971	70.97	10.9%
07-01-99	21:03	32.5%	0.29921	0.05111	0.920	70.92	10.8%
07-01-99	21:04	32.5%	0.29921	0.05111	0.869	70.87	10.7%
07-01-99	21:05	32.5%	0.29921	0.05111	0.818	70.82	10.7%
07-01-99	21:06	32.5%	0.29921	0.05111	0.767	70.77	10.6%
07-01-99	21:07	32.5%	0.29921	0.05111	0.716	70.72	10.5%
07-01-99	21:08	32.5%	0.29921	0.05111	0.664	70.66	10.4%
07-01-99	21:09	32.5%	0.29921	0.05111	0.613	70.61	10.3%
07-01-99	21:10	32.5%	0.29921	0.05111	0.562	70.56	10.3%
07-01-99	21:11	32.5%	0.29921	0.05111	0.511	70.51	10.2%
07-01-99	21:12	32.5%	0.29921	0.05111	0.460	70.46	10.1%
07-01-99	21:13	32.5%	0.29921	0.05111	0.409	70.41	10.0%
07-01-99	21:14	32.5%	0.29921	0.05111	0.358	70.36	9.9%
07-01-99	21:15	32.5%	0.29921	0.05111	0.307	70.31	9.9%
07-01-99	21:16	32.5%	0.29921	0.05111	0.256	70.26	9.8%
07-01-99	21:17	32.5%	0.29921	0.05111	0.204	70.20	9.7%
07-01-99	21:18	32.5%	0.29921	0.05111	0.153	70.15	9.6%
07-01-99	21:19	32.5%	0.29921	0.05111	0.102	70.10	9.5%
07-01-99	21:20	32.5%	0.29921	0.05111	0.051	70.05	9.5%

Table O.2

Date	Time	%MC kiln air (V/V)	Absolute Humidity lbH2O/lbdry air	Amount of water exhausted lbs	cumulative water exhausted lbs	Phase 2 Charge weight lbs	Phase 2 Wood %MC dry basis
07-01-99	4:35	3.0%	0.01909	0.00130	45.116	115.12	79.9%
07-01-99	4:36	3.0%	0.01909	0.00130	45.115	115.12	79.9%
07-01-99	4:37	3.0%	0.01909	0.00130	45.114	115.11	79.9%
07-01-99	4:38	3.1%	0.02002	0.00137	45.112	115.11	79.9%
07-01-99	4:39	3.0%	0.01952	0.00133	45.111	115.11	79.9%
07-01-99	4:40	3.5%	0.02245	0.00153	45.110	115.11	79.9%
07-01-99	4:41	3.7%	0.02409	0.00165	45.108	115.11	79.9%
07-01-99	4:42	3.8%	0.02460	0.00168	45.107	115.11	79.9%
07-01-99	4:43	3.6%	0.02295	0.00157	45.105	115.10	79.9%
07-01-99	4:44	3.6%	0.02321	0.00159	45.103	115.10	79.8%
07-01-99	4:45	3.4%	0.02217	0.00151	45.102	115.10	79.8%
07-01-99	4:46	3.5%	0.02242	0.00153	45.100	115.10	79.8%
07-01-99	4:47	3.5%	0.02242	0.00153	45.099	115.10	79.8%
07-01-99	4:48	3.5%	0.02242	0.00153	45.097	115.10	79.8%
07-01-99	4:49	3.4%	0.02217	0.00151	45.096	115.10	79.8%
07-01-99	4:50	3.5%	0.02269	0.00155	45.094	115.09	79.8%
07-01-99	4:51	3.6%	0.02321	0.00159	45.093	115.09	79.8%
07-01-99	4:52	3.6%	0.02295	0.00157	45.091	115.09	79.8%
07-01-99	4:53	3.7%	0.02376	0.00162	45.089	115.09	79.8%
07-01-99	4:54	3.7%	0.02376	0.00162	45.088	115.09	79.8%
07-01-99	4:55	3.8%	0.02460	0.00168	45.086	115.09	79.8%
07-01-99	4:56	3.8%	0.02460	0.00168	45.084	115.08	79.8%
07-01-99	4:57	4.0%	0.02571	0.00176	45.083	115.08	79.8%
07-01-99	4:58	4.1%	0.02660	0.00182	45.081	115.08	79.8%
07-01-99	4:59	4.1%	0.02634	0.00180	45.079	115.08	79.8%
07-01-99	5:00	4.0%	0.02608	0.00178	45.077	115.08	79.8%
07-01-99	5:01	4.2%	0.02725	0.00186	45.076	115.08	79.8%
07-01-99	5:02	4.2%	0.02725	0.00186	45.074	115.07	79.8%
07-01-99	5:03	4.2%	0.02725	0.00186	45.072	115.07	79.8%
07-01-99	5:04	4.5%	0.02917	0.00199	45.070	115.07	79.8%
07-01-99	5:05	4.5%	0.02917	0.00199	45.068	115.07	79.8%
07-01-99	5:06	4.5%	0.02917	0.00199	45.066	115.07	79.8%
07-01-99	5:07	4.4%	0.02891	0.00198	45.064	115.06	79.8%
07-01-99	5:08	4.6%	0.02991	0.00204	45.062	115.06	79.8%
07-01-99	5:09	4.6%	0.02965	0.00203	45.060	115.06	79.8%
07-01-99	5:10	4.7%	0.03094	0.00211	45.058	115.06	79.8%
07-01-99	5:11	4.9%	0.03200	0.00219	45.056	115.06	79.8%
07-01-99	5:12	4.9%	0.03200	0.00219	45.054	115.05	79.8%
07-01-99	5:13	4.9%	0.03200	0.00219	45.052	115.05	79.8%

Table O.3

Date	Time	%MC kiln air (V/V)	Absolute Humidity lbH2O/lbdry air	Amount of water exhausted lbs	cumulative water exhausted lbs	Phase 2 Charge weight lbs	Phase 2 Wood %MC dry basis
07-01-99	6:12	12.2%	0.08652	0.00591	36.068	106.068	65.7%
07-01-99	6:13	12.2%	0.08652	0.00591	36.062	106.062	65.7%
07-01-99	6:14	12.9%	0.09222	0.00630	36.056	106.056	65.7%
07-01-99	6:15	12.9%	0.09222	0.00630	36.050	106.050	65.7%
07-01-99	6:16	12.9%	0.09222	0.00630	36.044	106.044	65.7%
07-01-99	6:17	13.3%	0.09521	0.00651	36.037	106.037	65.7%
07-01-99	6:18	13.7%	0.09830	0.00672	36.031	106.031	65.7%
07-01-99	6:19	13.6%	0.09798	0.00669	36.024	106.024	65.7%
07-01-99	6:20	13.6%	0.09798	0.00669	36.017	106.017	65.7%
07-01-99	6:21	14.0%	0.10149	0.00693	36.011	106.011	65.6%
07-01-99	6:22	14.0%	0.10116	0.00691	36.004	106.004	65.6%
07-01-99	6:23	14.4%	0.10478	0.00716	35.997	105.997	65.6%
07-01-99	6:24	14.8%	0.10818	0.00739	35.990	105.990	65.6%
07-01-99	6:25	14.8%	0.10784	0.00737	35.982	105.982	65.6%
07-01-99	6:26	14.8%	0.10784	0.00737	35.975	105.975	65.6%
07-01-99	6:27	15.2%	0.11169	0.00763	35.967	105.967	65.6%
07-01-99	6:28	15.6%	0.11497	0.00786	35.960	105.960	65.6%
07-01-99	6:29	15.6%	0.11497	0.00786	35.952	105.952	65.5%
07-01-99	6:30	15.6%	0.11497	0.00786	35.944	105.944	65.5%
07-01-99	6:31	16.0%	0.11837	0.00809	35.936	105.936	65.5%
07-01-99	6:32	16.0%	0.11837	0.00809	35.928	105.928	65.5%
07-01-99	6:33	16.5%	0.12259	0.00838	35.920	105.920	65.5%
07-01-99	6:34	16.4%	0.12224	0.00835	35.912	105.912	65.5%
07-01-99	6:35	16.9%	0.12658	0.00865	35.903	105.903	65.5%
07-01-99	6:36	16.9%	0.12623	0.00863	35.895	105.895	65.5%
07-01-99	6:37	17.3%	0.13036	0.00891	35.886	105.886	65.4%
07-01-99	6:38	17.3%	0.13001	0.00888	35.877	105.877	65.4%
07-01-99	6:39	17.3%	0.13001	0.00888	35.868	105.868	65.4%
07-01-99	6:40	17.8%	0.13427	0.00917	35.859	105.859	65.4%
07-01-99	6:41	17.8%	0.13427	0.00917	35.850	105.850	65.4%
07-01-99	6:42	17.7%	0.13391	0.00915	35.841	105.841	65.4%
07-01-99	6:43	18.2%	0.13868	0.00948	35.832	105.832	65.4%
07-01-99	6:44	18.8%	0.14362	0.00981	35.822	105.822	65.3%
07-01-99	6:45	19.2%	0.14797	0.01011	35.813	105.813	65.3%
07-01-99	6:46	19.2%	0.14797	0.01011	35.803	105.803	65.3%
07-01-99	6:47	19.2%	0.14760	0.01009	35.802	105.802	65.3%
07-01-99	6:48	19.2%	0.14760	0.01009	35.802	105.802	65.3%
07-01-99	6:49	19.7%	0.15248	0.01042	35.802	105.802	65.3%
07-01-99	6:50	19.7%	0.15210	0.01039	35.802	105.802	65.3%
07-01-99	6:51	20.2%	0.15753	0.01076	35.801	105.801	65.3%
07-01-99	6:52	20.8%	0.16316	0.01115	35.801	105.801	65.3%
07-01-99	6:53	20.8%	0.16277	0.01112	35.800	105.800	65.3%
07-01-99	6:54	20.7%	0.16238	0.01110	35.798	105.798	65.3%

Table O.4

Date	Time	%MC kiln air (V/V)	Absolute Humidity lbH2O/lbdry air	Amount of water exhausted lbs	cumulative water exhausted lbs	Phase 2 Charge weight lbs	Phase 2 Wood %MC dry basis
07-01-99	4:35	3.0%	0.01909	0.00130	36.358	106.358	66.2%
07-01-99	4:36	3.0%	0.01909	0.00130	36.356	106.356	66.2%
07-01-99	4:37	3.0%	0.01909	0.00130	36.355	106.355	66.2%
07-01-99	4:38	3.1%	0.02002	0.00137	36.354	106.354	66.2%
07-01-99	4:39	3.0%	0.01952	0.00133	36.352	106.352	66.2%
07-01-99	4:40	3.5%	0.02245	0.00153	36.351	106.351	66.2%
07-01-99	4:41	3.7%	0.02409	0.00165	36.349	106.349	66.2%
07-01-99	4:42	3.8%	0.02460	0.00168	36.348	106.348	66.2%
07-01-99	4:43	3.6%	0.02295	0.00157	36.346	106.346	66.2%
07-01-99	4:44	3.6%	0.02321	0.00159	36.345	106.345	66.2%
07-01-99	4:45	3.4%	0.02217	0.00151	36.343	106.343	66.2%
07-01-99	4:46	3.5%	0.02242	0.00153	36.341	106.341	66.2%
07-01-99	4:47	3.5%	0.02242	0.00153	36.340	106.340	66.2%
07-01-99	4:48	3.5%	0.02242	0.00153	36.338	106.338	66.2%
07-01-99	4:49	3.4%	0.02217	0.00151	36.337	106.337	66.2%
07-01-99	4:50	3.5%	0.02269	0.00155	36.335	106.335	66.1%
07-01-99	4:51	3.6%	0.02321	0.00159	36.334	106.334	66.1%
07-01-99	4:52	3.6%	0.02295	0.00157	36.332	106.332	66.1%
07-01-99	4:53	3.7%	0.02376	0.00162	36.331	106.331	66.1%
07-01-99	4:54	3.7%	0.02376	0.00162	36.329	106.329	66.1%
07-01-99	4:55	3.8%	0.02460	0.00168	36.327	106.327	66.1%
07-01-99	4:56	3.8%	0.02460	0.00168	36.326	106.326	66.1%
07-01-99	4:57	4.0%	0.02571	0.00176	36.324	106.324	66.1%
07-01-99	4:58	4.1%	0.02660	0.00182	36.322	106.322	66.1%
07-01-99	4:59	4.1%	0.02634	0.00180	36.320	106.320	66.1%
07-01-99	5:00	4.0%	0.02608	0.00178	36.319	106.319	66.1%
07-01-99	5:01	4.2%	0.02725	0.00186	36.317	106.317	66.1%
07-01-99	5:02	4.2%	0.02725	0.00186	36.315	106.315	66.1%
07-01-99	5:03	4.2%	0.02725	0.00186	36.313	106.313	66.1%
07-01-99	5:04	4.5%	0.02917	0.00199	36.311	106.311	66.1%
07-01-99	5:05	4.5%	0.02917	0.00199	36.309	106.309	66.1%
07-01-99	5:06	4.5%	0.02917	0.00199	36.307	106.307	66.1%
07-01-99	5:07	4.4%	0.02891	0.00198	36.305	106.305	66.1%
07-01-99	5:08	4.6%	0.02991	0.00204	36.303	106.303	66.1%
07-01-99	5:09	4.6%	0.02965	0.00203	36.301	106.301	66.1%
07-01-99	5:10	4.7%	0.03094	0.00211	36.299	106.299	66.1%
07-01-99	5:11	4.9%	0.03200	0.00219	36.297	106.297	66.1%
07-01-99	5:12	4.9%	0.03200	0.00219	36.295	106.295	66.1%
07-01-99	5:13	4.9%	0.03200	0.00219	36.293	106.293	66.1%
07-01-99	5:14	5.3%	0.03449	0.00236	36.291	106.291	66.1%
07-01-99	5:15	5.2%	0.03422	0.00234	36.288	106.288	66.1%
07-01-99	5:16	5.4%	0.03539	0.00242	36.286	106.286	66.1%

Table O.5

Date	Time	%MC kiln air (V/V)	Absolute Humidity lbH2O/lbdry air	Amount of water exhausted lbs	cumulative water exhausted lbs	Phase 2 Charge weight lbs	Phase 2 Wood %MC dry basis
07-01-99	19:33	34.2%	0.32353	0.05527	4.738	74.738	16.8%
07-01-99	19:34	34.2%	0.32352	0.05527	4.693	74.693	16.7%
07-01-99	19:35	34.3%	0.32409	0.06459	4.647	74.647	16.6%
07-01-99	19:36	34.3%	0.32409	0.06459	4.593	74.593	16.6%
07-01-99	19:37	34.3%	0.32409	0.05536	4.538	74.538	16.5%
07-01-99	19:38	34.3%	0.32408	0.05536	4.493	74.493	16.4%
07-01-99	19:39	34.2%	0.32351	0.05526	4.448	74.448	16.3%
07-01-99	19:40	34.2%	0.32351	0.05526	4.402	74.402	16.3%
07-01-99	19:41	34.3%	0.32407	0.05536	4.357	74.357	16.2%
07-01-99	19:42	34.3%	0.32407	0.05536	4.312	74.312	16.1%
07-01-99	19:43	34.3%	0.32407	0.05536	4.266	74.266	16.0%
07-01-99	19:44	34.3%	0.32407	0.05536	4.221	74.221	16.0%
07-01-99	19:45	34.3%	0.32406	0.05536	4.176	74.176	15.9%
07-01-99	19:46	34.3%	0.32406	0.05536	4.130	74.130	15.8%
07-01-99	19:47	34.3%	0.32406	0.05536	4.085	74.085	15.8%
07-01-99	19:48	34.3%	0.32405	0.05536	4.040	74.040	15.7%
07-01-99	19:49	34.3%	0.32405	0.05536	3.994	73.994	15.6%
07-01-99	19:50	34.3%	0.32405	0.05536	3.949	73.949	15.5%
07-01-99	19:51	34.3%	0.32405	0.05536	3.904	73.904	15.5%
07-01-99	19:52	34.3%	0.32404	0.05536	3.858	73.858	15.4%
07-01-99	19:53	34.3%	0.32404	0.05536	3.813	73.813	15.3%
07-01-99	19:54	34.3%	0.32404	0.05535	3.767	73.767	15.3%
07-01-99	19:55	34.3%	0.32403	0.05535	3.722	73.722	15.2%
07-01-99	19:56	34.3%	0.32403	0.05535	3.677	73.677	15.1%
07-01-99	19:57	34.3%	0.32403	0.05535	3.631	73.631	15.0%
07-01-99	19:58	34.3%	0.32403	0.05535	3.586	73.586	15.0%
07-01-99	19:59	34.3%	0.32402	0.05535	3.541	73.541	14.9%
07-01-99	20:00	34.3%	0.32402	0.05535	3.495	73.495	14.8%
07-01-99	20:01	34.3%	0.32402	0.05535	3.450	73.450	14.8%
07-01-99	20:02	34.3%	0.32401	0.05535	3.405	73.405	14.7%
07-01-99	20:03	34.3%	0.32401	0.06458	3.359	73.359	14.6%
07-01-99	20:04	34.3%	0.32401	0.05535	3.305	73.305	14.5%
07-01-99	20:05	34.3%	0.32401	0.05535	3.260	73.260	14.5%
07-01-99	20:06	34.3%	0.32401	0.05535	3.214	73.214	14.4%
07-01-99	20:07	34.2%	0.32344	0.05525	3.169	73.169	14.3%
07-01-99	20:08	34.2%	0.32344	0.05525	3.124	73.124	14.3%
07-01-99	20:09	34.2%	0.32344	0.05525	3.078	73.078	14.2%
07-01-99	20:10	34.2%	0.32344	0.05525	3.033	73.033	14.1%
07-01-99	20:11	34.3%	0.32401	0.05535	2.988	72.988	14.0%
07-01-99	20:12	34.3%	0.32401	0.05535	2.943	72.943	14.0%
07-01-99	20:13	34.3%	0.32401	0.05535	2.897	72.897	13.9%
07-01-99	20:14	34.3%	0.32401	0.05535	2.852	72.852	13.8%
07-01-99	20:15	34.3%	0.32401	0.05535	2.806	72.806	13.8%
07-01-99	20:16	34.3%	0.32401	0.05535	2.761	72.761	13.7%
07-01-99	20:17	34.3%	0.32401	0.05535	2.716	72.716	13.6%
07-01-99	20:18	34.3%	0.32401	0.05535	2.670	72.670	13.5%
07-01-99	20:19	34.3%	0.32401	0.05535	2.625	72.625	13.5%
07-01-99	20:20	33.4%	0.31133	0.05318	2.580	72.580	13.4%
07-01-99	20:21	33.4%	0.31133	0.05318	2.537	72.537	13.3%
07-01-99	20:22	33.4%	0.31133	0.05318	2.493	72.493	13.3%
07-01-99	20:23	33.4%	0.31133	0.05318	2.450	72.450	13.2%
07-01-99	20:24	33.4%	0.31133	0.05318	2.407	72.407	13.1%
07-01-99	20:25	33.4%	0.31133	0.05318	2.364	72.364	13.1%
07-01-99	20:26	33.4%	0.31133	0.05318	2.321	72.321	13.0%
07-01-99	20:27	33.4%	0.31133	0.05318	2.278	72.278	12.9%

Table O.5

Date	Time	%MC kiln air (V/V)	Absolute Humidity lbH2O/lbdry air	Amount of water exhausted lbs	cumulative water exhausted lbs	Phase 2 Charge weight lbs	Phase 2 Wood %MC dry basis
07-01-99	20:28	33.4%	0.31133	0.05318	2.234	72.234	12.9%
07-01-99	20:29	33.4%	0.31133	0.05318	2.191	72.191	12.8%
07-01-99	20:30	33.4%	0.31133	0.05318	2.148	72.148	12.7%
07-01-99	20:31	33.4%	0.31133	0.05318	2.105	72.105	12.7%
07-01-99	20:32	33.4%	0.31133	0.05318	2.062	72.062	12.6%
07-01-99	20:33	33.4%	0.31133	0.05318	2.019	72.019	12.5%
07-01-99	20:34	33.4%	0.31133	0.05318	1.975	71.975	12.5%
07-01-99	20:35	33.4%	0.31133	0.05318	1.932	71.932	12.4%
07-01-99	20:36	33.4%	0.31133	0.05318	1.889	71.889	12.3%
07-01-99	20:37	33.4%	0.31133	0.05318	1.846	71.846	12.3%
07-01-99	20:38	33.4%	0.31133	0.05318	1.803	71.803	12.2%
07-01-99	20:39	33.4%	0.31133	0.05318	1.759	71.759	12.1%
07-01-99	20:40	33.4%	0.31133	0.05318	1.716	71.716	12.1%
07-01-99	20:41	33.4%	0.31133	0.05318	1.673	71.673	12.0%
07-01-99	20:42	33.4%	0.31133	0.05318	1.630	71.630	11.9%
07-01-99	20:43	33.4%	0.31133	0.05318	1.587	71.587	11.9%
07-01-99	20:44	33.4%	0.31133	0.05318	1.544	71.544	11.8%
07-01-99	20:45	33.4%	0.31133	0.05318	1.500	71.500	11.7%
07-01-99	20:46	33.4%	0.31133	0.05318	1.457	71.457	11.7%
07-01-99	20:47	33.4%	0.31133	0.05318	1.414	71.414	11.6%
07-01-99	20:48	33.4%	0.31133	0.05318	1.371	71.371	11.5%
07-01-99	20:49	33.4%	0.31133	0.05318	1.328	71.328	11.4%
07-01-99	20:50	33.4%	0.31133	0.05318	1.285	71.285	11.4%
07-01-99	20:51	33.4%	0.31133	0.05318	1.241	71.241	11.3%
07-01-99	20:52	33.4%	0.31133	0.05318	1.198	71.198	11.2%
07-01-99	20:53	33.4%	0.31133	0.05318	1.155	71.155	11.2%
07-01-99	20:54	33.4%	0.31133	0.05318	1.112	71.112	11.1%
07-01-99	20:55	32.5%	0.29921	0.05111	1.069	71.069	11.0%
07-01-99	20:56	32.5%	0.29921	0.05111	1.028	71.028	11.0%
07-01-99	20:57	32.5%	0.29921	0.05111	0.986	70.986	10.9%
07-01-99	20:58	32.5%	0.29921	0.05111	0.945	70.945	10.9%
07-01-99	20:59	32.5%	0.29921	0.05111	0.904	70.904	10.8%
07-01-99	21:00	32.5%	0.29921	0.05111	0.863	70.863	10.7%
07-01-99	21:01	32.5%	0.29921	0.05111	0.822	70.822	10.7%
07-01-99	21:02	32.5%	0.29921	0.05111	0.781	70.781	10.6%
07-01-99	21:03	32.5%	0.29921	0.05111	0.740	70.740	10.5%
07-01-99	21:04	32.5%	0.29921	0.05111	0.699	70.699	10.5%
07-01-99	21:05	32.5%	0.29921	0.05111	0.658	70.658	10.4%
07-01-99	21:06	32.5%	0.29921	0.05111	0.617	70.617	10.3%
07-01-99	21:07	32.5%	0.29921	0.05111	0.575	70.575	10.3%
07-01-99	21:08	32.5%	0.29921	0.05111	0.534	70.534	10.2%
07-01-99	21:09	32.5%	0.29921	0.05111	0.493	70.493	10.1%
07-01-99	21:10	32.5%	0.29921	0.05111	0.452	70.452	10.1%
07-01-99	21:11	32.5%	0.29921	0.05111	0.411	70.411	10.0%
07-01-99	21:12	32.5%	0.29921	0.05111	0.370	70.370	10.0%
07-01-99	21:13	32.5%	0.29921	0.05111	0.329	70.329	9.9%
07-01-99	21:14	32.5%	0.29921	0.05111	0.288	70.288	9.8%
07-01-99	21:15	32.5%	0.29921	0.05111	0.247	70.247	9.8%
07-01-99	21:16	32.5%	0.29921	0.05111	0.206	70.206	9.7%
07-01-99	21:17	32.5%	0.29921	0.05111	0.164	70.164	9.6%
07-01-99	21:18	32.5%	0.29921	0.05111	0.123	70.123	9.6%
07-01-99	21:19	32.5%	0.29921	0.05111	0.082	70.082	9.5%
07-01-99	21:20	32.5%	0.29921	0.05111	0.041	70.041	9.4%

APPENDIX P

FULL-SCALE KILN AND SMALL-SCALE KILN PHASE II VOC MASS EMISSION RATE RESULTS FOR LUMBER CHANGES DRIED UNDER THE DIRECT-FIRED TEMPERATURE SCHEDULE

Kiln Charge FSK DF1
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**4.19**
	%MC Wood	Per Sample Run:
Run 1		0.6892
Run 2		0.6671
Run 3		0.4754
Run 4		0.3657
Run 5		0.5580
Run 6		1.1905
Run 7	11.7%	0.2465

Kiln Charge FSK DF1
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	19.37	0.00	19.38
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
11.93	62%	7:07	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	0	0	180
Run 3	120	120	180
Run 4	97	77	180
Run 5	122	122	180
Run 6	217	217	263
Run 7	0	0	0

Kiln Charge FSK DF2
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**4.70**
	%MC Wood	Per Sample Run:
Run 1		0.5288
Run 2		0.7906
Run 3		0.7433
Run 4		0.8286
Run 5		0.7564
Run 6	15.5%	1.0562

Kiln Charge FSK DF2
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	17.72	0.00	17.73
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
14.55	82%	2:51	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	147	147	180
Run 2	149	0	180
Run 3	149	149	180
Run 4	149	129	180
Run 5	137	137	180
Run 6	162	162	164
Run 7	0	0	0

Kiln Charge FSK DF3
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**4.22**
	%MC Wood	Per Sample Run:
Run 1		0.5796
Run 2		0.5957
Run 3		0.5287
Run 4		0.5869
Run 5		0.8074
Run 6	12.6%	1.1222

Kiln Charge FSK DF3
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	17.98	0.00	18.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
14.12	78%	3:33	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	150	150	180
Run 2	130	0	180
Run 3	148	148	180
Run 4	145	125	180
Run 5	146	146	180
Run 6	148	148	180
Run 7	0	0	0

Kiln Charge FSK DF4
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.90**
	%MC Wood	Per Sample Run:
Run 1		0.2718
Run 2		0.5244
Run 3		0.4437
Run 4		0.5666
Run 5		0.8075
Run 6		0.2844

Kiln Charge FSK DF4
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	16.18	0.00	16.22
Actual sampling time for the adjusted Sample Event (hour)	**Percent of sampling time for the total adjusted drying cycle**	**Total calibration period during drying cycle (hour:min)**	**Duration of data loss during data collection (hour:min)**
15.75	97%	0:28	
Run #	**Reported duration of data collection by contractor (minutes)**	**Actual duration of data collection by contractor (minutes)**	**NCASI Extrapolated Sample Run (minutes)**
Run 1	180	180	180
Run 2	169	169	180
Run 3	177	177	180
Run 4	177	177	180
Run 5	177	177	180
Run 6	64	64	73
Run 7	0	0	0

Kiln Charge FSK DF5
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**3.40**
	%MC Wood	Per Sample Run:
Run 1		0.4681
Run 2		0.6042
Run 3		0.4651
Run 4		0.6353
Run 5		1.0313
Run 6		0.2001

Kiln Charge FSK DF5
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	15.73	0.00	15.75

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
9.12	58%	6:38	

Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	178	178	180
Run 3	178	178	180
Run 4	178	178	180
Run 5	179	179	180
Run 6	35	35	45
Run 7	0	0	0

Kiln Charge FSK DF6
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

Sum Total for the Sample Event:		NCASI integrated value
		3.59
	%MC Wood	Per Sample Run:
Run 1		0.3857
Run 2		0.6440
Run 3		0.4052
Run 4		0.7446
Run 5		1.0330
Run 6		0.3746

Kiln Charge FSK DF6
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	16.27	0.00	16.28
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
16.03	98%	0:15	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	179	179	180
Run 3	179	179	180
Run 4	178	178	180
Run 5	179	179	180
Run 6	67	67	77
Run 7	0	0	0

Kiln Charge MSU DF1A
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**3.21**
	%MC Wood	Per Sample Run:
Run 1	69.7%	0.5082
Run 2	57.7%	0.8379
Run 3	42.4%	0.4419
Run 4	26.9%	0.4959
Run 5: 1st hour	22.0%	
2nd hour	17.5%	
3rd hour	13.1%	0.8248
Run 6	11.8%	0.0966

Kiln Charge MSU DF1A
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	15.30	0.00	15.30
Actual sampling time for the adjusted Sample Event (hour)	**Percent of sampling time for the total adjusted drying cycle**	**Total calibration period during drying cycle to end (hour:min)**	**Duration of data loss during data collection (hour:min)**
13.67	89%	1:12	0:26
Run #	**MSU reported duration of data collection (minutes)**	**MSU reported actual duration of data collection (minutes)**	**Extrapolated Sample Run (minutes)**
Run 1	181	181	180
Run 2	161	155	180
Run 3	165	162	180
Run 4	151	146	180
Run 5	188	176	198
Run 6	0	0	0

Kiln Charge MSU DF1B
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.71**
	%MC Wood	Per Sample Run:
Run 1	88.6%	0.3826
Run 2	76.7%	0.5112
Run 3	59.9%	0.3307
Run 4	40.6%	0.3529
Run 5	21.9%	0.5849
Run 6: 1st hour	16.8%	
2nd hour	12.8%	
end of cycle	11.9%	0.5437

Kiln Charge MSU DF1B
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	16.72	-0.55	17.27

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
12.93	75%	4:52	0:00

Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	177	177	180
Run 2	136	136	180
Run 3	136	136	180
Run 4	136	136	180
Run 5	115	115	180
Run 6	43	43	136

Kiln Charge MSU DF2
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.46**
	%MC Wood	Per Sample Run:
Run 1	64.9%	0.2251
Run 2	55.1%	0.4301
Run 3	43.7%	0.3280
Run 4	30.1%	0.4796
Run 5	16.7%	0.7059
Run 6: 1st hour end of charge	12.5%	0.2940

Kiln Charge MSU DF2
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	16.77	0.77	16.00
Actual sampling time for the adjusted Sample Event (hour)	**Percent of sampling time for the total adjusted drying cycle**	**Total calibration period during drying cycle to end (hour:min)**	**Duration of data loss during data collection (hour:min)**
13.45	84%	2:51	0:01
Run #	**MSU reported duration of data collection (minutes)**	**MSU reported actual duration of data collection (minutes)**	**Extrapolated Sample Run (minutes)**
Run 1	176	175	180
Run 2	148	148	180
Run 3	151	151	180
Run 4	150	150	180
Run 5	152	152	180
Run 6	58	58	60

Kiln Charge MSU DF3A
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.20**
	%MC Wood	Per Sample Run:
Run 1	69.8%	0.27
Run 2	57.5%	0.48
Run 3	42.2%	0.31
Run 4	27.3%	0.37
Run 5	14.9%	0.49
Run 6: 1st hour	11.7%	0.28
2nd hour	9.4%	

Kiln Charge MSU DF3A
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	16.87	0.87	16.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
13.30	83%	2:57	0:00
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	175	175	180
Run 2	155	155	180
Run 3	155	155	180
Run 4	153	153	180
Run 5	123	123	180
Run 6	72	72	60

Kiln Charge MSU DF3B
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.63**
	%MC Wood	Per Sample Run:
Run 1	65.9%	0.2638
Run 2	52.2%	0.6332
Run 3	38.5%	0.3665
Run 4	25.0%	0.3680
Run 5	13.9%	0.6892
Run 6: 1st hour	10.7%	0.3131
end of charge	7.9%	

Kiln Charge MSU DF3B
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	17.00	1.00	16.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
13.45	84%	2:34	0:09
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	179	175	180
Run 2	150	150	180
Run 3	150	145	180
Run 4	148	148	180
Run 5	151	151	180
Run 6	77	77	60

Kiln Charge MSU DF4
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**1.88**
	%MC Wood	Per Sample Run:
Run 1	92.8%	0.131
Run 2	72.6%	0.350
Run 3	52.1%	0.359
Run 4	33.3%	0.412
Run 5	16.9%	0.439
Run 6	11.6%	0.191

Kiln Charge MSU DF4
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	16.10	0.00	16.10
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
12.67	79%	3:18	0:08
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	184	182	180
Run 2	141	141	180
Run 3	151	147	180
Run 4	147	146	180
Run 5	145	144	180
Run 6	41	41	66

MSU Kiln Charge DF5
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**1.86**
	%MC Wood	Per Sample Run:
Run 1	64.8%	0.21
Run 2	49.4%	0.38
Run 3	32.5%	0.37
Run 4	19.3%	0.48
Run 5: 1st hour	15.9%	0.42
2nd hour	13.0%	
3rd hour	11.0%	

MSU Kiln Charge DF5
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	14.77	0.77	14.00
Actual sampling time for the adjusted Sample Event (hour)	**Percent of sampling time for the total adjusted drying cycle**	**Total calibration period during drying cycle to end (hour:min)**	**Duration of data loss during data collection (hour:min)**
12.02	86%	1:55	0:04

Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	181	179	180
Run 2	146	145	180
Run 3	142	142	180
Run 4	150	149	180
Run 5	152	152	120
Run 6	0	0	0

MSU Kiln Charge DF6
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.57**
	%MC Wood	Per Sample Run:
Run 1	69.3%	0.22
Run 2	55.7%	0.51
Run 3	40.5%	0.44
Run 4	25.5%	0.52
Run 5	13.1%	0.77
Run 6	11.8%	0.10

MSU Kiln Charge DF6
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	15.37	0.00	15.37
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
13.35	87%	2:01	0:00
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	181	181	180
Run 2	148	148	180
Run 3	150	150	180
Run 4	154	154	180
Run 5	168	168	180
Run 6	0	0	22

Kiln Charge OSU DF1
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI integrated value
Sum Total for the Sample Event:			**3.09**
		%MC Wood	Per Sample Run:
Run 1		76.1%	0.0491
Run 2		68.6%	0.6609
Run 3		56.4%	0.3836
Run 4		42.0%	0.4202
Run 5		28.4%	0.5043
Run 6		16.9%	0.6200
Run 7	1st hour	14.1%	
	end of charge	11.8%	0.4481

Kiln Charge OSU DF1
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	20.13	-0.02	20.15

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
18.75	93%	1:24	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	173	173	180
Run 2	180	180	180
Run 3	180	180	180
Run 4	165	165	180
Run 5	153	153	180
Run 6	185	185	180
Run 7	72	72	129
Run 8	0	0	0

Kiln Charge OSU DF2C
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI integrated value
Sum Total for the Sample Event:			**3.87**
		%MC Wood	Per Sample Run:
Run 1		68.6%	0.21
Run 2		58.4%	0.77
Run 3		44.7%	0.57
Run 4		31.4%	0.67
Run 5		18.9%	0.95
Run 6	1st hour	15.8%	
	end of charge	12.9%	0.70

Kiln Charge OSU DF2C
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	16.95	0.00	16.95

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
15.58	92%	1:52	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	161	161	180
Run 2	168	168	180
Run 3	167	167	180
Run 4	171	171	180
Run 5	177	177	180
Run 6	45	45	117
Run 7	0	0	0
Run 8	0	0	0

Kiln Charge OSU DF3
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI integrated value
Sum Total for the Sample Event:			**3.79**
		%MC Wood	Per Sample Run:
Run 1		64.4%	0.1599
Run 2		56.5%	0.7403
Run 3		45.5%	0.4445
Run 4		34.4%	0.4938
Run 5		24.3%	0.6158
Run 6		13.8%	1.1114
Run 7	end of charge	12.2%	0.2283

Kiln Charge OSU DF3
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	18.65	0.00	18.65
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
17.43	93%	1:13	0:00
Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	180	180	180
Run 2	177	177	180
Run 3	190	190	180
Run 4	164	164	180
Run 5	165	165	180
Run 6	164	164	180
Run 7	0	0	39
Run 8	0	0	0

OSU Kiln Charge DF4
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI integrated value
Sum Total for the Sample Event:			**2.96**
		%MC Wood	Per Sample Run:
Run 1		52.9%	0.12
Run 2		44.8%	0.53
Run 3		34.3%	0.52
Run 4		23.8%	0.61
Run 5		14.3%	0.88
Run 6	1st hour	11.6%	0.30

OSU Kiln Charge DF4
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	16.05	0.05	16.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
15.02	94%	0:59	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	182	182	180
Run 2	180	180	180
Run 3	180	180	180
Run 4	180	180	180
Run 5	158	158	180
Run 6	0	0	60
Run 7	0	0	0
Run 8	0	0	0

Kiln Charge OSU DF5
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI integrated value
Sum Total for the Sample Event:			2.00
		%MC Wood	Per Sample Run:
Run 1		76.0%	0.10
Run 2		65.7%	0.46
Run 3		49.7%	0.39
Run 4		32.8%	0.39
Run 5		17.4%	0.53
Run 6	1st hour	14.8%	0.13

Kiln Charge OSU DF5
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	15.60	0.00	15.60

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
14.82	95%	0:44	0:03

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	159	157	180
Run 2	180	180	180
Run 3	180	177	180
Run 4	180	180	180
Run 5	181	180	180
Run 6	0	0	36
Run 7	0	0	0
Run 8	0	0	0

Kiln Charge OSU DF6
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI Method integrated value
Sum Total for the Sample Event:			**2.43**
		%MC Wood	Per Sample Run:
Run 1		72.0%	0.11
Run 2		62.3%	0.46
Run 3		47.8%	0.37
Run 4		32.7%	0.42
Run 5		18.8%	0.60
	1st hour	15.6%	
Run 6	end of charge	13.3%	0.46

Kiln Charge OSU DF6
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	17.50	0.50	17.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
15.77	93%	1:14	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	182	182	180
Run 2	180	180	180
Run 3	180	180	180
Run 4	180	180	180
Run 5	120	120	180
Run 6	118	118	120
Run 7	0	0	0
Run 8	0	0	0

APPENDIX Q

FULL-SCALE KILN AND SMALL-SCALE KILN PHASE II VOC MASS EMISSION RATE RESULTS FOR THE LUMBER CHANGES DRIED UNDER THE STEAM TEMPERATURE SCHEDULE

Kiln Charge FSK INDF1
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

	%MC Wood	NCASI integrated value
Sum Total for the Sample Event:		**3.01**
		Per Sample Run:
Run 1		0.6014
Run 2		0.6100
Run 3		0.5581
Run 4		0.2413
Run 5		0.2145
Run 6		0.2269
Run 7		0.2265
Run 8		0.2248
Run 9		0.1066

Kiln Charge FSK INDF1
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	25.12	0.00	25.12
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
		0:09	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	179	179	180
Run 3	179	179	180
Run 4	179	179	180
Run 5	179	179	180
Run 6	179	179	180
Run 7	178	178	180
Run 8	180	180	180
Run 9	65	65	67

Kiln Charge FSK INDF2
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		3.90
	%MC Wood	Per Sample Run:
Run 1		0.7881
Run 2		0.6727
Run 3		0.5679
Run 4		0.3996
Run 5		0.3353
Run 6		0.2845
Run 7		0.3125
Run 8		0.3762
Run 9		0.1611

Kiln Charge FSK INDF2
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	24.90	0.00	24.92
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
		0:10	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	179	179	180
Run 3	179	179	180
Run 4	179	179	180
Run 5	179	179	180
Run 6	179	179	180
Run 7	179	179	180
Run 8	179	179	180
Run 9	50	50	55

Kiln Charge FSK INDF3 VOC Mass Emission Rate (Pounds of VOC as Carbon/MBF)		
		NCASI integrated value
Sum Total for the Sample Event:		**4.71**
	%MC Wood	Per Sample Run:
Run 1		0.6296
Run 2		0.9377
Run 3		0.5601
Run 4		0.4997
Run 5		0.4544
Run 6		0.4048
Run 7		0.3260
Run 8		0.3023
Run 9		0.3355
Run 10		0.2626

Kiln Charge FSK INDF3 Time Schedules			
Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	28.90	0.00	28.90
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
		0:13	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	178	123	180
Run 3	179	179	180
Run 4	179	179	180
Run 5	179	179	180
Run 6	179	179	180
Run 7	179	179	180
Run 8	125	125	180
Run 9	341	341	294

Kiln Charge FSK INDF5
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**3.07**
	%MC Wood	Per Sample Run:
Run 1		0.2678
Run 2		0.5995
Run 3		0.5698
Run 4		0.3880
Run 5		0.2692
Run 6		0.2520
Run 7		0.2667
Run 8		0.3388
Run 9		0.1204

Kiln Charge FSK INDF5
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	24.95	0.00	24.97
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
		0:38	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	179	176	180
Run 2	175	134	180
Run 3	179	179	180
Run 4	173	173	180
Run 5	178	178	180
Run 6	176	176	180
Run 7	179	179	180
Run 8	177	177	180
Run 9	42	42	58

Kiln Charge FSK INDF6 VOC Mass Emission Rate (Pounds of VOC as Carbon/MBF)		
		NCASI integrated value
Sum Total for the Sample Event		**3.00**
	%MC Wood	Per Sample Run:
Run 1		0.5159
Run 2		0.6611
Run 3		0.4374
Run 4		0.2774
Run 5		0.1917
Run 6		0.2134
Run 7		0.2811
Run 8		0.3197
Run 9		0.1004

Kiln Charge FSK INDF6 Time Schedules			
Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	24.98	0.00	25.12
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
		0:21	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	163	180
Run 2	176	176	180
Run 3	179	179	180
Run 4	177	175	180
Run 5	179	179	180
Run 6	179	179	180
Run 7	176	174	180
Run 8	179	179	180
Run 9	53	53	67

Kiln Charge FSK INDF7
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**3.46**
	%MC Wood	Per Sample Run:
Run 1		0.4603
Run 2		0.7174
Run 3		0.6011
Run 4		0.3276
Run 5		0.2801
Run 6		0.2647
Run 7		0.2958
Run 8		0.3592
Run 9		0.1492

Kiln Charge FSK INDF7
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	25.08	0.00	25.10
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
		0:13	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	179	179	180
Run 3	179	179	180
Run 4	178	178	180
Run 5	179	179	180
Run 6	179	179	180
Run 7	179	179	180
Run 8	178	178	180
Run 9	61	61	66

Kiln Charge MSU INDF1
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**4.82**
	%MC Wood	Per Sample Run:
Run 1	80.5%	0.5881
Run 2	51.0%	1.8424
Run 3	26.4%	1.2189
Run 4: 1st hour	20.9%	
2nd hour	16.7%	
3rd hour	13.5%	1.1679
Run 5	7.8%	
Run 6	5.7%	

Kiln Charge MSU INDF1
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	16.63	4.63	12.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
9.55	80%	2:23	0:04
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	173	171	180
Run 2	152	151	180
Run 3	157	157	180
Run 4	155	154	180
Run 5	140	140	0
Run 6	78	78	0

Kiln Charge MSU INDF2
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.63**
	%MC Wood	Per Sample Run:
Run 1	113.7%	0.3963
Run 2	70.6%	0.8212
Run 3	34.2%	0.7168
Run 4	14.0%	0.6957
Run 5	7.9%	
Run 6	7.0%	

Kiln Charge MSU INDF2
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	16.00	4.00	12.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	calibration period during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
10.62	88%	2:12	0:04
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	179	177	180
Run 2	149	148	180
Run 3	157	157	180
Run 4	159	158	180
Run 5	120	120	0
Run 6	64	64	0

Kiln Charge MSU INDF3
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.62**
	%MC Wood	Per Sample Run:
Run 1	106.5%	0.3212
Run 2	63.0%	0.8788
Run 3	26.5%	0.6591
Run 4	11.5%	0.7584
Run 5	6.4%	-
Run 6	4.9%	

Kiln Charge MSU INDF3
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	17.02	5.02	12.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Calibration periods during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
9.42	78%	4:24	0:04
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	175	173	180
Run 2	147	146	180
Run 3	112	112	180
Run 4	131	130	180
Run 5	114	114	0
Run 6	78	78	0

Kiln Charge MSU INDF5
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**3.33**
	%MC Wood	Per Sample Run:
Run 1	93.5%	0.2323
Run 2	80.6%	0.6084
Run 3	58.7%	0.7716
Run 4	38.7%	0.5823
Run 5	23.6%	0.5776
Run 6	13.2%	0.5604

Kiln Charge MSU INDF5
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	21.33	3.33	18.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Calibration periods during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
16.02	89%	3:42	0:04
Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	184	182	180
Run 2	151	150	180
Run 3	149	149	180
Run 4	132	131	180
Run 5	125	125	180
Run 6	128	128	180

Kiln Charge MSU INDF6
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.64**
	%MC Wood	Per Sample Run:
Run 1	84.7%	0.6257
Run 2	53.1%	0.8664
Run 3	28.1%	0.6119
Run 4	14.6%	0.5346
Run 5	7.0%	
Run 6	6.1%	

Kiln Charge MSU INDF6
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	15.08	3.08	12.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Calibration periods during drying cycle to end (hour:min)	Duration of data loss during data collection (hour:min)
9.92	83%	2:37	0:04

Run #	MSU reported duration of data collection (minutes)	MSU reported actual duration of data collection (minutes)	Extrapolated Sample Run (minutes)
Run 1	178	176	180
Run 2	124	123	180
Run 3	159	159	180
Run 4	150	149	180
Run 5	137	137	0
Run 6	0	0	0

Kiln Charge MSU-INDF7
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.35**
	%MC Wood	Per Sample Run:
Run 1	89.5%	0.3704
Run 2	53.8%	0.7152
Run 3	28.0%	0.5725
Run 4	15.8%	0.5332
Run 5: 1st hour	12.9%	0.1555
2nd hour	10.5%	
3rd hour	8.4%	
Run 6	6.6%	

Kiln Charge MSU-INDF7
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of charge (hour)	NCASI sampling time with rampup to end (hour)
3.00	15.97	2.97	13.00
Actual sampling time for the adjusted Sample Event (hour)	**Percent of sampling time for the total adjusted drying cycle**	**Calibration periods during drying cycle to end (hour:min)**	**Duration of data loss during data collection (hour:min)**
9.87	76%	3:35	0:04
Run #	**MSU reported duration of data collection (minutes)**	**MSU reported actual duration of data collection (minutes)**	**Extrapolated Sample Run (minutes)**
Run 1	184	182	180
Run 2	143	142	180
Run 3	140	140	180
Run 4	100	99	180
Run 5	137	137	60
Run 6	39	39	0

Kiln Charge OSU INDF1
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI integrated value
Sum Total for the Sample Event:			4.42
		%MC Wood	Per Sample Run:
Run 1		95.8%	0.3634
Run 2		77.2%	1.0878
Run 3		46.4%	0.9916
Run 4		28.5%	0.8323
Run 5		18.4%	0.7374
Run 6	1st hour	16.1%	0.4111
	2nd hour	14.3%	
	3rd hour	12.8%	
Run 7		9.8%	

Kiln Charge OSU INDF1
Time Schedules

Rampup Time (hour)	sampling time based on data collection (hour)	truncated to reach NCASI Ending %MC (hour)	sampling time with rampup to the ending %MC (hour)
3.00	21.00	4.00	17.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
14.75	87%	2:48	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	183	183	180
Run 2	177	177	180
Run 3	177	177	180
Run 4	168	168	180
Run 5	177	177	180
Run 6	165	165	120
Run 7	45	45	0
Run 8	0	0	0

Kiln Charge OSU INDF2
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI integrated value
Sum Total for the Sample Event:			**3.90**
		%MC Wood	Per Sample Run:
Run 1		82.1%	0.4265
Run 2		62.2%	1.0451
Run 3		40.5%	0.7769
Run 4		25.1%	0.6745
Run 5		16.1%	0.7451
Run 6	1st hour	13.9%	0.2284
	2nd hour	12.3%	
	3rd hour	10.9%	
Run 7		8.5%	

Kiln Charge OSU INDF2
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	20.55	4.55	16.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
13.67	85%	2:44	0:00
Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	180	180	180
Run 2	174	174	180
Run 3	167	167	180
Run 4	173	173	180
Run 5	174	174	180
Run 6	157	157	60
Run 7	44	44	0
Run 8	0	0	0

Kiln Charge OSU INDF3
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI Method integrated value
Sum Total for the Sample Event:			**4.62**
		%MC Wood	Per Sample Run:
Run 1		92.5%	0.4172
Run 2		72.9%	1.2511
Run 3		51.6%	0.9613
Run 4		35.2%	0.7345
Run 5		23.2%	0.6089
Run 6		15.5%	0.4970
Run 7	1st hour	13.7%	0.1511
	2nd hour	12.2%	
	3rd hour	11.8%	

Kiln Charge OSU INDF3
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	20.18	1.18	19.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
17.15	90%	2:12	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	174	174	180
Run 2	177	177	180
Run 3	180	180	180
Run 4	174	174	180
Run 5	177	177	180
Run 6	165	165	180
Run 7	32	32	60
Run 8	0	0	0

Kiln Charge OSU INDF5
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI Method integrated value
Sum Total for the Sample Event:			**3.77**
		%MC Wood	Per Sample Run:
Run 1		75.6%	0.2446
Run 2		59.8%	0.9642
Run 3		40.6%	0.9987
Run 4		25.9%	0.7201
Run 5		17.2%	0.5612
Run 6	1st hour	15.3%	0.2827
	2nd hour	13.7%	
	3rd hour	12.3%	
Run 7		9.0%	
Run 8		6.8%	
Run 9		6.0%	

Kiln Charge OSU.INDF5
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	23.45	6.45	17.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
14.65	86%	3:18	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	183	183	180
Run 2	177	177	180
Run 3	174	174	180
Run 4	183	183	180
Run 5	168	168	180
Run 6	174	174	120
Run 7	177	177	0
Run 8	90	90	0

Kiln Charge OSU INDF6
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI Method integrated value
Sum Total for the Sample Event:			**4.38**
		%MC Wood	Per Sample Run:
Run 1		83.5%	0.3310
Run 2		65.9%	1.1926
Run 3		45.0%	0.8889
Run 4		29.6%	0.7086
Run 5		19.7%	0.6724
Run 6	1st hour	17.3%	
	2nd hour	15.1%	
	3rd hour	13.3%	0.5896
Run 7		10.6%	

Kiln Charge OSU INDF6
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	20.05	2.05	18.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
16.32	91%	2:00	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	171	171	180
Run 2	192	192	180
Run 3	174	174	180
Run 4	174	174	180
Run 5	183	183	180
Run 6	180	180	180
Run 7	9	9	0
Run 8	0	0	0

Kiln Charge OSU INDF7B
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

			NCASI Method integrated value
Sum Total for the Sample Event:			4.40
		%MC Wood	Per Sample Run:
Run 1		98.0%	0.3270
Run 2		78.0%	1.2273
Run 3		55.0%	0.8419
Run 4		37.2%	0.6393
Run 5		24.4%	0.6386
Run 6		16.3%	0.5559
	1st hour	14.3%	0.1679
Run 7	2nd hour	13.4%	

Kiln Charge OSU INDF7B
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach NCASI Ending %MC (hour)	NCASI sampling time with rampup to the ending %MC (hour)
3.00	19.50	0.50	19.00

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle to ending %MC (hour:min)	Duration of data loss during data collection (hour:min)
17.05	90%	1:57	0:00

Run #	Reported duration of data collection for sample runs (minutes)	Actual duration of data collection for sample runs (minutes)	Extrapolated Sample Run times (minutes)
Run 1	180	180	180
Run 2	213	213	180
Run 3	171	171	180
Run 4	171	171	180
Run 5	168	168	180
Run 6	150	150	180
Run 7	0	0	60
Run 8	0	0	0

APPENDIX R

FORMALDEHYDE AND METHANOL PHASE II MASS EMISSION RATES FOR LUMBER CHARGES DRIED UNDER THE DIRECT-FIRED AND STEAM TEMPERATURE SCHEDULES

Kiln Charge FSK-DF2
Pounds Formaldehyde and Methanol/MBF for the Sample Event

SUM Total	Formaldehyde 0.091	Methanol 0.171
	by Sample Run:	by Sample Run:
Runs 1	0.009	0.006
Runs 2	0.016	0.014
Runs 3	0.013	0.020
Runs 4	0.014	0.029
Runs 5	0.018	0.042
Runs 6	0.021	0.060

Kiln Charge FSK-DF2
F/M Time Schedules

Rampup Time (hour)	Total reported sampling time based on the F/M data collection (hour)	Duration of the complete F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	17.03	17.73	0.70

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
11.07	62%	6.67	38%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run time reported to 15% (minutes)
1	40	16	180
2	40	19	180
3	40	54	180
4	40	11	180
5	40	14	180
6	40	27	164
7	40	17	
8	40	18	
9	30	42	
10	40	6	
11	40	7	
12	40	7	
13	40	7	
14	40	6	
15	37	39	
16	40	6	
17	40	44	

Kiln Charge FSK-DF5
Pounds Formaldehyde and Methanol/MBF
for the Sample Event

	Formaldehyde	Methanol
SUM Total	**0.114**	**0.151**
	by Sample Run:	by Sample Run:
Runs 1	0.012	0.007
Runs 2	0.014	0.012
Runs 3	0.016	0.022
Runs 4	0.022	0.035
Runs 5	0.039	0.057
Runs 6	0.012	0.018

Kiln Charge FSK-DF5
F/M Time Schedules

Rampup Time (hour)	Total reported sampling time based on the F/M data collection (hour)	Duration of the complete F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	15.30	15.75	0.45

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
9.43	60%	6.32	40%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run time reported to 15% (minutes)
1	40	30	180
2	40	10	180
3	36	34	180
4	40	49	180
5	40	20	180
6	40	26	45
7	40	15	
8	40	10	
9	40	40	
10	40	15	
11	40	10	
12	40	0	
13	64	0	

Kiln Charge MSU DF2
Pounds/MBF for each Drying Cycle
and per 3 hour Sample Run

	Formaldehyde	**Methanol**
SUM Total	**0.020**	**0.101**
Reported:	0.015	0.078
By Run:		
Run 1	0.00071	0.00358
Run 2	0.00273	0.01327
Run 3	0.00314	0.01533
Run 4	0.00436	0.02238
Run 5	0.00661	0.03447
Run 6	0.00269	0.01240
Run 7		
Run 8		
Run 9		
Run 10		

Kiln Charge MSU DF2
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	16.33	16.00	-0.33

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
15.00	94%	1.33	8%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	165	15	180
2	175	10	180
3	175	8	180
4	157	13	180
5	165	14	180
6	83	20	60
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Kiln Charge MSU DF5
Pounds/MBF for Sample Event

	Formaldehyde	Methanol
SUM Total	**0.020**	**0.112**
Reported:	0.031	0.159
	by Sample Run:	by Sample Run:
Run 1	0.00081	0.01434
Run 2	0.00302	0.02279
Run 3	0.00445	0.03093
Run 4	0.00591	0.02367
Run 5	0.00541	0.02015
Run 6		
Run 7		
Run 8		
Run 9		
Run 10		

Kiln Charge MSU DF5
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	14.75	14.00	-0.75

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
13.52	97%	0.48	3%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	178	7	180
2	175	10	180
3	176	9	180
4	180	3	180
5	147	0	120
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Kiln Charge OSU DF2C
Pounds/MBF for Sample Event

	Formaldehyde	Methanol
SUM Total	**0.009**	**0.142**
By Run:		
Run 1	0.00030	0.00659
Run 2	0.00104	0.02039
Run 3	0.00129	0.01993
Run 4	0.00189	0.02664
Run 5	0.00260	0.03837
Run 6	0.00170	0.03030
Run 7		
Run 8		
Run 9		
Run 10		

Kiln Charge OSU DF2C
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	16.45	16.92	0.47

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
15.73	93%	1.67	10%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	177	15	180
2	173	13	180
3	171	12	180
4	186	18	180
5	180	13	180
6	30	29	115
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Kiln Charge OSU DF5A
Pounds/MBF for Sample Event

	Formaldehyde	Methanol
SUM Total	**0.008**	**0.089**
By Run:		
Run 1	0.00021	0.00489
Run 2	0.00079	0.01326
Run 3	0.00136	0.01710
Run 4	0.00209	0.02346
Run 5	0.00286	0.02548
Run 6	0.00060	0.00514
Run 7		
Run 8		
Run 9		
Run 10		

Kiln Charge OSU DF5A
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	15.53	15.60	0.07
Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
14.60	94%	1.00	6%
Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	180	15	180
2	180	13	180
3	180	16	180
4	180	16	180
5	152	0	180
6	0	0	36
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Kiln Charge FSK INDF1
Pounds Formaldehyde and Methanol/MBF for the Sample Event

	Formaldehyde	Methanol
SUM Total	**0.012**	**0.145**
	by Sample Run:	by Sample Run:
Run 1	0.00027	0.00218
Run 2	0.00048	0.00545
Run 3	0.00102	0.01051
Run 4	0.00126	0.01424
Run 5	0.00137	0.01593
Run 6	0.00181	0.02224
Run 7	0.00219	0.02828
Run 8	0.00251	0.03340
Run 9	0.00095	0.01270
Run 10		

Kiln Charge FSK INDF1
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	25.15	25.12	-0.03

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
24.18	96%	0.93	4%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	135	45	180
2	172	8	180
3	180	0	180
4	180	0	180
5	180	0	180
6	180	0	180
7	180	3	180
8	247	0	180
9	0	0	67
10	0	0	0

Kiln Charge MSU INDF1
Pounds/MBF for Sample Event

	Formaldehyde	Methanol
SUM Total	**0.003**	**0.165**
Reporting:	0.004	0.182
	by Sample Run:	by Sample Run:
Run 1	0.00012	0.02556
Run 2	0.00073	0.03429
Run 3	0.00103	0.04959
Run 4	0.00097	0.05604
Run 5		
Run 6		
Run 7		
Run 8		
Run 9		
Run 10		

Kiln Charge MSU INDF1
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	16.52	12.00	-4.52

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
11.58	97%	0.42	3%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	180	5	180
2	175	5	180
3	175	5	180
4	175	5	180
5	175	5	0
6	86	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Kiln Charge OSU INDF1
Pounds/MBF for Sample Event

	Formaldehyde	Methanol
SUM Total	**0.019**	**0.176**
	by Sample Run:	by Sample Run:
Run 1	0.00056	0.00368
Run 2	0.00252	0.01610
Run 3	0.00428	0.03754
Run 4	0.00451	0.04319
Run 5	0.00426	0.04636
Run 6	0.00269	0.02940
Run 7		
Run 8		
Run 9		
Run 10		

Kiln Charge OSU INDF1
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	20.95	16.98	-3.97
Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
16.87	99%	0.12	1%
Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	180	1	179
2	179	1	180
3	179	1	180
4	188	1	180
5	170	3	180
6	177	0	120
7	178	0	0
8	0	0	0
9	0	0	0
10	0	0	0

Kiln Charge MSU INDF2
Pounds/MBF for Sample Event

	Formaldehyde	Methanol
SUM Total	**0.003**	**0.169**
Reporting:	0.004	0.195
	by Sample Run:	by Sample Run:
Run 1	0.00023	0.00994
Run 2	0.00068	0.03698
Run 3	0.00096	0.05552
Run 4	0.00096	0.06665
Run 5		
Run 6		
Run 7		
Run 8		
Run 9		
Run 10		

Kiln Charge MSU INDF2
F/M Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	15.92	12.00	-3.92

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
11.25	94%	0.75	6%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	180	5	180
2	170	10	180
3	170	10	180
4	170	10	180
5	160	10	0
6	60	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0

APPENDIX S

SPECIATED VOC MASS EMISSION RATE RESULTS FOR VARIABILITY STUDY KILN CHARGE AT NORTH CAROLINA STATE UNIVERSITY AND PHASE II KILN CHARGE AT THE STEAM KILN AND OREGON STATE UNIVERSITY KILN

NCSU/DEECO Phase I Kiln Charge 3
Pounds/MBF for the Sample Event

Note: Ending Wood Moisture Content was 22% for this charge

	Acetaldehyde	Acetone	Acrolein	Formaldehyde
SUM Total	0.030	0.054	0.003	0.013
By Run:				
Run 1	0.00052	0.00090	0.00000	0.00007
Run 2	0.00270	0.00358	0.00002	0.00063
Run 3	0.00377	0.00551	0.00040	0.00108
Run 4	0.00399	0.00671	0.00059	0.00149
Run 5	0.00427	0.00738	0.00059	0.00170
Run 6	0.00496	0.00937	0.00059	0.00218
Run 7	0.00536	0.01248	0.00053	0.00314
Run 8	0.00377	0.00744	0.00025	0.00205
Run 9	0.00053	0.00095	0.00003	0.00028
Run 10	0.00000	0.00000	0.00000	0.00000

	Methanol	MIBK	O-xylene	Propionaldehyde
SUM Total	0.182			0.001
By Run:				
Run 1	0.00118	0.00000	0.00000	0.00000
Run 2	0.00878	0.00000	0.00000	0.00000
Run 3	0.01428	0.00000	0.00000	0.00000
Run 4	0.01963	0.00000	0.00000	0.00006
Run 5	0.02364	0.00000	0.00000	0.00012
Run 6	0.03242	0.00000	0.00000	0.00014
Run 7	0.04678	0.00000	0.00000	0.00014
Run 8	0.03124	0.00000	0.00000	0.00003
Run 9	0.00424	0.00000	0.00000	0.00000
Run 10	0.00000	0.00000	0.00000	0.00000

	Toluene	Alpha-pinene	Beta-pinene
SUM Total		1.320	0.323
By Run:			
Run 1	0.00000	0.05880	0.01649
Run 2	0.00000	0.21197	0.05887
Run 3	0.00000	0.22486	0.06045
Run 4	0.00000	0.17855	0.04562
Run 5	0.00000	0.15594	0.03729
Run 6	0.00000	0.15846	0.03566
Run 7	0.00000	0.15556	0.03321
Run 8	0.00000	0.15155	0.03093
Run 9	0.00000	0.02424	0.00488
Run 10	0.00000	0.00000	0.00000

NCSU/DEECO Phase I Kiln Charge 3
Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	24.22	24.48	0.27

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
20.65	84%	3.83	16%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	180	25	180
2	180	30	180
3	158	47	180
4	180	30	180
5	190	15	180
6	180	23	180
7	156	0	180
8	0	0	180
9	0	0	29
10	0	0	0

Kiln Charge FSK INDF3
Pounds/MBF for the Sample Event

	Acetaldehyde	Acetone	Acrolein	Formaldehyde
SUM Total	0.039	0.037	0.006	0.019
By Run:				
Run 1	0.00123	0.00129	0.00010	0.00017
Run 2	0.00233	0.00369	0.00057	0.00076
Run 3	0.00279	0.00389	0.00061	0.00105
Run 4	0.00379	0.00474	0.00066	0.00163
Run 5	0.00429	0.00476	0.00061	0.00180
Run 6	0.00434	0.00400	0.00052	0.00185
Run 7	0.00528	0.00414	0.00055	0.00220
Run 8	0.00558	0.00387	0.00068	0.00256
Run 9	0.00576	0.00382	0.00087	0.00339
Run 10	0.00385	0.00262	0.00061	0.00314

	Methanol	MIBK	O-xylene	Propionaldehyde
SUM Total	0.265	0.001	0.000	0.001
By Run:				
Run 1	0.00293	0.00000	0.00000	0.00001
Run 2	0.00937	0.00000	0.00000	0.00006
Run 3	0.01345	0.00000	0.00000	0.00008
Run 4	0.02085	0.00001	0.00002	0.00009
Run 5	0.02593	0.00002	0.00002	0.00009
Run 6	0.02898	0.00004	0.00002	0.00009
Run 7	0.03923	0.00017	0.00003	0.00011
Run 8	0.04293	0.00030	0.00004	0.00014
Run 9	0.04745	0.00036	0.00004	0.00023
Run 10	0.03381	0.00021	0.00003	0.00021

	Toluene	Alpha-pinene	Beta-pinene
SUM Total	0.00009	0.291	0.130
By Run:			
Run 1	0.00000	0.03385	0.01650
Run 2	0.00000	0.04705	0.03044
Run 3	0.00001	0.02917	0.01844
Run 4	0.00002	0.02548	0.01269
Run 5	0.00002	0.02246	0.00809
Run 6	0.00001	0.02390	0.00986
Run 7	0.00001	0.02508	0.01063
Run 8	0.00001	0.02590	0.00723
Run 9	0.00000	0.03139	0.00691
Run 10	0.00000	0.02676	0.00950

Kiln Charge FSK INDF3
Time Schedules

Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	28.87	28.88	0.02

Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
28.53	99%	0.35	1%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	181	0	180
2	180	0	180
3	179	1	180
4	179	1	180
5	179	1	180
6	179	1	180
7	179	0	180
8	180	8	179
9	172	9	180
10	105	0	114

Kiln Charge OSU INDF3
Pounds/MBF for the Sample Event

	Acetaldehyde	Acetone	Acrolein	Formaldehyde
SUM Total	0.065	0.083	0.009	0.023
By Run:				
Run 1	0.00943	0.00703	0.00032	0.00079
Run 2	0.01652	0.02235	0.00212	0.00365
Run 3	0.01148	0.01890	0.00195	0.00424
Run 4	0.00975	0.01340	0.00166	0.00447
Run 5	0.00830	0.01022	0.00125	0.00475
Run 6	0.00721	0.00845	0.00117	0.00402
Run 7	0.00217	0.00249	0.00037	0.00121
Run 8				
Run 9				
Run 10				

	Methanol	MIBK	O-xylene	Propionaldehyde
SUM Total	0.274	0.0005		0.003
By Run:				
Run 1	0.00683	0.00000	0.00000	0.00028
Run 2	0.02917	0.00000	0.00000	0.00091
Run 3	0.04282	0.00000	0.00000	0.00067
Run 4	0.05436	0.00002	0.00000	0.00048
Run 5	0.05868	0.00017	0.00000	0.00035
Run 6	0.06223	0.00021	0.00000	0.00038
Run 7	0.02023	0.00008	0.00000	0.00013
Run 8				
Run 9				
Run 10				

	Toluene	Alpha-pinene	Beta-pinene
SUM Total	0.00012	0.361	0.184
By Run:			
Run 1	0.00000	0.06236	0.03213
Run 2	0.00001	0.09173	0.05061
Run 3	0.00006	0.06458	0.03307
Run 4	0.00004	0.05549	0.02766
Run 5	0.00001	0.04246	0.02049
Run 6	0.00000	0.03576	0.01652
Run 7	0.00001	0.00844	0.00377
Run 8			
Run 9			
Run 10			

Kiln Charge OSU INDF3
Time Schedules

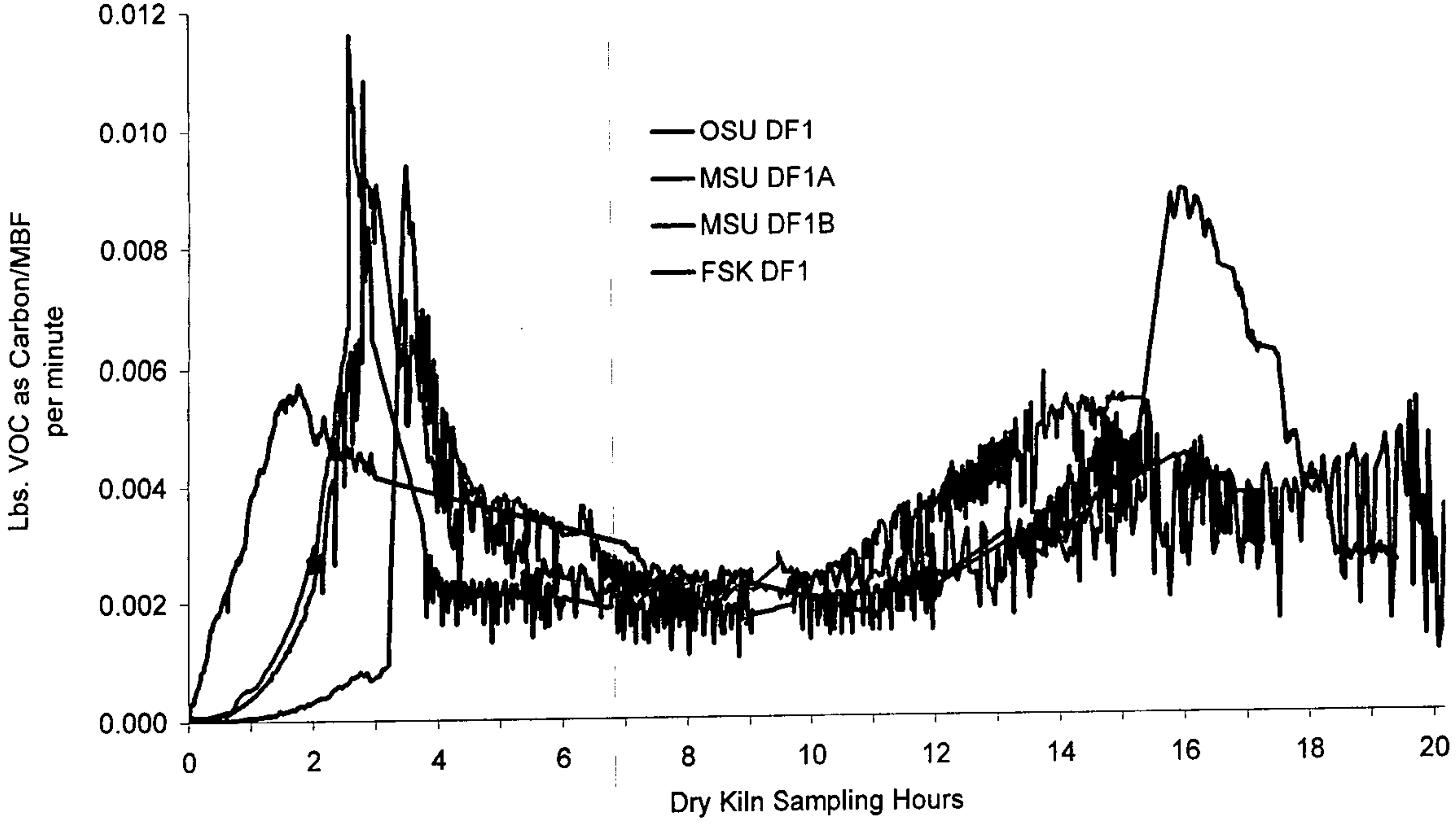
Rampup Time (hour)	Sampling time based on the F/M data collection (hour)	Duration of the F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	18.98	19.00	0.02
Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
18.80	99%	0.20	1%

Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run (minutes)
1	180	1	180
2	180	2	180
3	180	2	180
4	175	3	180
5	178	2	180
6	178	2	180
7	130	0	60
8	0	0	0
9	0	0	0
10	0	0	0

APPENDIX T

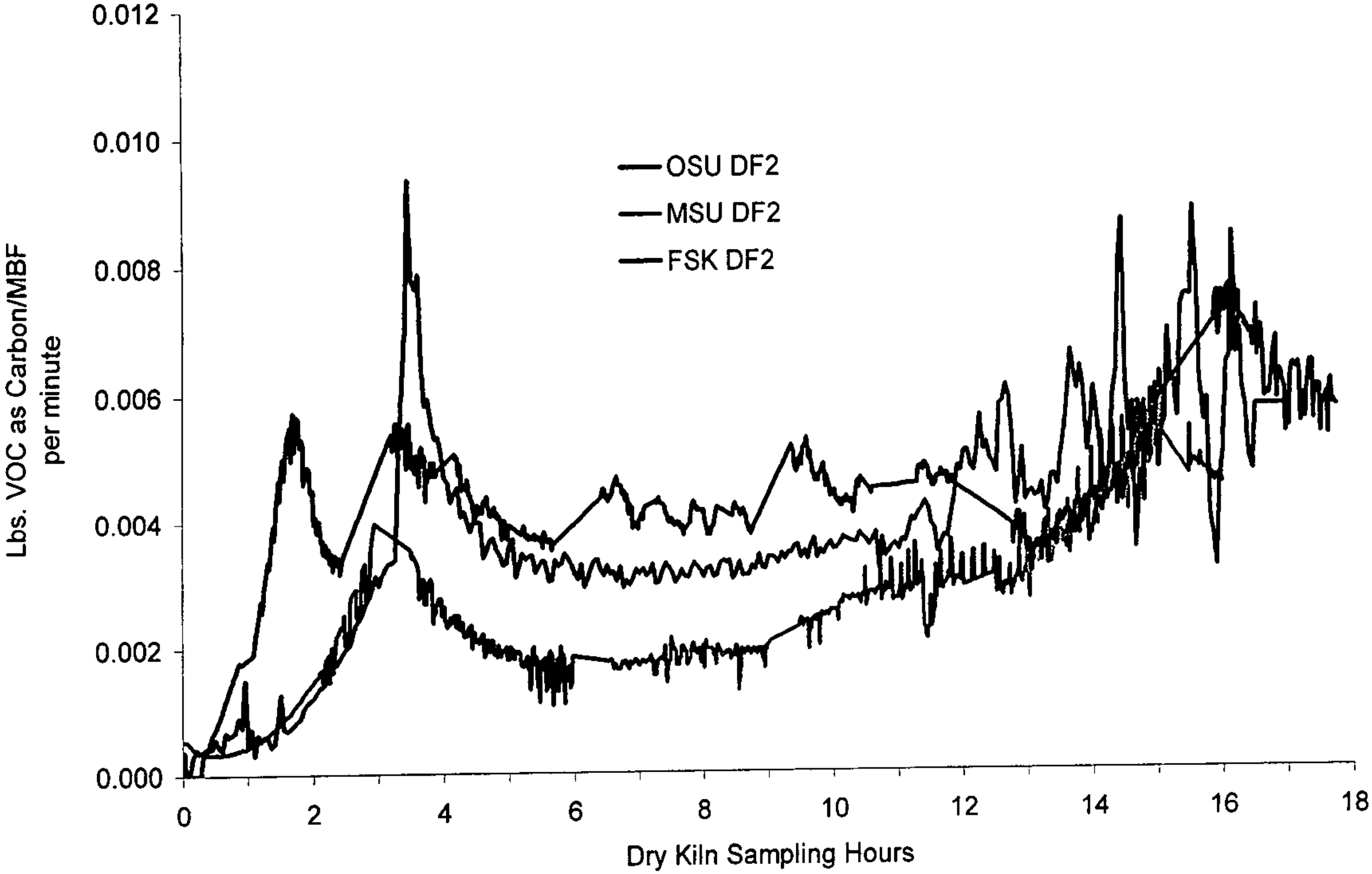
COMPARISON OF THE PHASE II VOC MASS EMISSION RATE CURVES ON A CHARGE-BY-CHARGE BASIS

Kiln Charge DF1
Comparison of VOC Mass Emission Rates



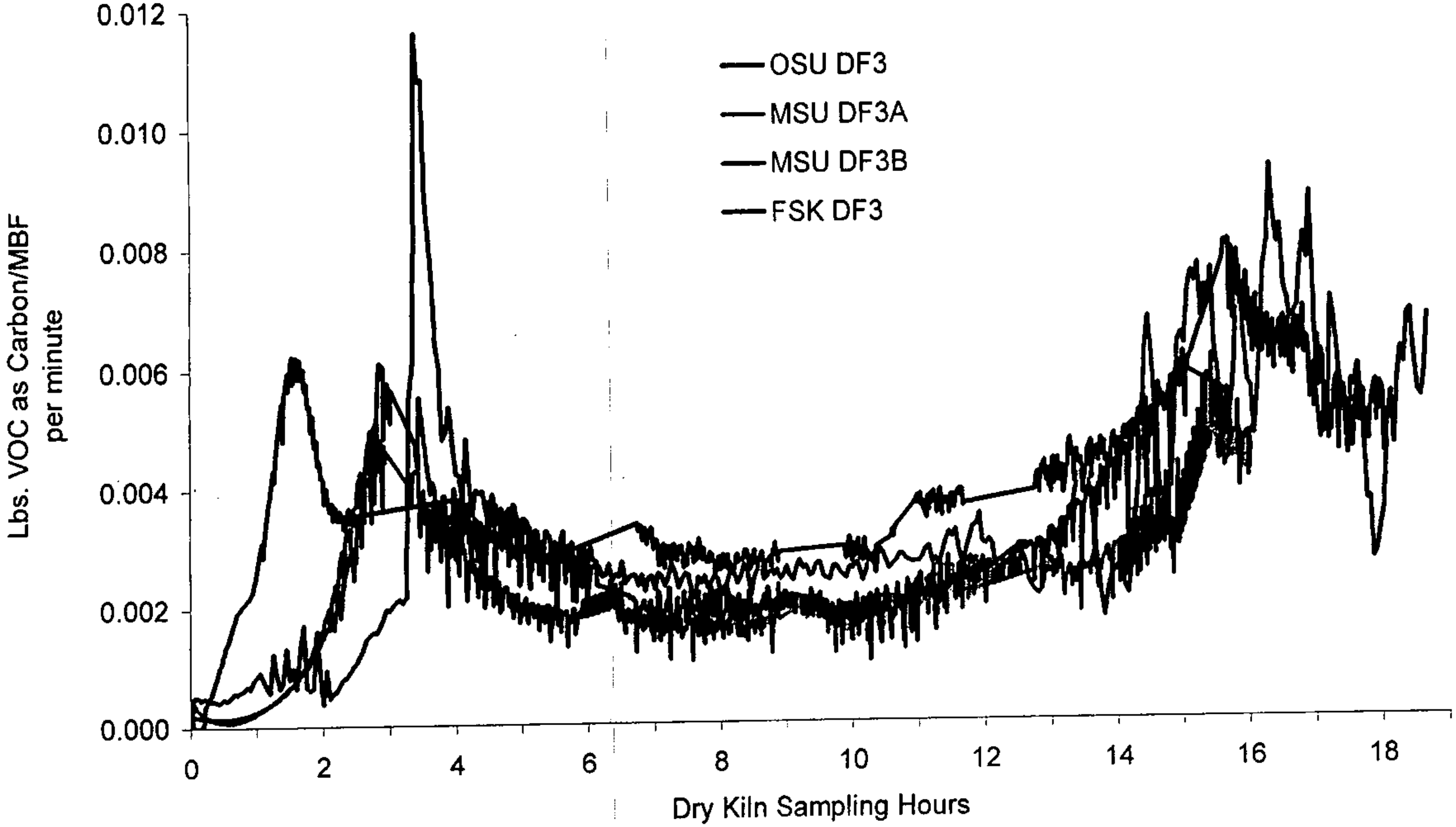
T1

Kiln Charge DF2
Comparison of VOC Mass Emission Rates



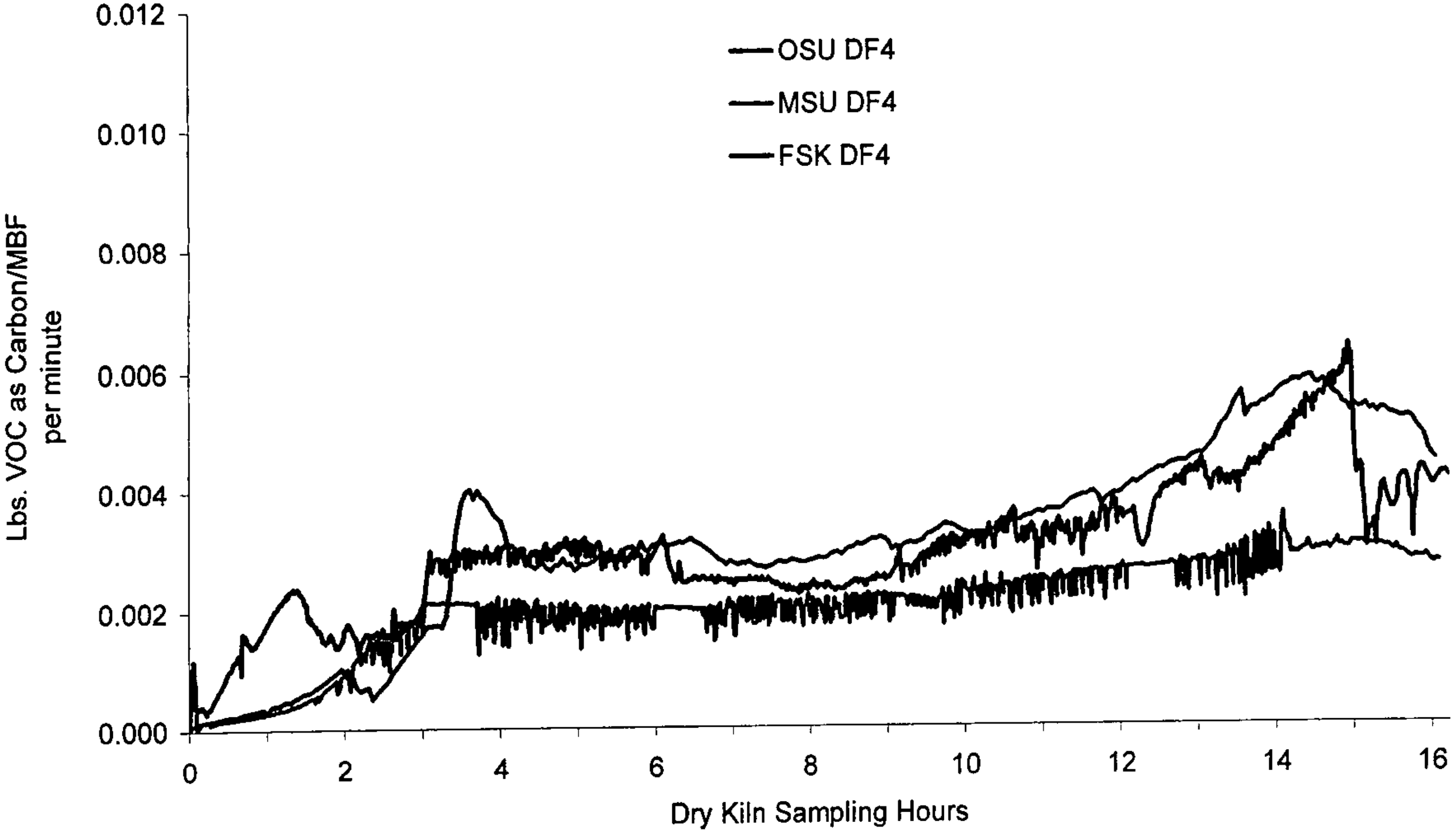
T2

Kiln Charge DF3
Comparison of VOC Mass Emission Rates

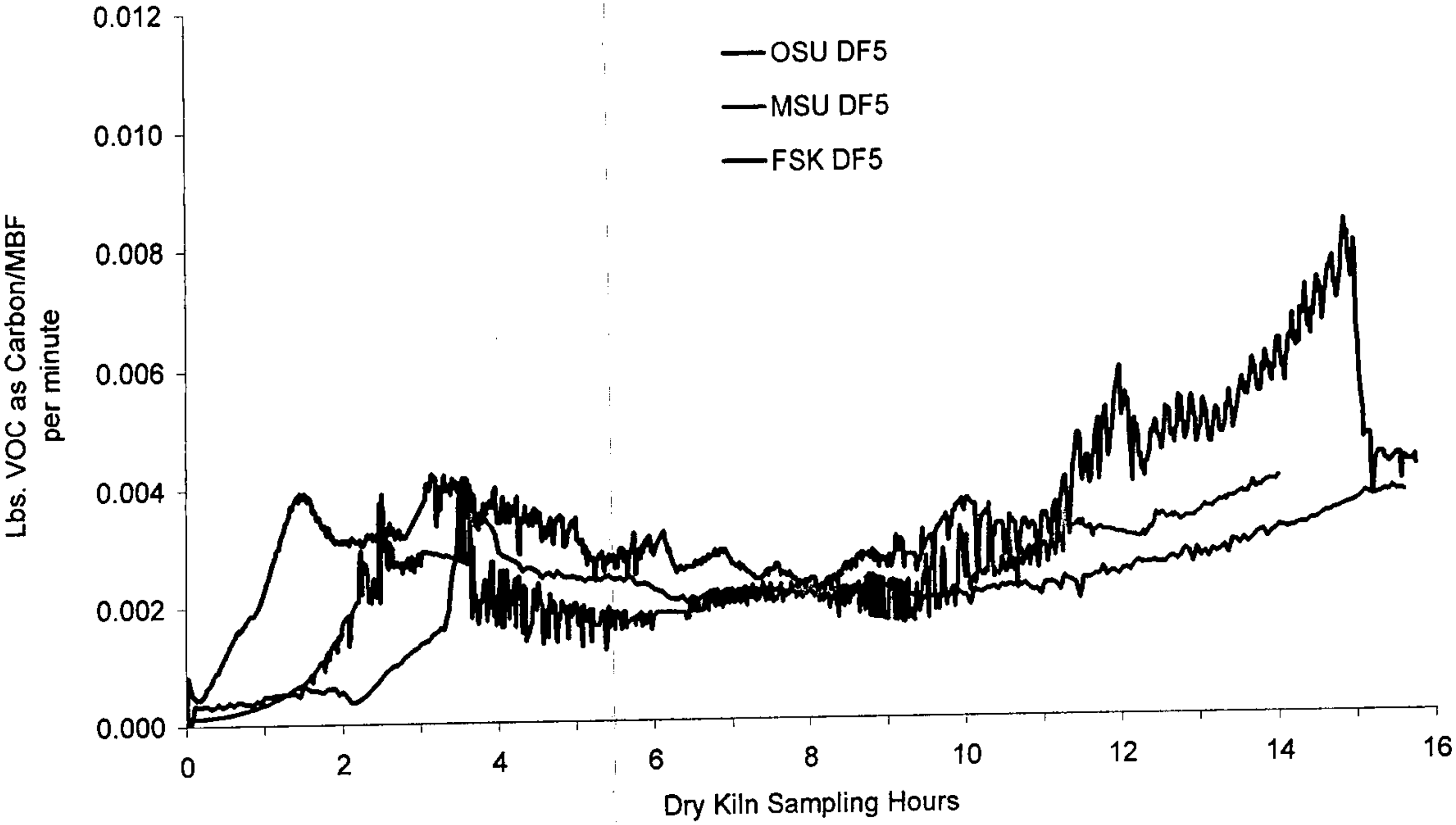


T4

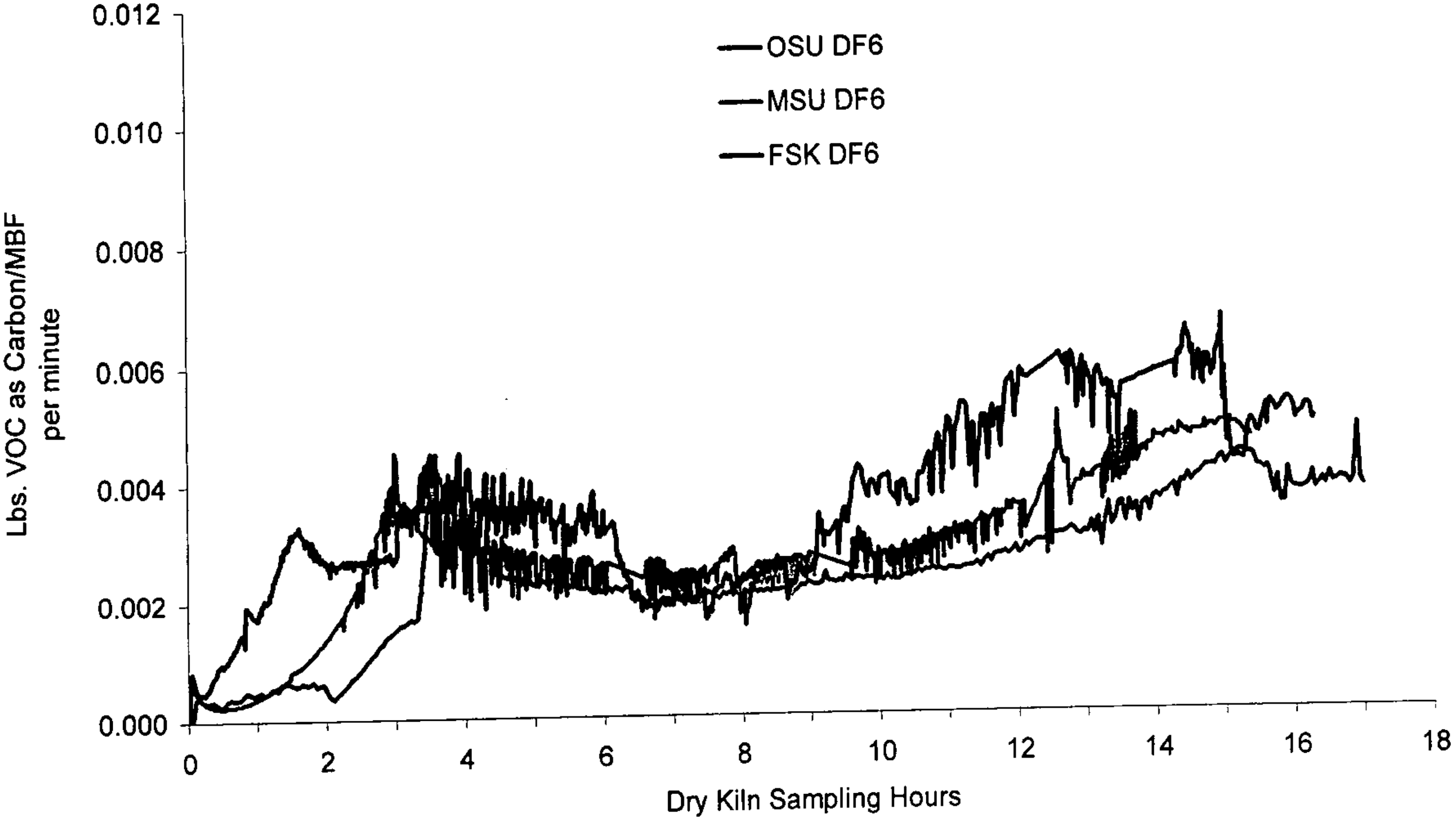
Kiln Charge DF4
Comparison of VOC Mass Emission Rates



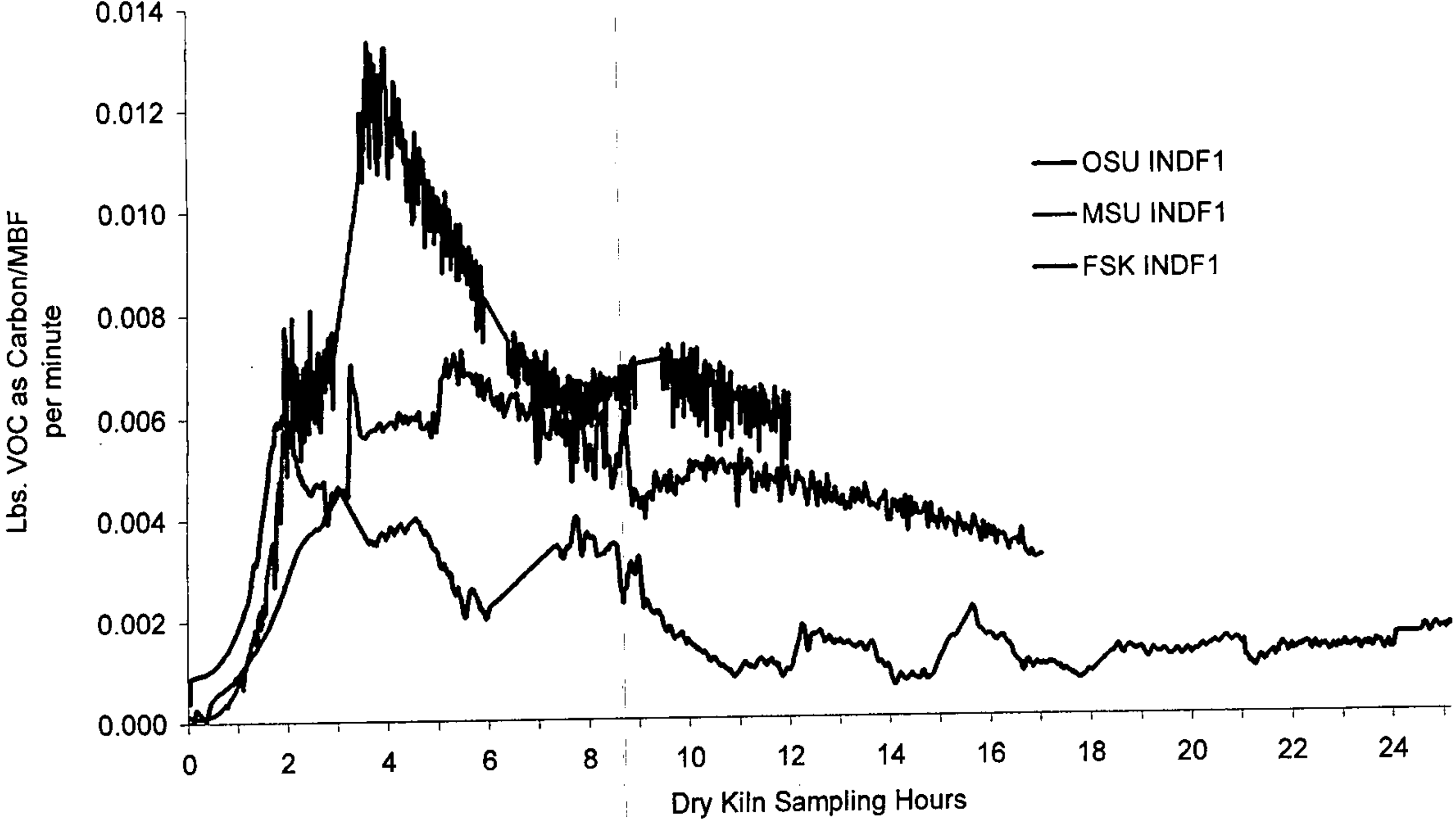
Kiln Charge DF5
Comparison of VOC Mass Emission Rates



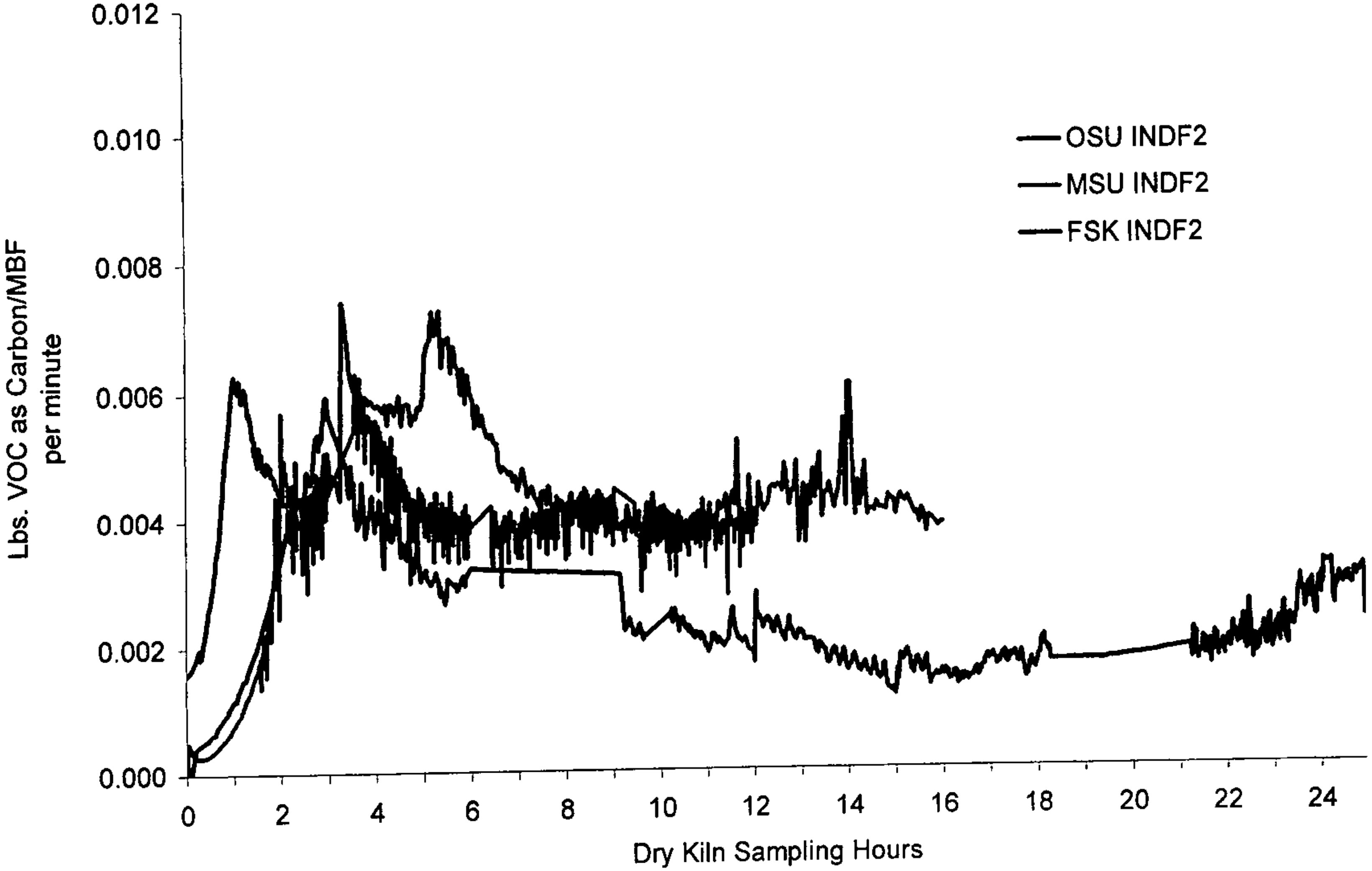
Kiln Charge DF6
Comparison of VOC Mass Emission Rates



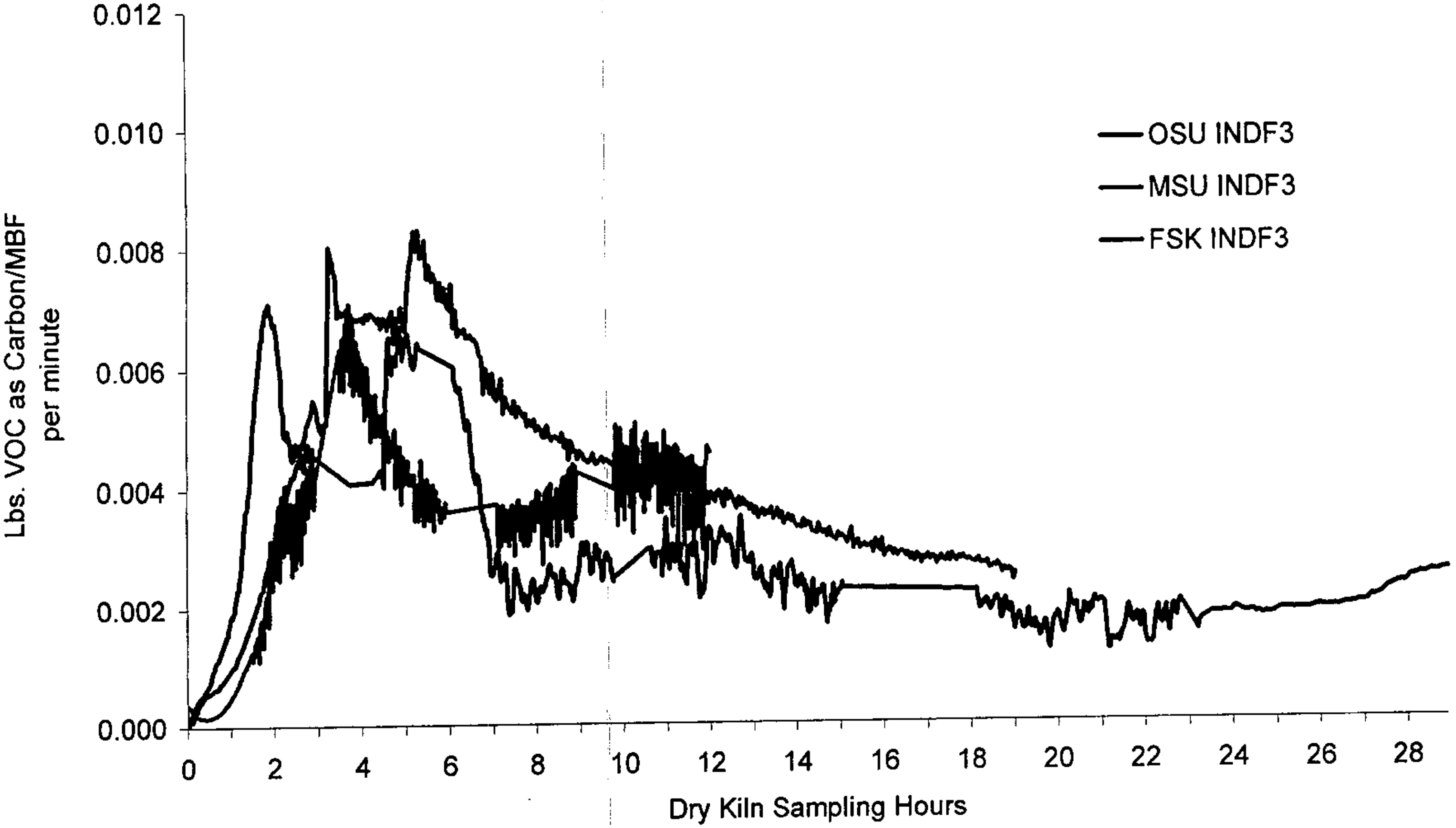
Kiln Charge INDF1
Comparison of VOC Mass Emission Rates



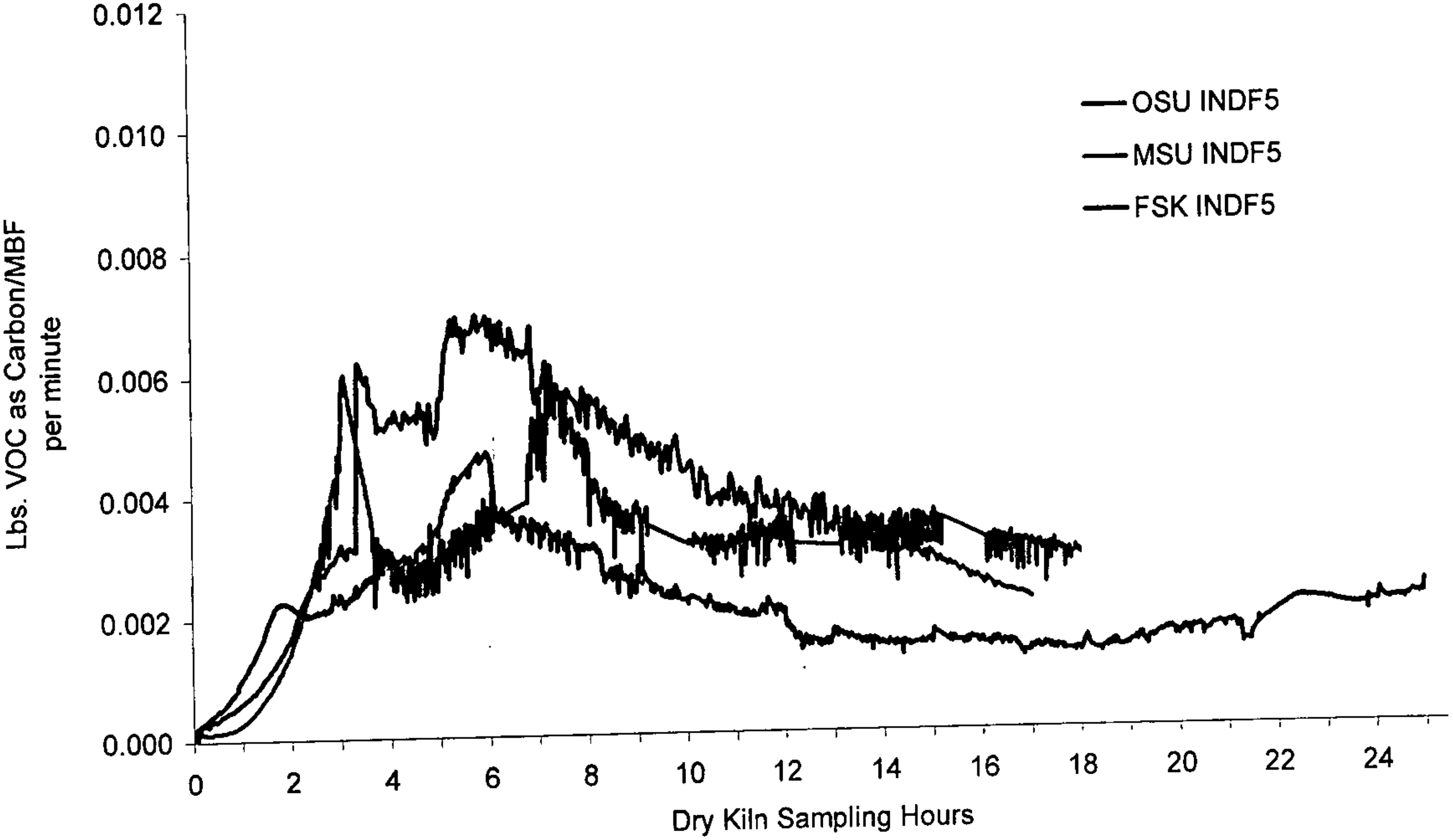
Kiln Charge INDF2
Comparison of VOC Mass Emission Rates



Kiln Charge INDF3
Comparison of VOC Mass Emission Rates

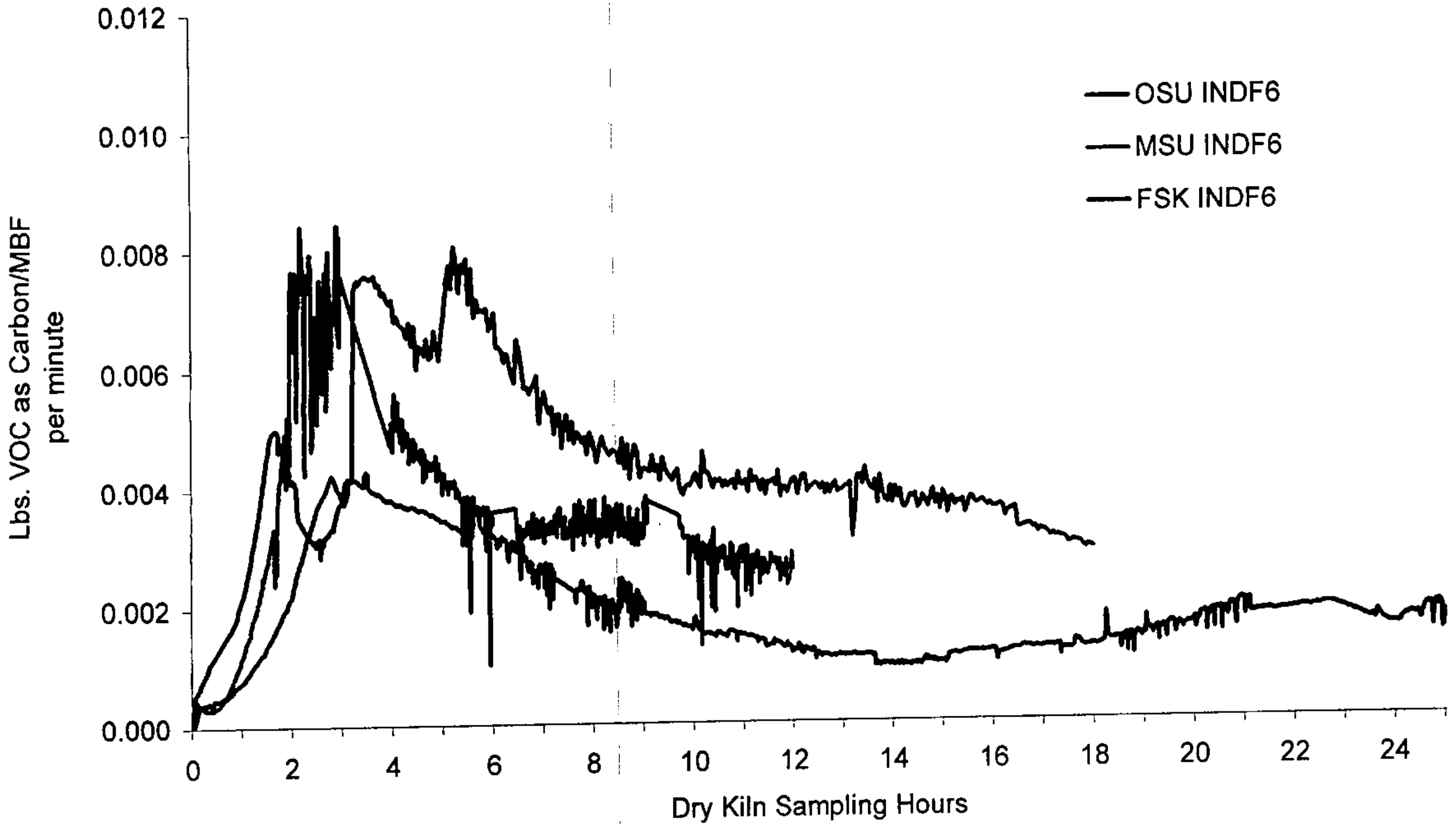


Kiln Charge INDF5
Comparison of VOC Mass Emission Rates

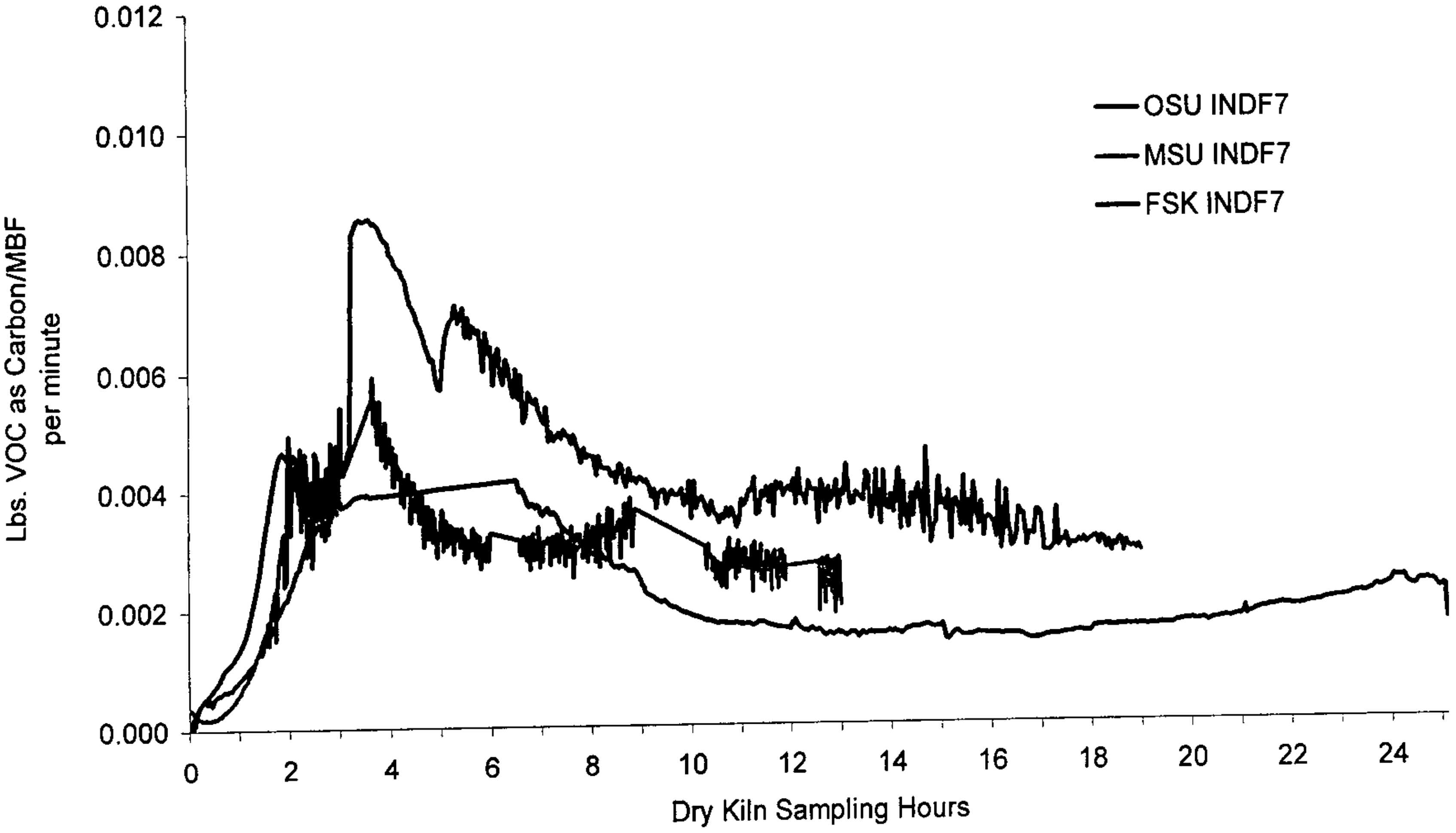


T10

Kiln Charge INDF6
Comparison of VOC Mass Emission Rates



Kiln Charge INDF7
Comparison of VOC Mass Emission Rates



APPENDIX U

STATISTICAL ANALYSIS OF THE PHASE II VOC MASS EMISSION RATE RESULTS SEPARATED BY STAGES I, II, AND III

Table U.1

FSK to MSU Comparison

Stage I Direct-fired Data (DF1 through DF3)

	FSK	MSU	Difference
DF1	4.2	2.95	1.25
DF2	4.7	2.5	2.2
DF3	4.2	2.4	1.8
mean	4.3667	2.6167	1.750
std dev	0.2887	0.2930	
var	0.0833	0.0858	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	4.367	2.617
Variance	0.083	0.086
Observations	3	3
Pearson Correlation	0.000	
Hypo. Mean Difference	4.000	
t Stat	7.370 <==	
P(T<=t) two-tail	0.002	
t Critical two-tail	2.776 <==	

CONCLUSION: Means differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	4.3667	2.6167
Variance	0.0833	0.0858
Observations	3	3
Pearson Correlation	-0.3449	
Hypo. Mean Difference	0.0000	
df	2	
t Stat	6.3549 <==	
P(T<=t) two-tail	0.0239	
t Critical two-tail	4.3027 <==	

CONCLUSION: The VOC mass emission rate from the MSU kiln was significantly less than the DF kiln.

FSK to OSU Comparison

Stage I Direct-fired Data (DF1 through DF3)

	FSK	OSU	Difference
DF1	4.2	3.1	1.1
DF2	4.7	3.9	0.8
DF3	4.2	3.8	0.4
mean	4.3667	3.6000	0.767
std dev	0.2887	0.4359	
var	0.0833	0.1900	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	4.3667	3.6000
Variance	0.0833	0.1900
Observations	3	3
Pearson Correlation	0.0000	
Hypo. Mean Difference	3.000	
t Stat	2.5399 <==	
P(T<=t) two-tail	0.0847	
t Critical two-tail	3.1824 <==	

CONCLUSION: Means do not differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	4.3667	3.6000
Variance	0.0833	0.1900
Observations	3	3
Pearson Correlation	0.5960	
Hypo. Mean Difference	0.0000	
df	2	
t Stat	3.7812 <==	
P(T<=t) two-tail	0.0634	
t Critical two-tail	4.3027 <==	

CONCLUSION: The VOC mass emission rate from the OSU kiln was not significantly different than the DF kiln.

Table U.2

FSK to MSU Comparison

Stage II Direct-fired Data (DF4 through DF6)

	FSK	MSU	Difference
DF4	2.9	1.9	1.0
DF5	3.4	1.9	1.5
DF6	3.6	2.6	1.0
mean	3.300	2.133	1.167
std dev	0.361	0.404	
var	0.130	0.163	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*	
Mean	3.300	2.133	
Variance	0.130	0.163	
Observations	3	3	
Hypo. Mean Difference	0.000		
df	4		
t Stat	3.731		<==
P(T<=t) two-tail	0.020		
t Critical two-tail	2.776		<==

CONCLUSION: Means differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*	
Mean	3.300	2.133	
Variance	0.130	0.163	
Observations	3	3	
Pearson Correlation	0.721		
Hypo. Mean Difference	0.000		
df	2		
t Stat	7.000		<==
P(T<=t) two-tail	0.020		
t Critical two-tail	4.303		<==

CONCLUSION: The VOC mass emission rate from the MSU kiln was significantly less than the DF kiln.

FSK to OSU Comparison

Stage II Direct-fired Data (DF4 through DF6)

	FSK	OSU	Difference
DF4	2.9	3.0	-0.1
DF5	3.4	2.0	1.4
DF6	3.6	2.4	1.2
mean	3.300	2.467	0.833
std dev	0.361	0.503	
var	0.130	0.253	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*	
Mean	3.300	2.467	
Variance	0.130	0.253	
Observations	3	3	
Hypo. Mean Difference	0.000		
df	4		
t Stat	2.331		<==
P(T<=t) two-tail	0.080		
t Critical two-tail	2.776		<==

CONCLUSION: Means do not differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%.

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*	
Mean	3.300	2.467	
Variance	0.130	0.253	
Observations	3	3	
Pearson Correlation	-0.771		
Hypo. Mean Difference	0.00		
df	2		
t Stat	1.772		<==
P(T<=t) two-tail	0.218		
t Critical two-tail	4.303		<==

CONCLUSION: The VOC mass emission rate from the OSU kiln was not significantly different than the DF kiln.

Table U.3

FSK to MSU Comparison

Stage III Steam Data (INDF1 through INDF7)

	FSK	MSU	Difference
INDF1	3.0	4.8	-1.8
INDF2	3.9	2.6	1.3
INDF3	4.7	2.6	2.1
INDF5	3.1	3.3	-0.2
INDF6	3.0	2.6	0.4
INDF7	3.5	2.4	1.1
mean	3.533	3.050	0.483
std dev	0.671	0.912	
var	0.451	0.831	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	3.533	3.050
Variance	0.451	0.831
Observations	6	6
Pearson Correlation	0.000	
Hypo. Mean Difference	9.000	
t Stat	1.046 <==	
P(T<=t) two-tail	0.323	
t Critical two-tail	2.262 <==	

CONCLUSION: Means do not differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	3.533	3.050
Variance	0.451	0.831
Observations	6	6
Pearson Correlation	-0.4804	
Hypo. Mean Difference	0.000	
df	5	
t Stat	0.866 <==	
P(T<=t) two-tail	0.426	
t Critical two-tail	2.571 <==	

CONCLUSION: The VOC mass emission rate from the OSU kiln was not significantly different than the steam kiln.

FSK to OSU Comparison

Stage III Steam Data (INDF1 through INDF7)

	FSK	OSU	Difference
INDF1	3.0	4.4	-1.4
INDF2	3.9	3.9	0
INDF3	4.7	4.6	0.1
INDF5	3.1	3.8	-0.7
INDF6	3.0	4.4	-1.4
INDF7	3.5	4.4	-0.9
mean	3.533	4.250	0.717
std dev	0.671	0.321	
var	0.451	0.103	

Case 1: Student-t Test of Means

confidence interval: 95%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	3.533	4.250
Variance	0.451	0.103
Observations	6	6
Pearson Correlation	0.000	
Hypo. Mean Difference	7.000	
t Stat	-2.359 <==	
P(T<=t) two-tail	0.050	
t Critical two-tail	2.365 <==	

CONCLUSION: Means do not differ significantly

CASE 2: Paired Difference of Means

confidence interval: 95%

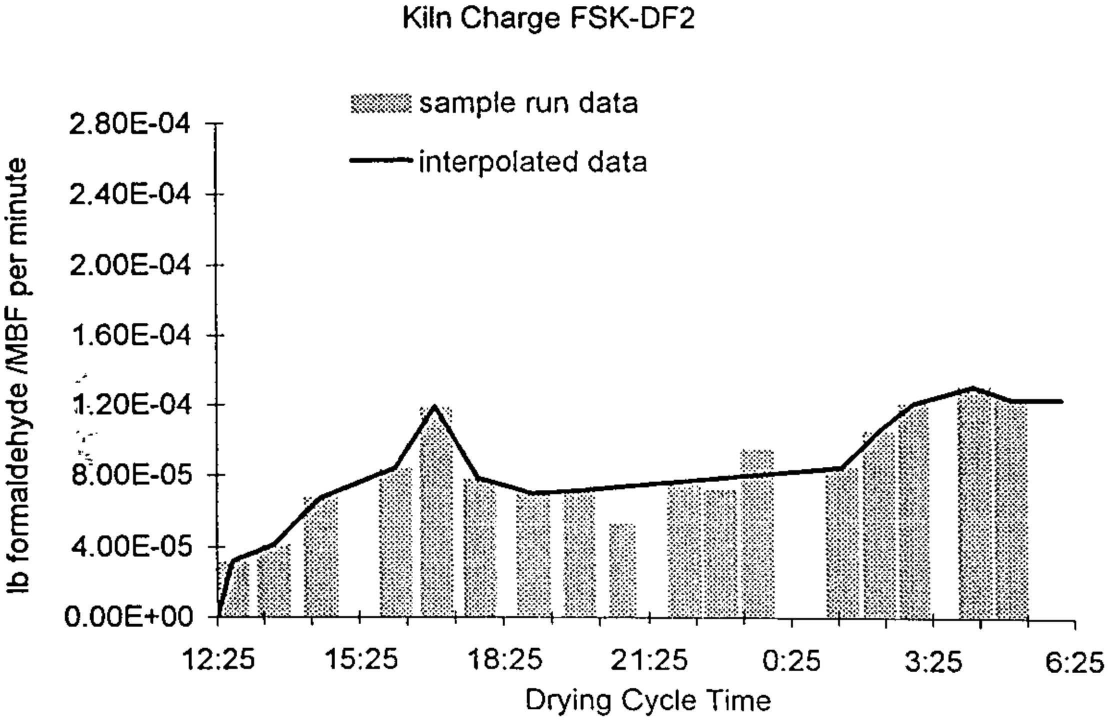
t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	3.533	4.250
Variance	0.451	0.103
Observations	6	6
Pearson Correlation	0.2878	
Hypo. Mean Difference	0.000	
df	5	
t Stat	-2.678 <==	
P(T<=t) two-tail	0.044	
t Critical two-tail	2.571 <==	

CONCLUSION: The VOC mass emission rate from the OSU kiln was slightly more than the steam kiln.

APPENDIX V

PHASE II FORMALDEHYDE AND METHANOL MASS EMISSION RATE CURVES



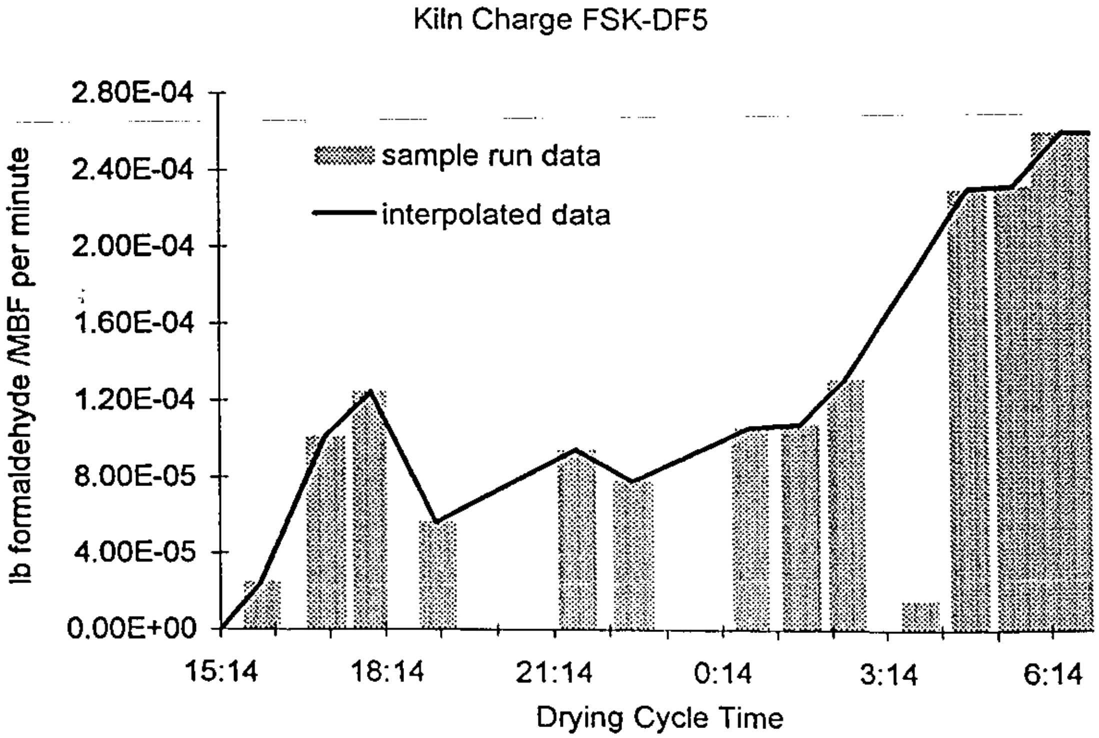
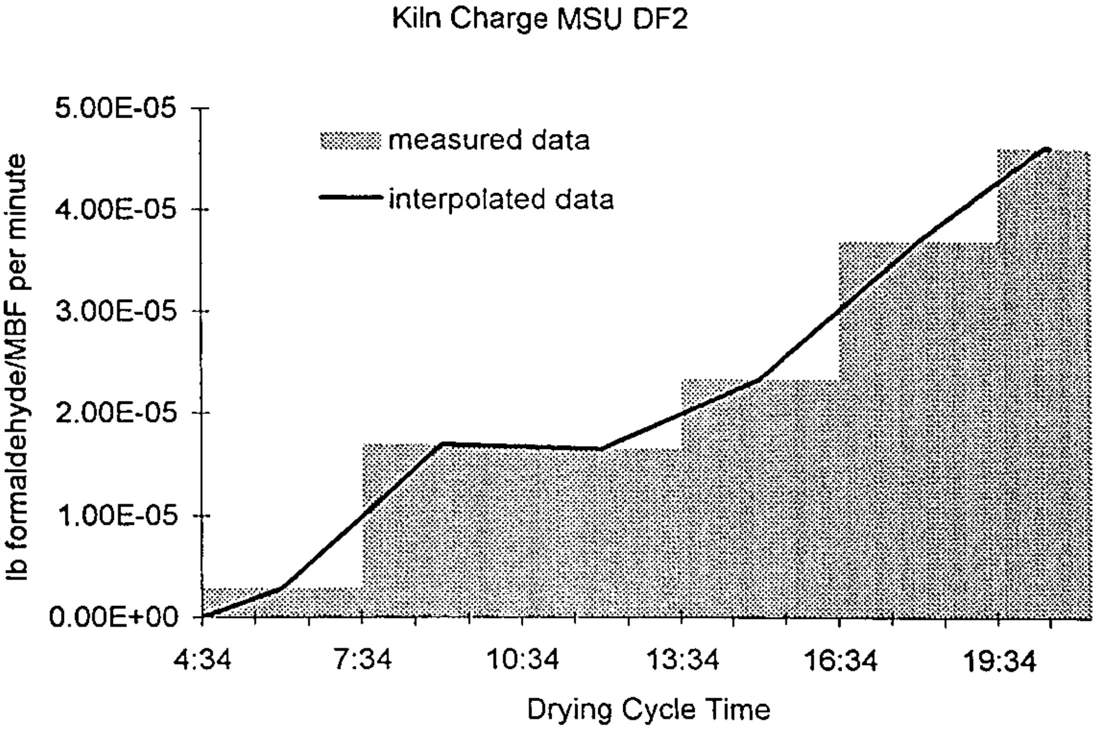
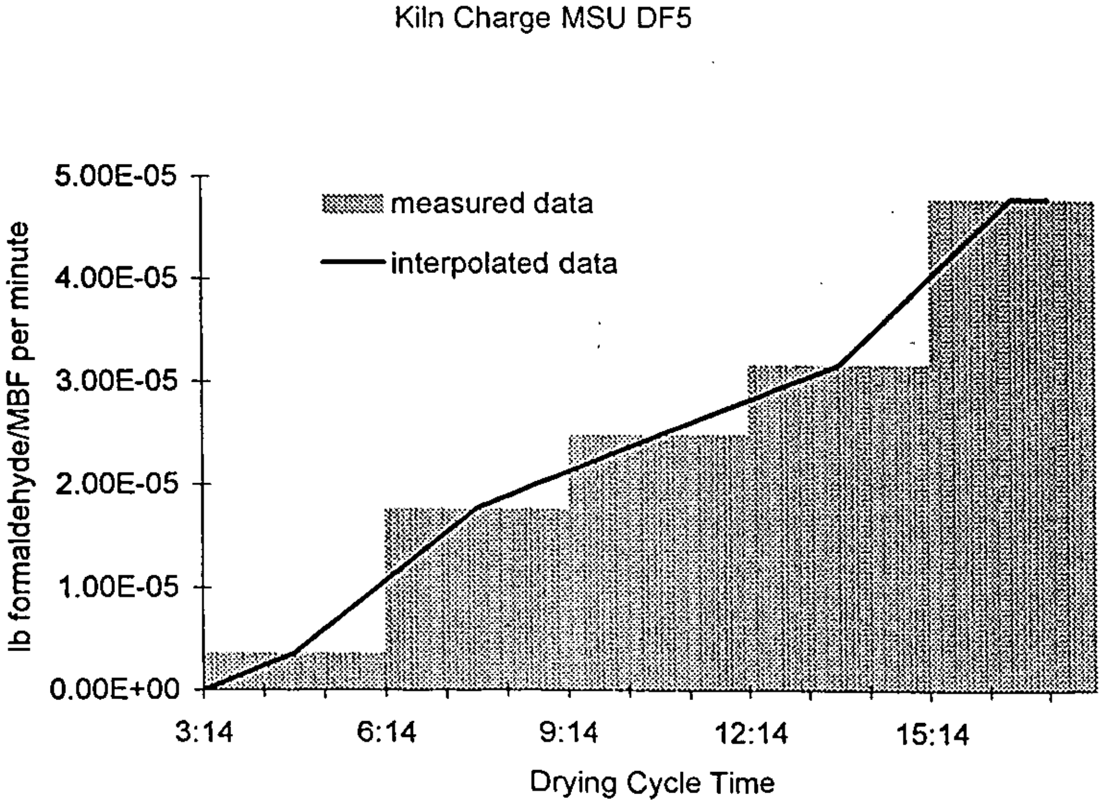


Figure V.1. Formaldehyde Mass Emission Rates from the Direct-Fired Kiln

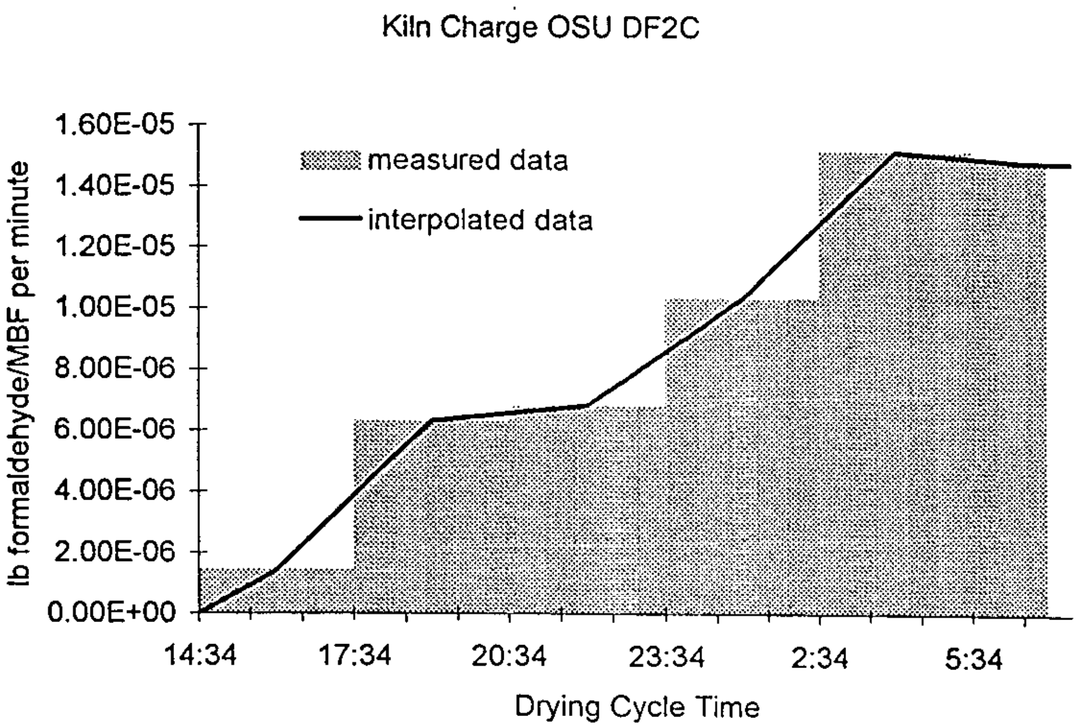


Kiln Charge MSU DF2

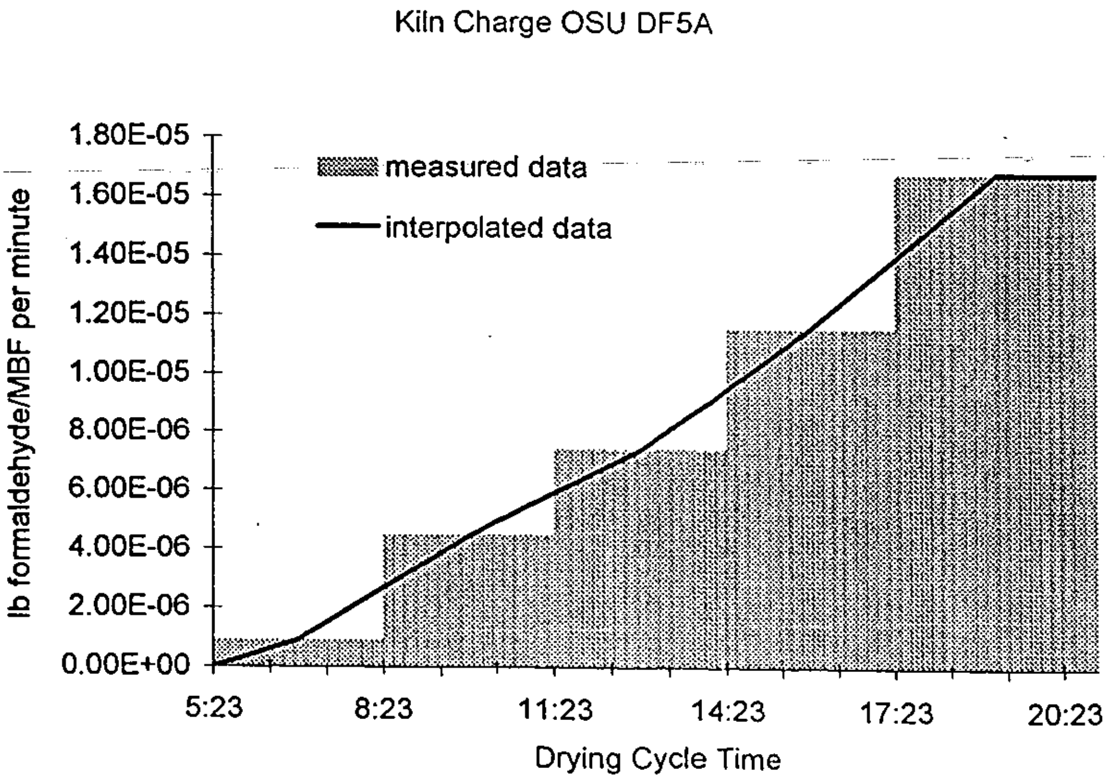


Kiln Charge MSU DF5

Figure V.2. Formaldehyde Mass Emission Rate for the Direct-Fired Drying Schedule at MSU

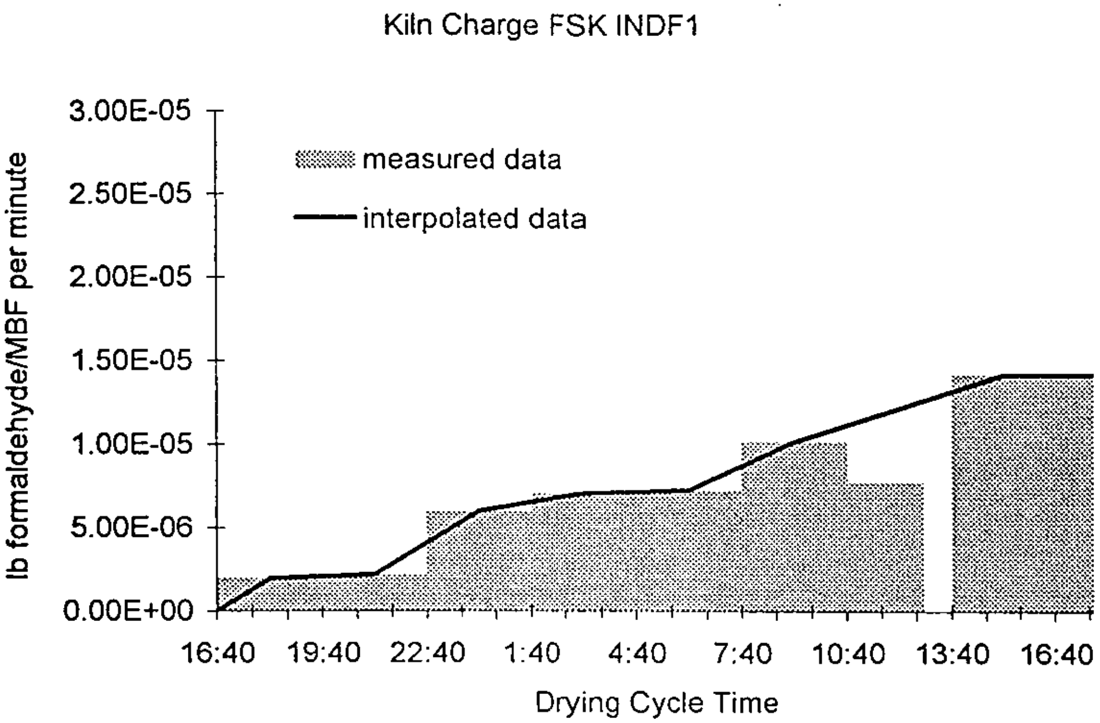


Kiln Charge OSU DF2C



Kiln Charge OSU DF5A

Figure V.3. Formaldehyde Mass Emission Rate for the Direct-Fired Drying Schedule at OSU



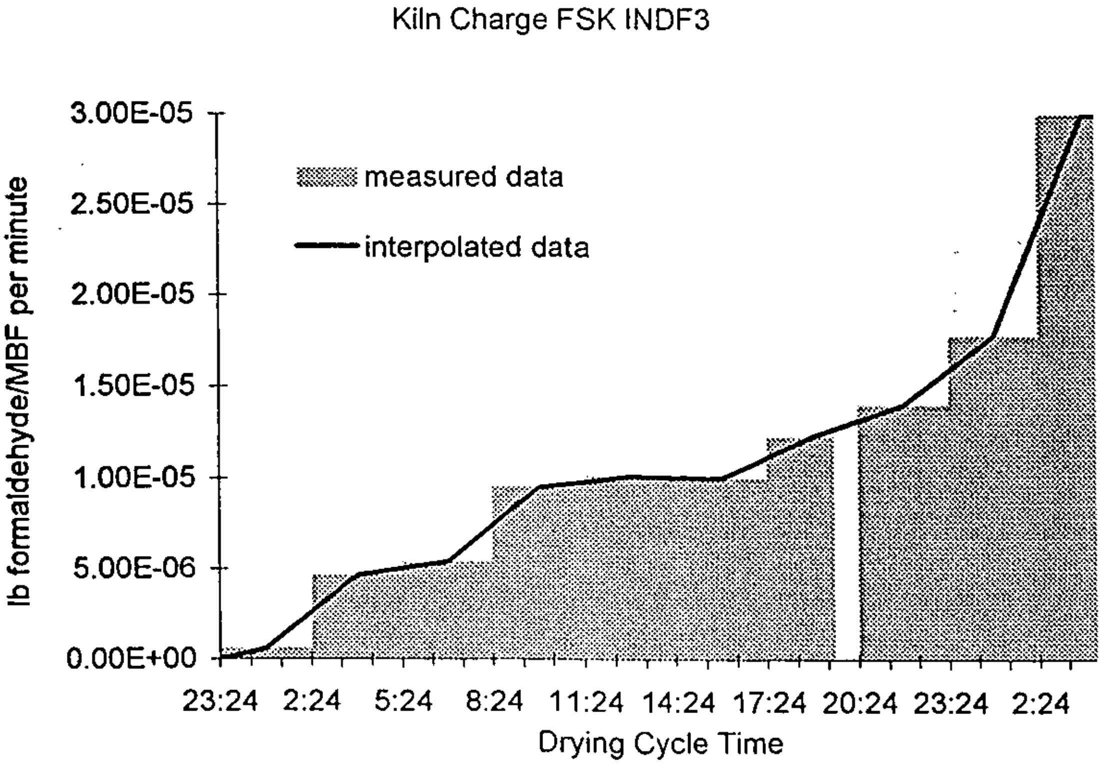
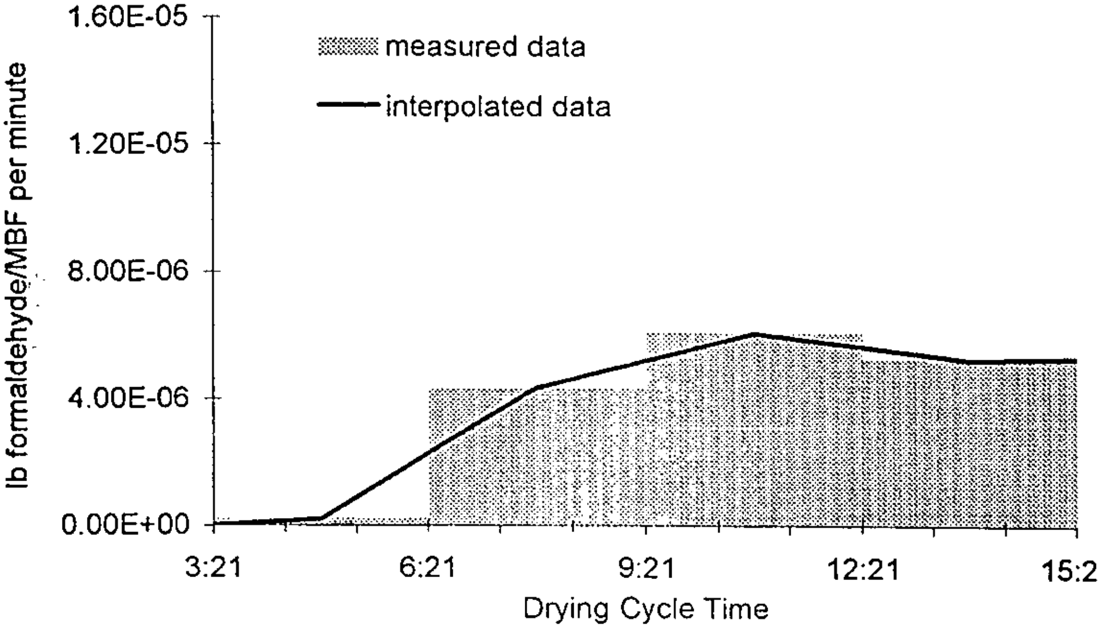


Figure V.4. Formaldehyde Mass Emission Rate from the Steam-Heated Kiln


Kiln Charge MSU INDF1

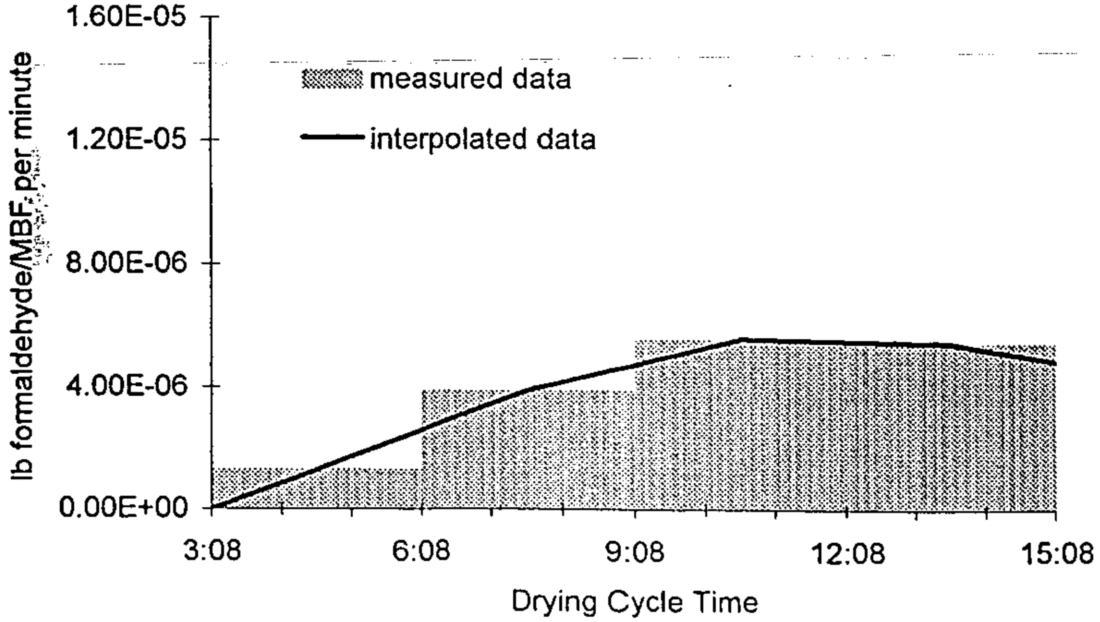
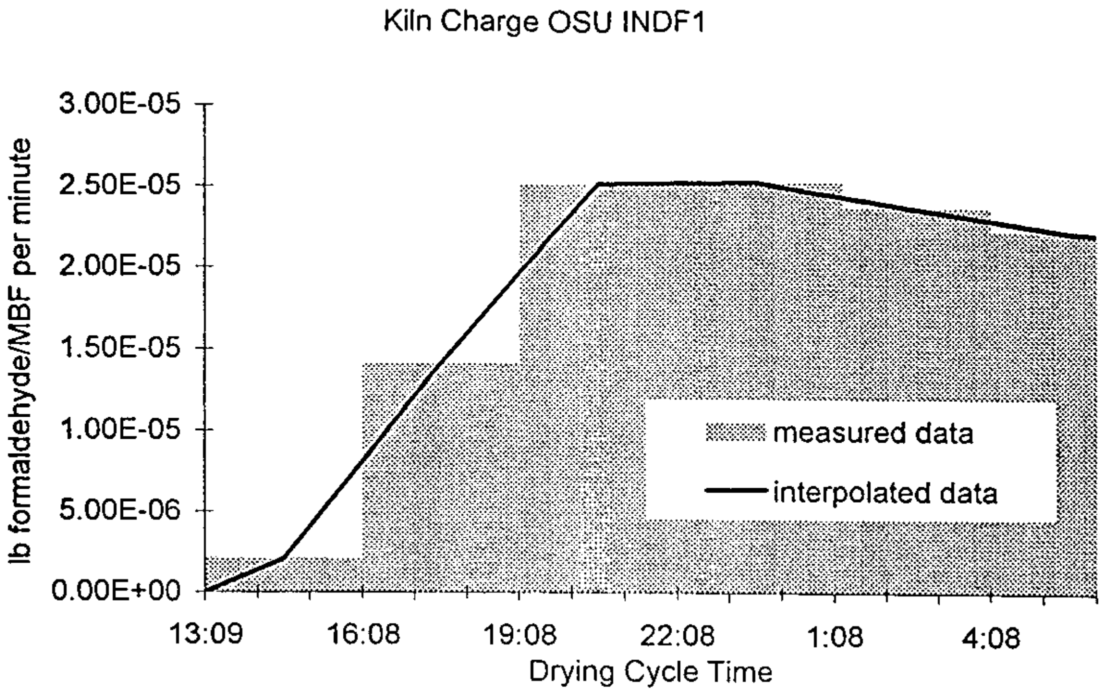
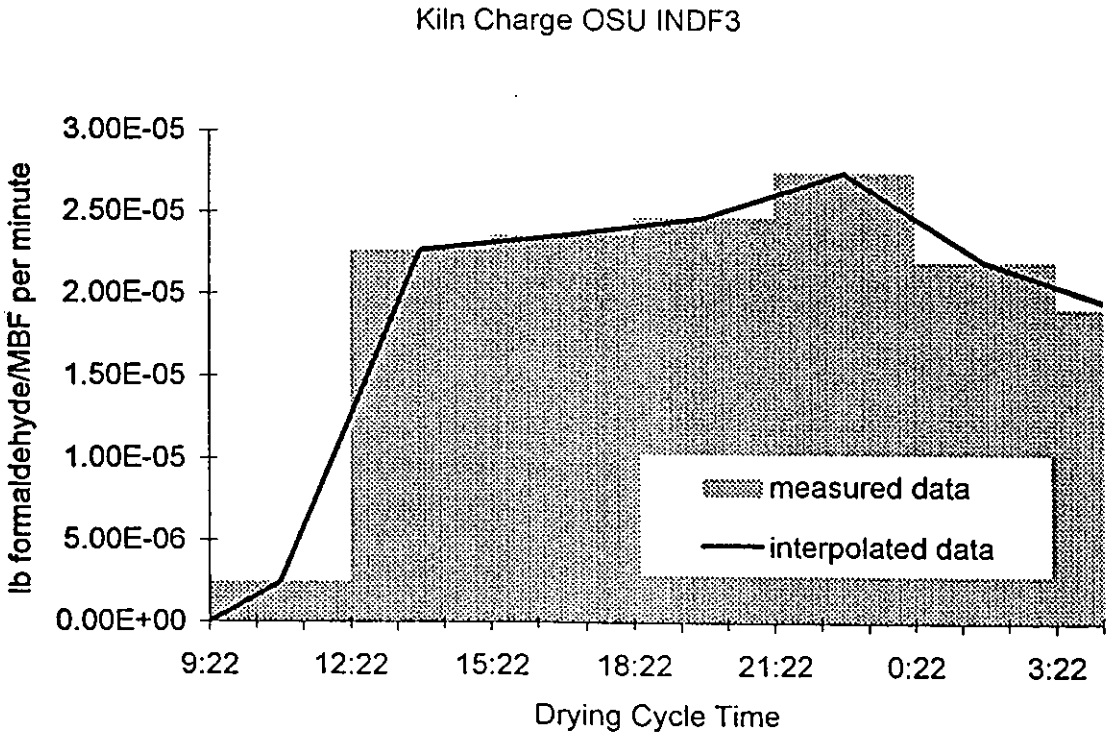

Kiln Charge MSU INDF2

Figure V.5. Formaldehyde Mass Emission Rate for the Steam-Heated Drying Schedule at MSU



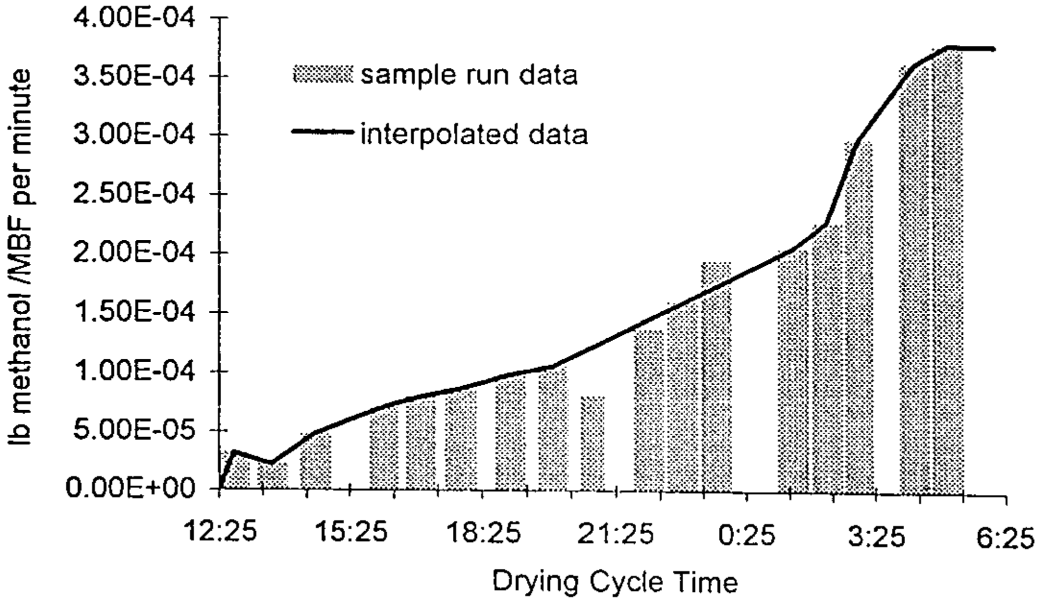
Kiln Charge OSU INDF1



Kiln Charge OSU INDF3

Figure V.6. Formaldehyde Mass Emission Rate for the Steam-Heated Drying Schedule at OSU

Kiln Charge FSK-DF2



Kiln Charge FSK-DF5

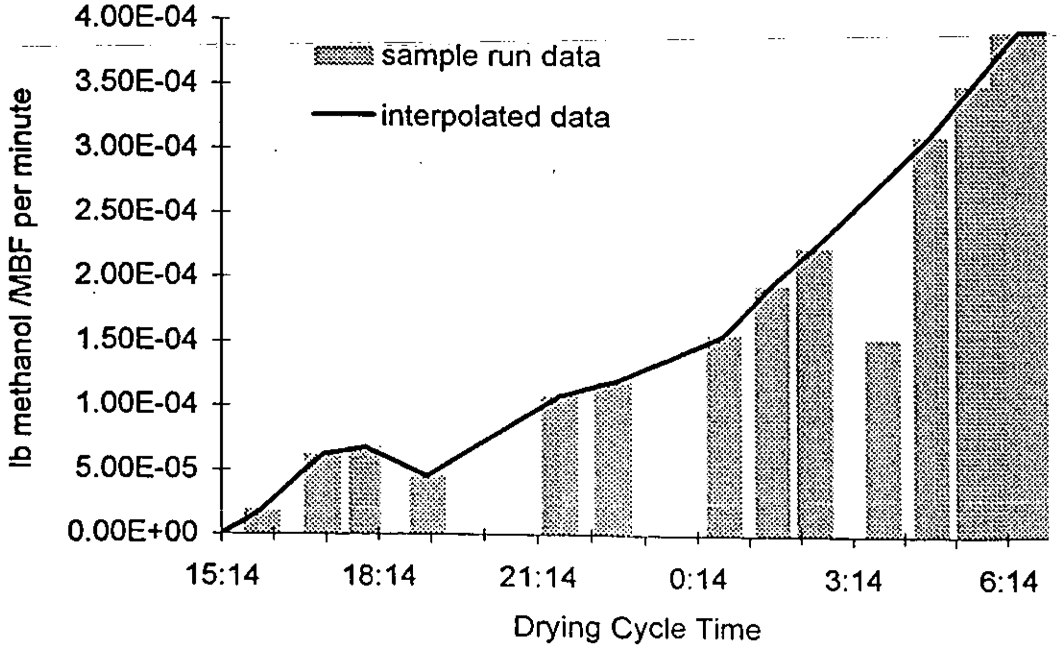
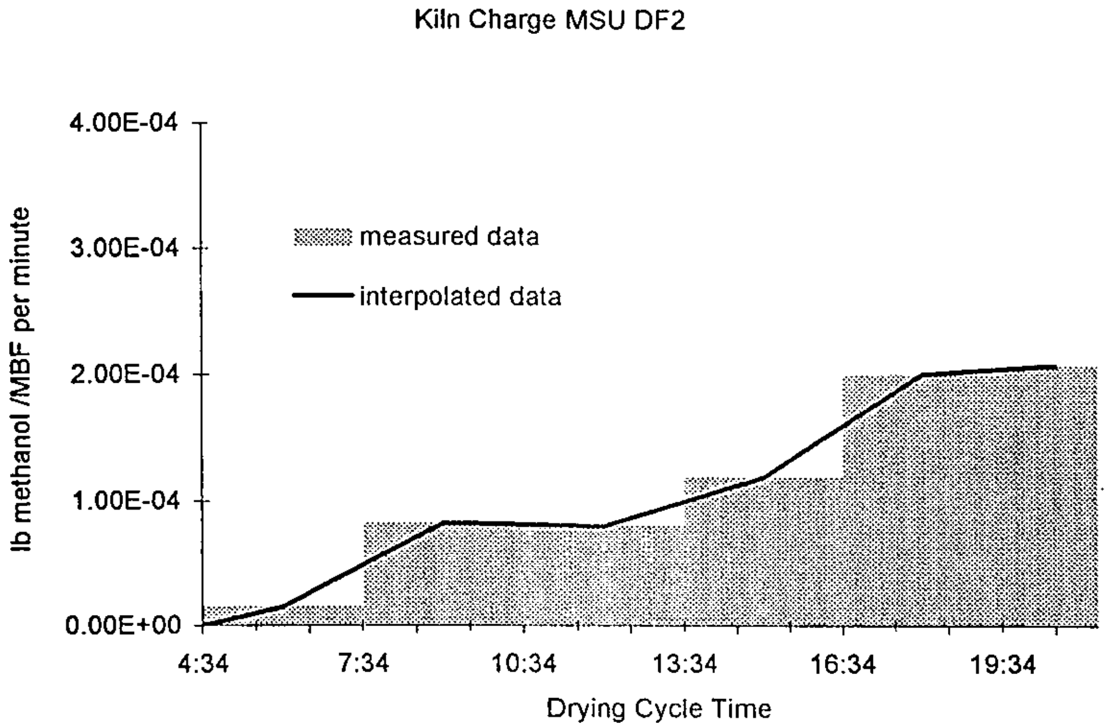


Figure V.7. Methanol Mass Emission Rate from the Direct-Fired Kiln



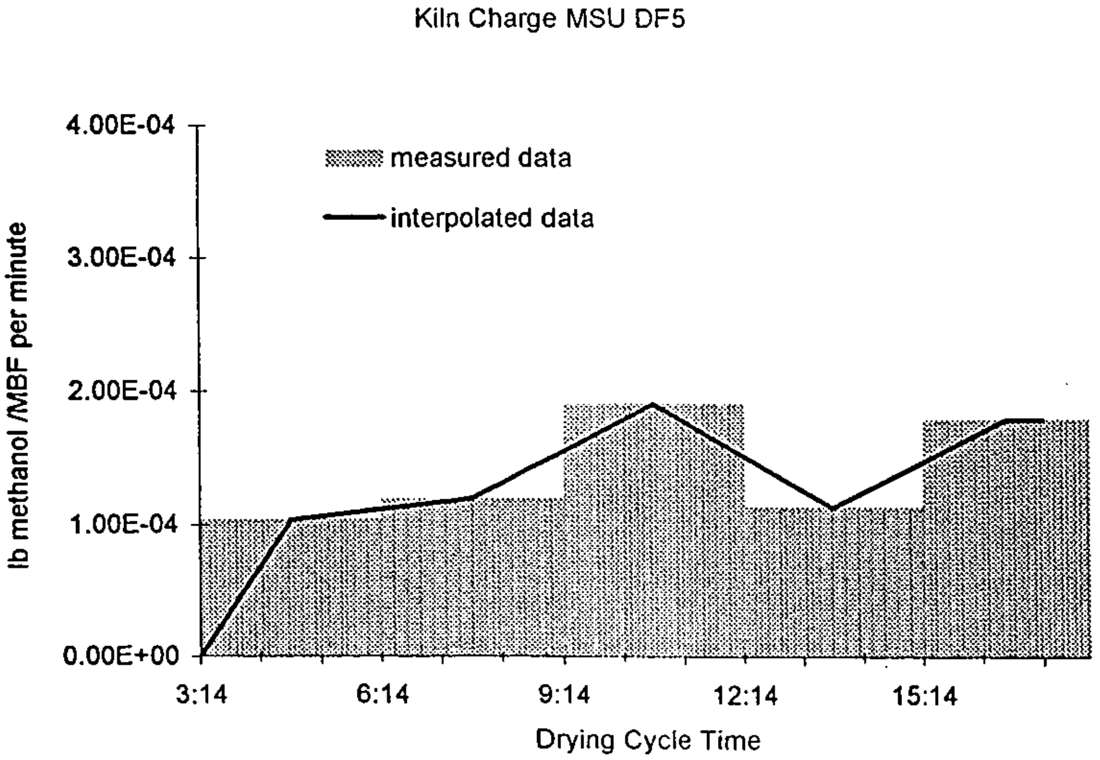
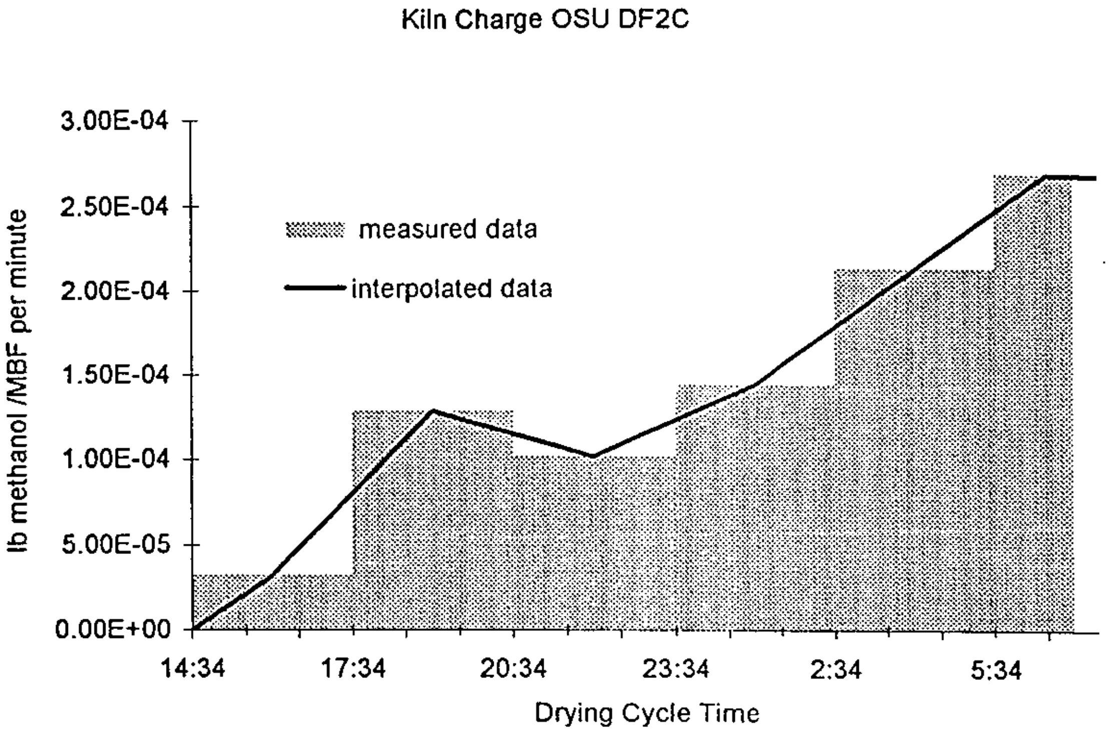


Figure V.8. Methanol Mass Emission Rate for the Direct-Fired Drying Schedule at MSU



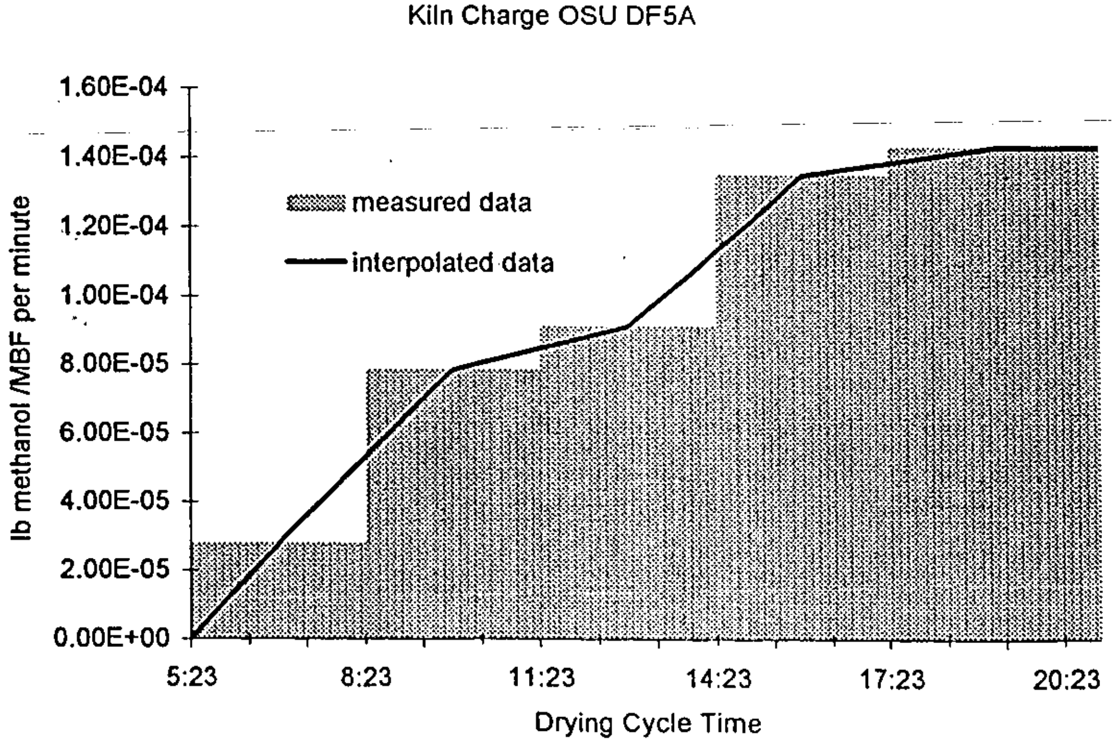
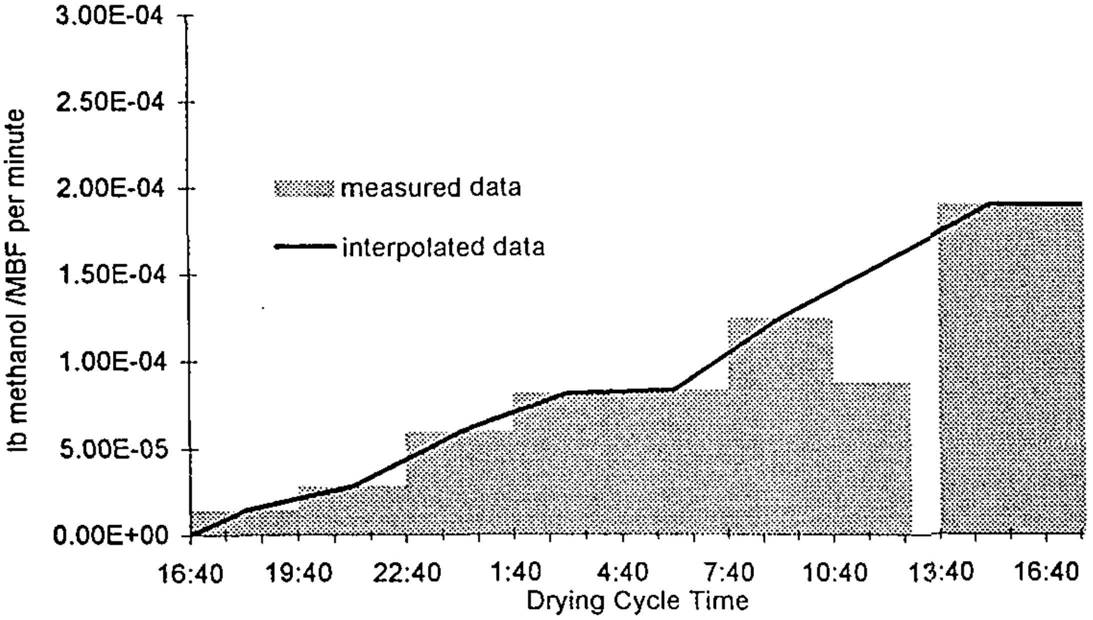


Figure V.9. Methanol Mass Emission Rate for the Direct-Fired Drying Schedule at OSU

Kiln Charge FSK INDF1



Kiln Charge FSK INDF3

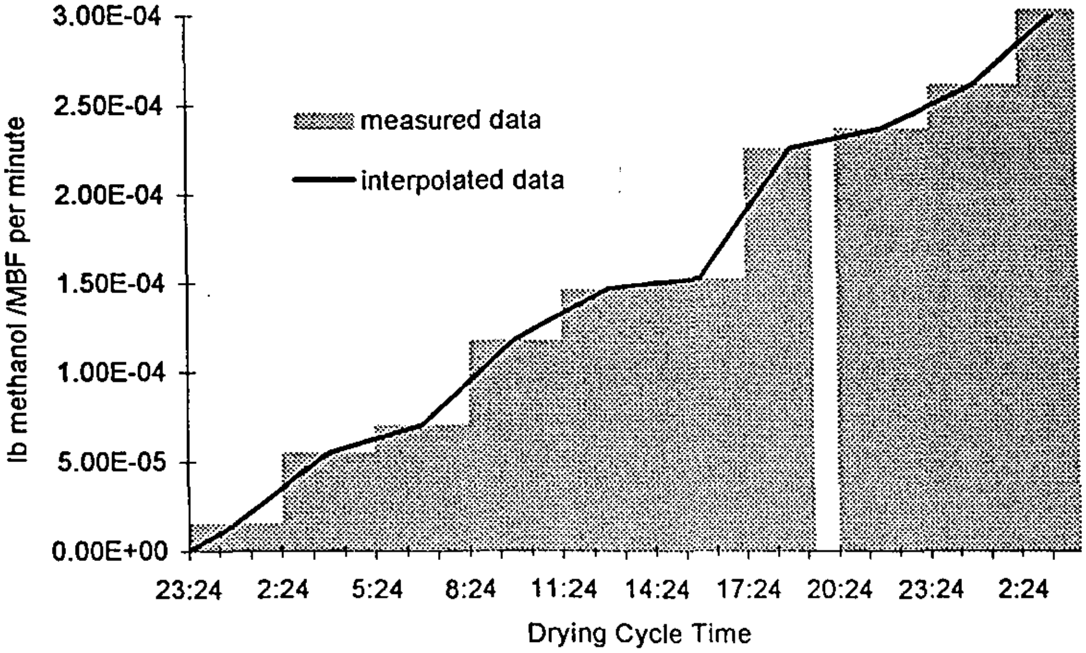
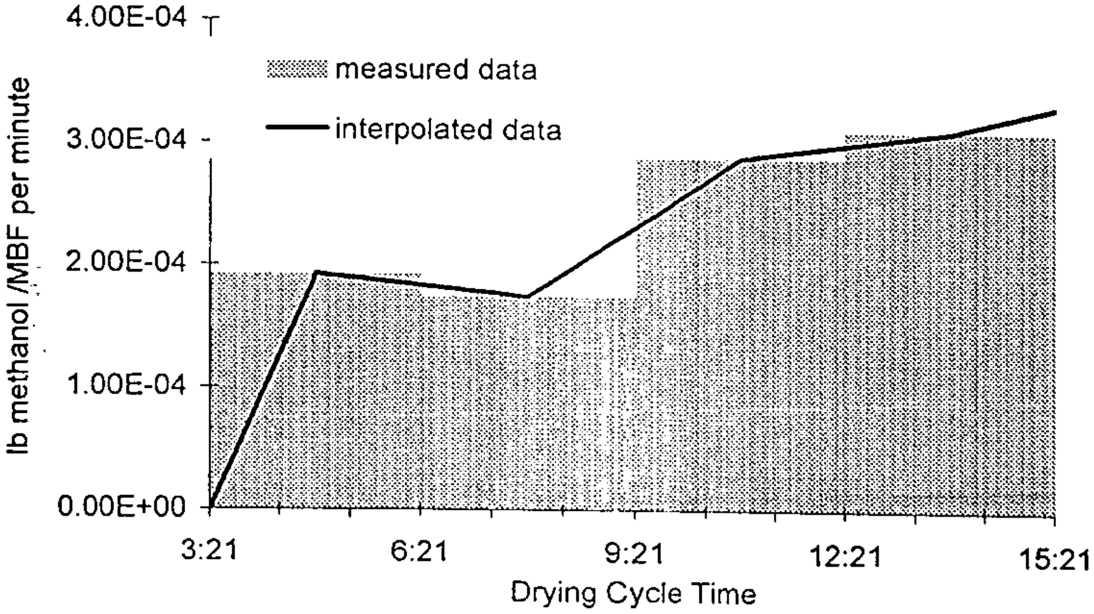


Figure V.10. Methanol Mass Emission Rate from the Steam-Heated Kiln

Kiln Charge MSU INDF1



Kiln Charge MSU INDF2

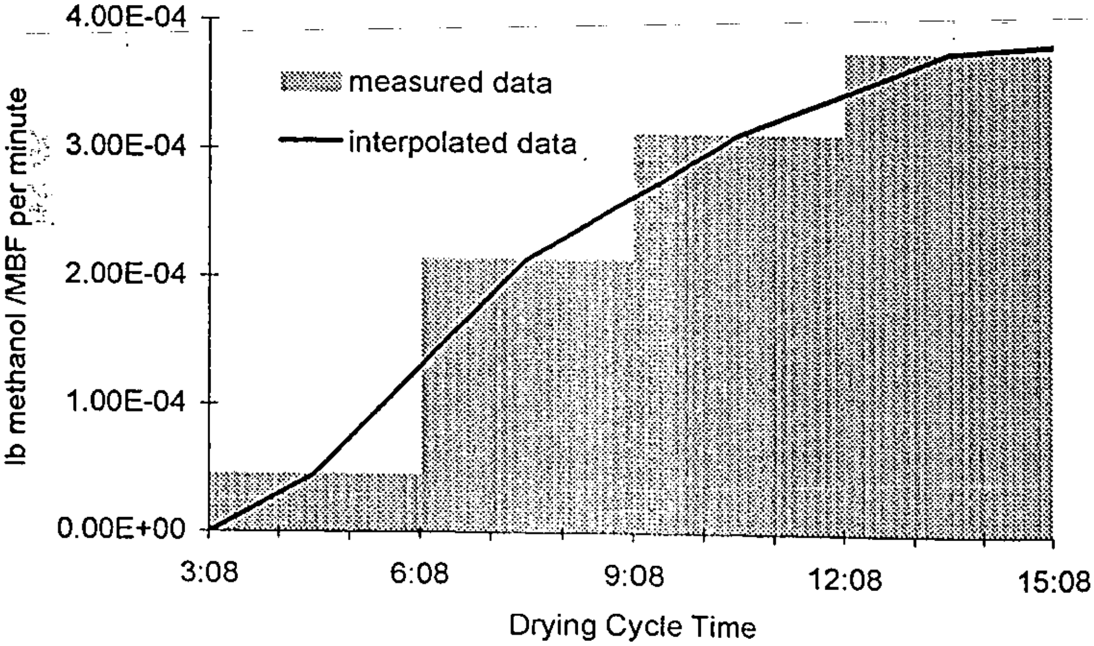


Figure V.11. Methanol Mass Emission Rate for the Steam-Heated Drying Schedule at MSU

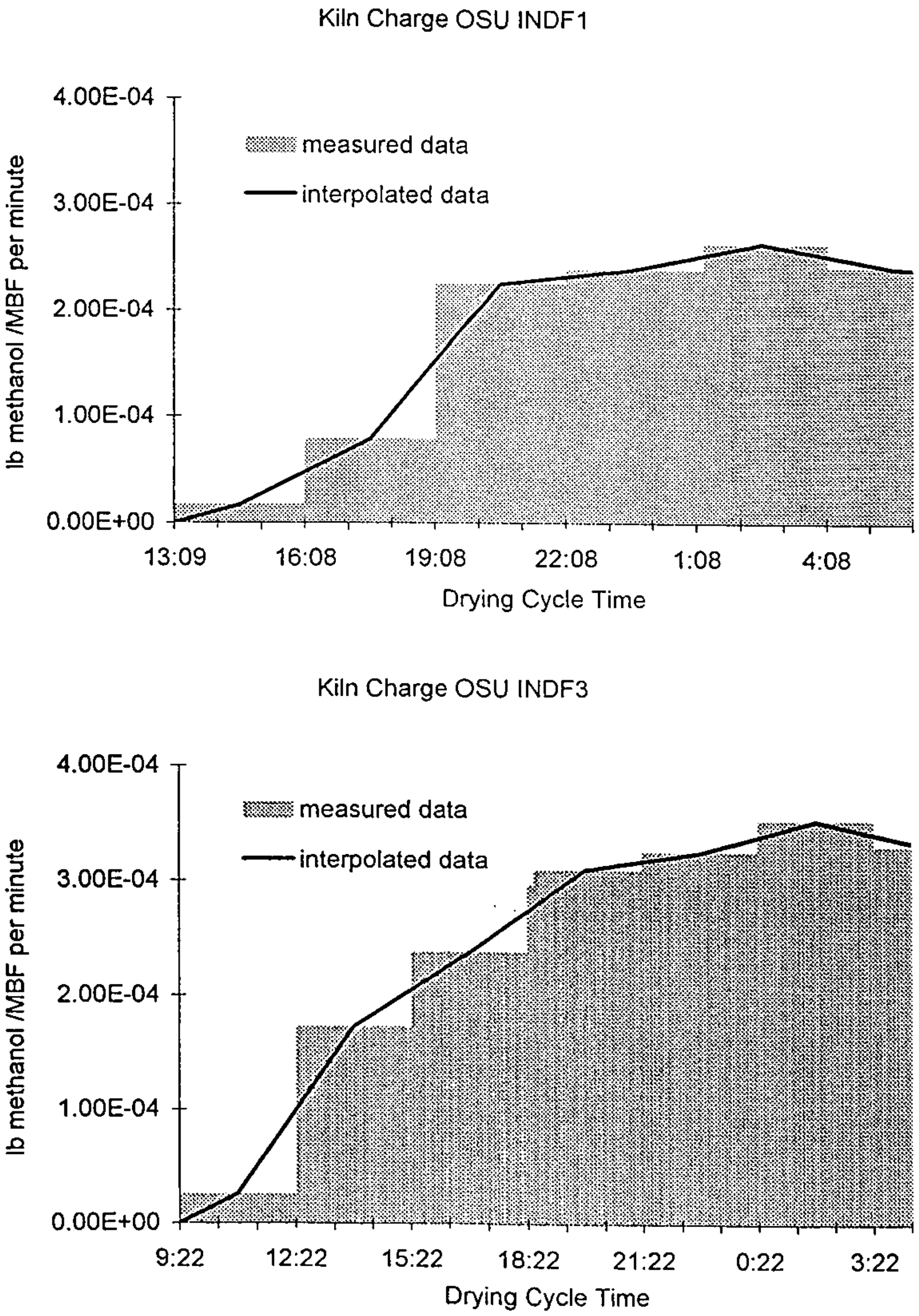


Figure V.12. Methanol Mass Emission Rate for the Steam-Heated Drying Schedule at OSU

APPENDIX W

PHASE II SPECIATED VOC MASS EMISSION RATES

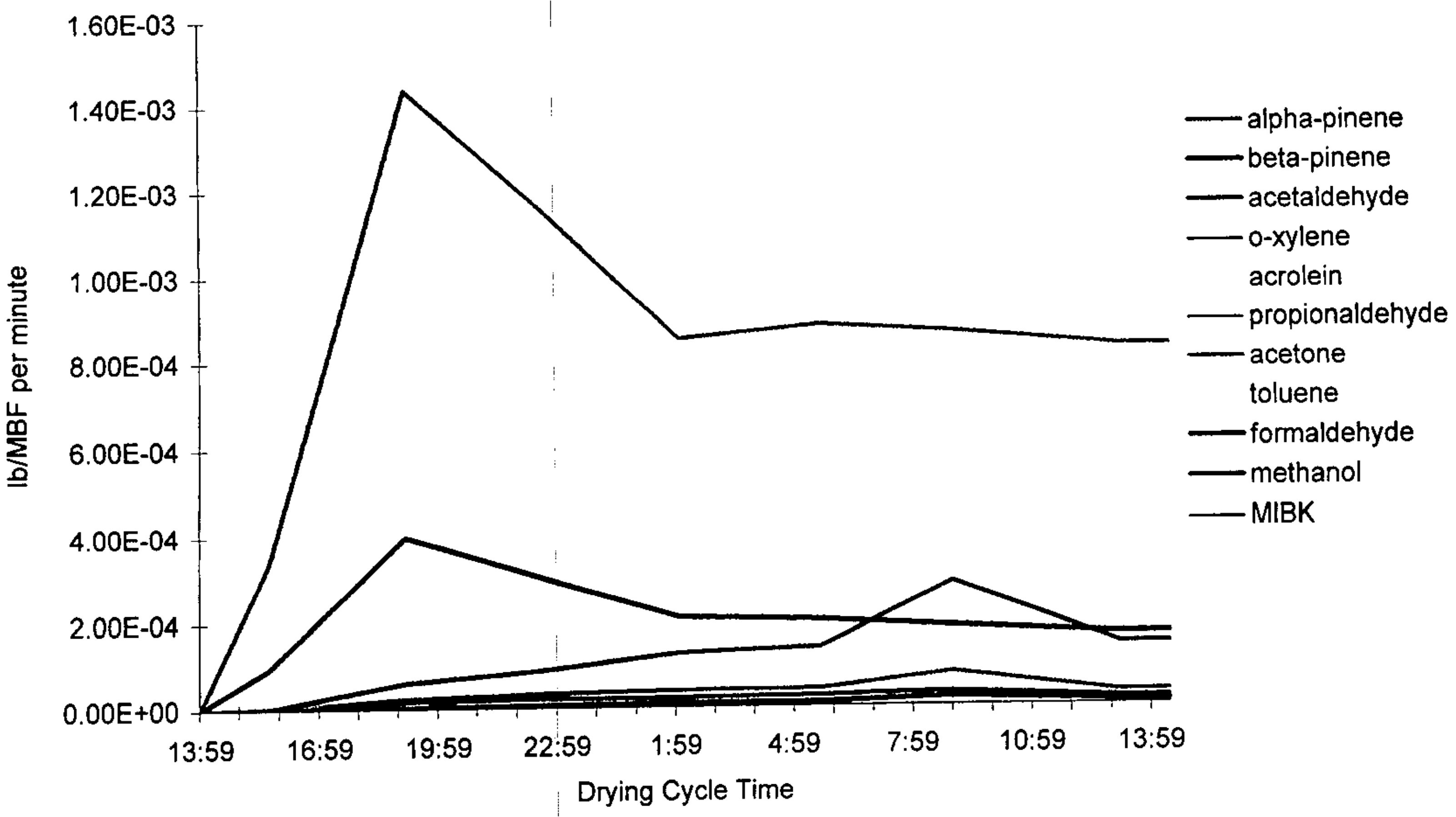


Figure W.1. Comparison of Variability Study Speciated VOC Mass Emission Rates (Kiln Charge NCSU/DEECO 3)

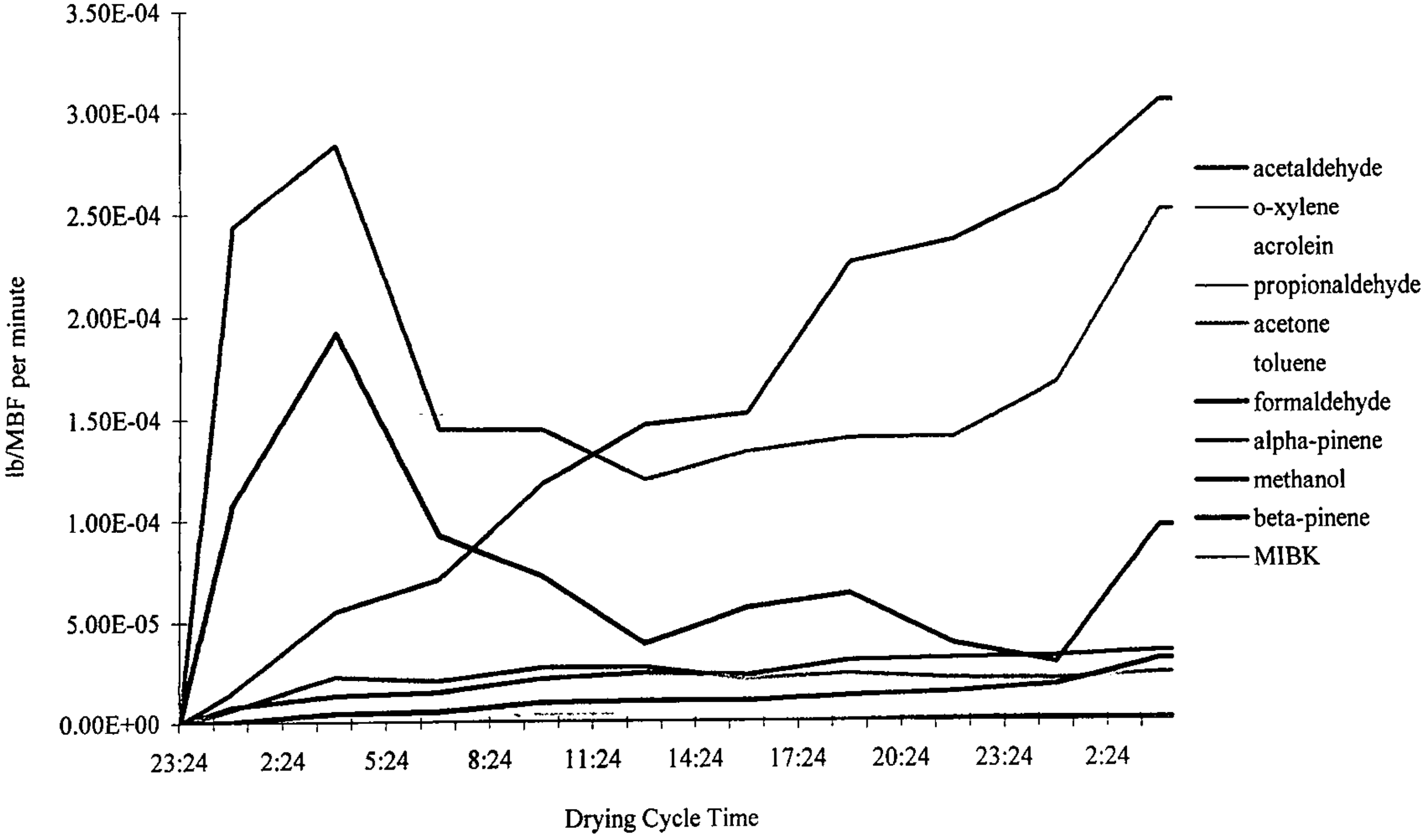


Figure W.2. Comparison of Phase II Speciated VOC Mass Emission Rates (Kiln Charge FSK INDF3)

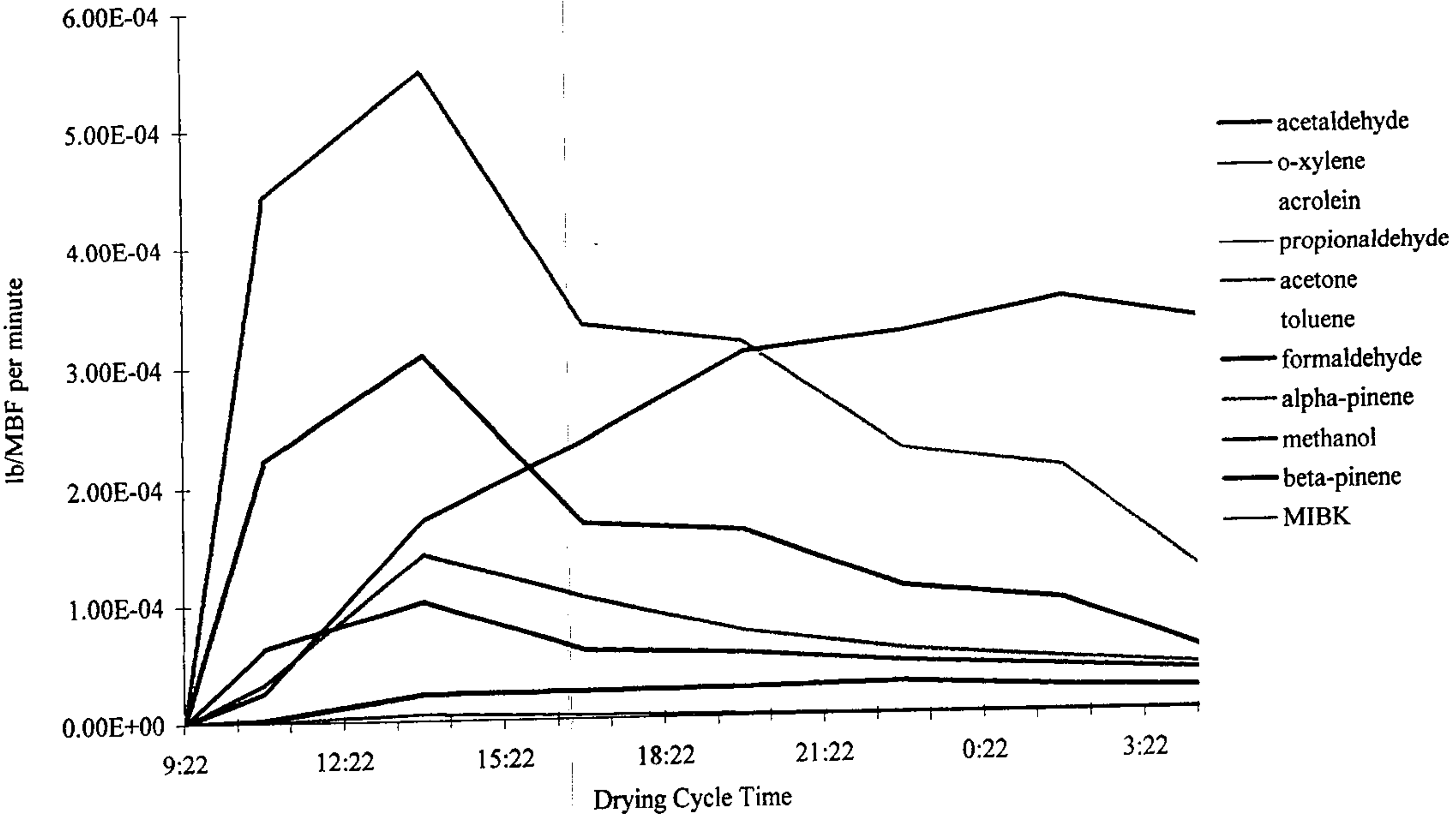
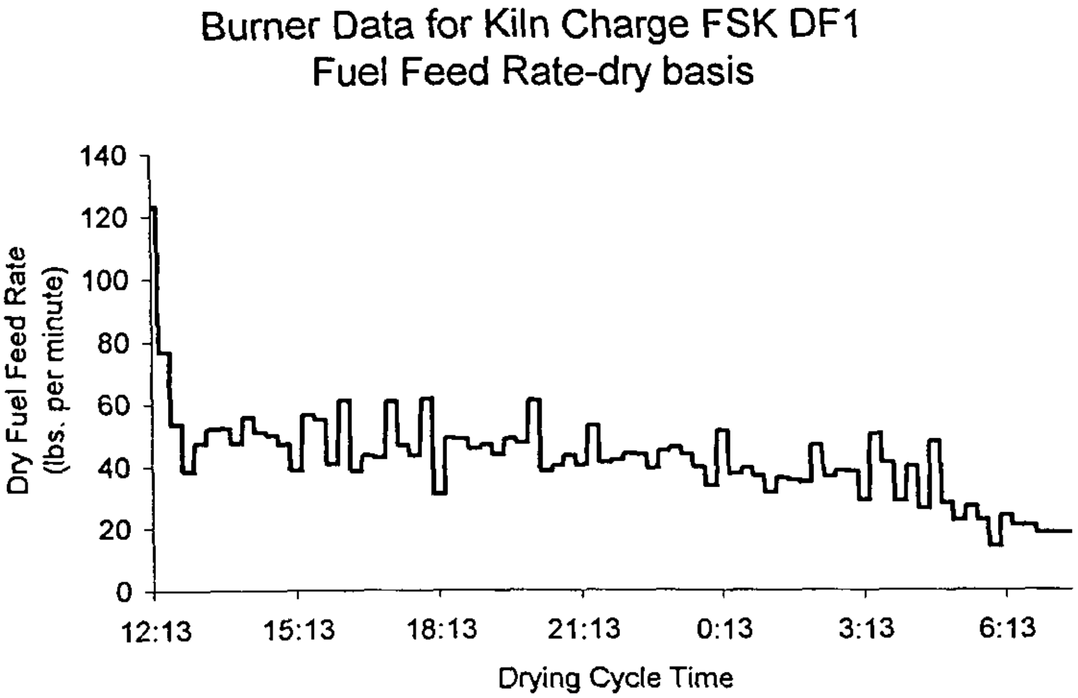


Figure W.3. Comparison of Phase II Speciated VOC Mass Emission Rates (Kiln Charge OSU INDF3)

APPENDIX X

DIRECT-FIRED BURNER PROFILES FOR FUEL FEED RATE, MOISTURE TRAIN, AND VOC MASS EMISSION RATES



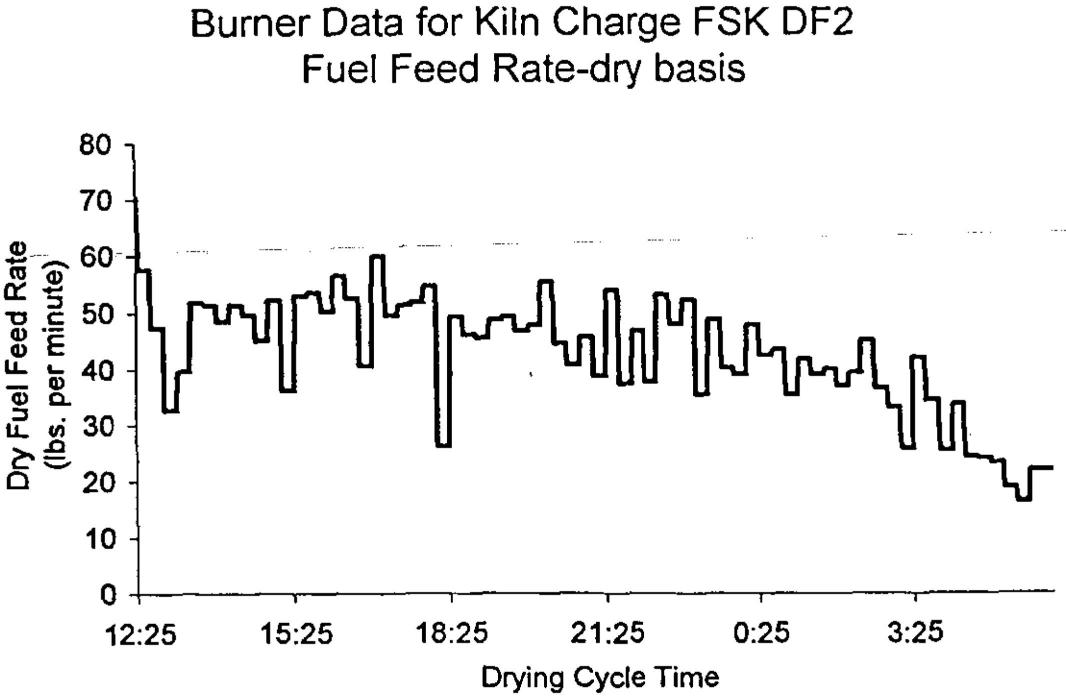
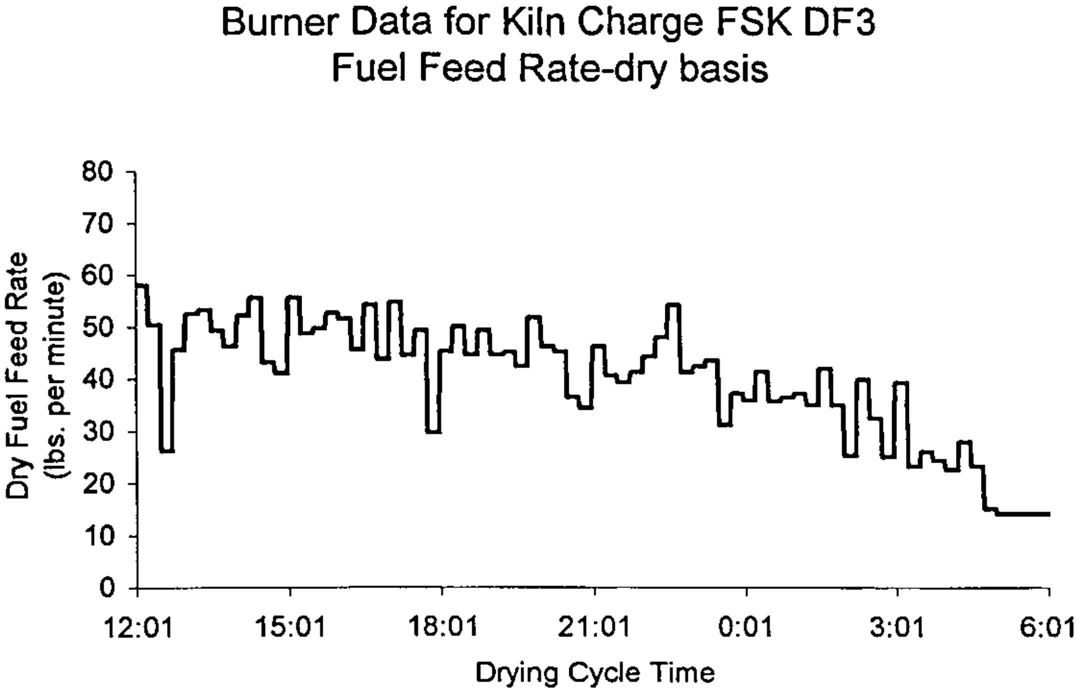


Figure X.1. Direct-Fired Burner Fuel Feed Rate for Kiln Charges FSK DF1 and DF2


Burner Data for Kiln Charge FSK DF3
Fuel Feed Rate-dry basis

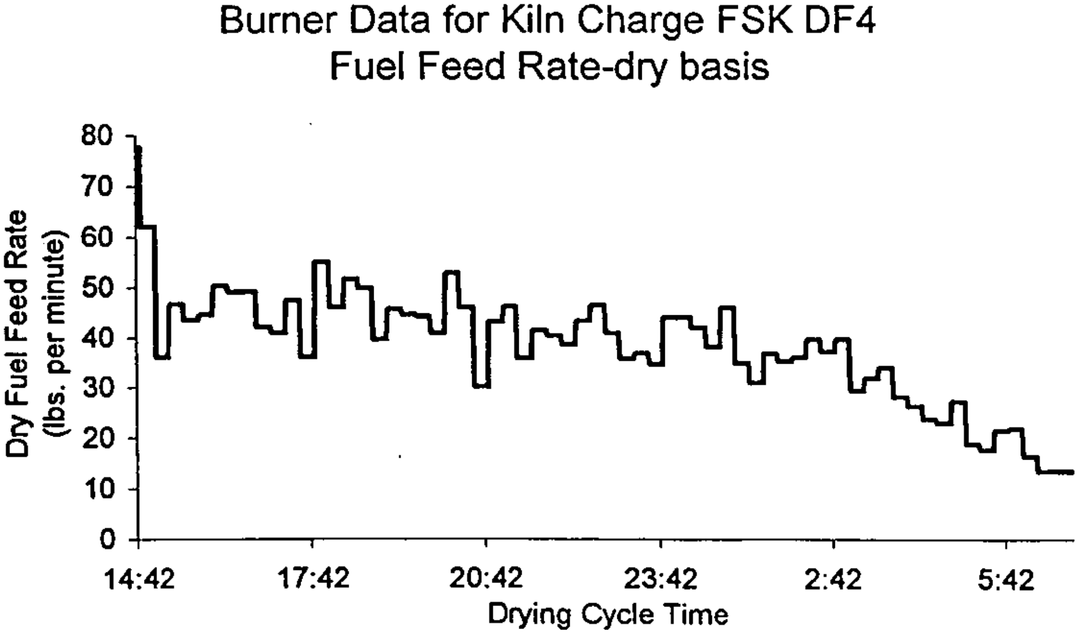
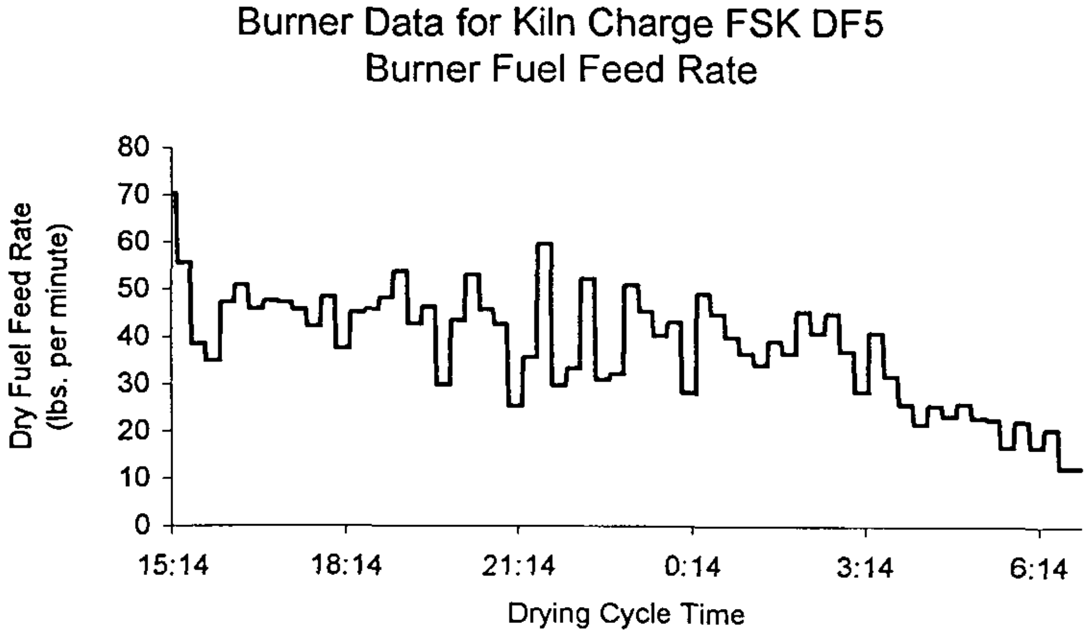

Burner Data for Kiln Charge FSK DF4
Fuel Feed Rate-dry basis

Figure X.2. Direct-Fired Burner Fuel Feed Rate for Kiln Charges FSK DF3 and DF4



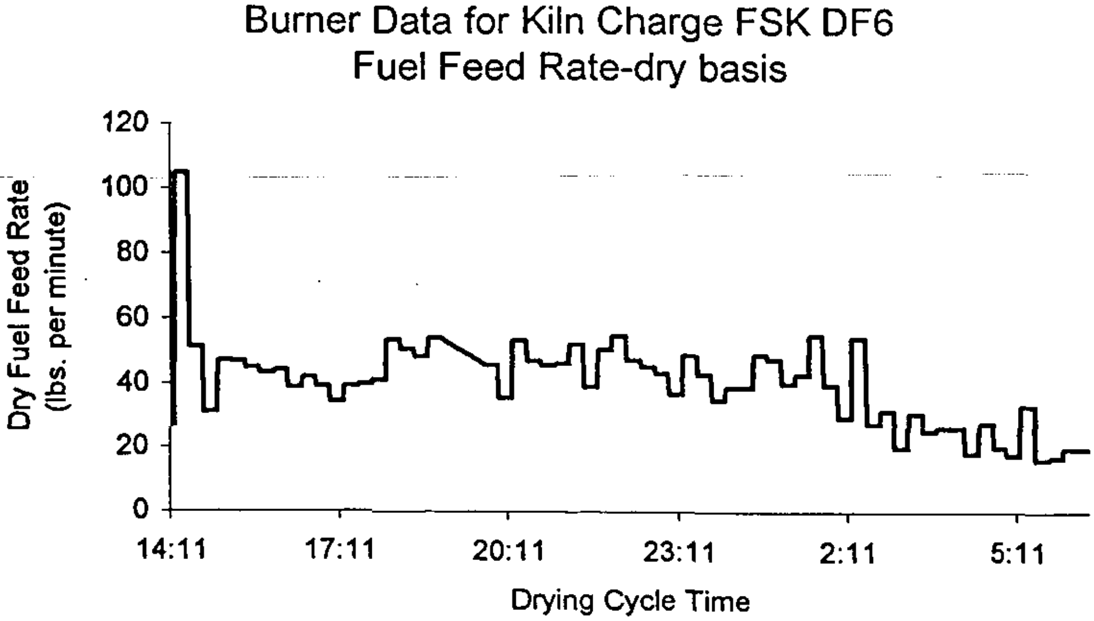


Figure X.3. Direct-Fired Burner Fuel Feed Rate for Kiln Charges FSK DF5 and DF6

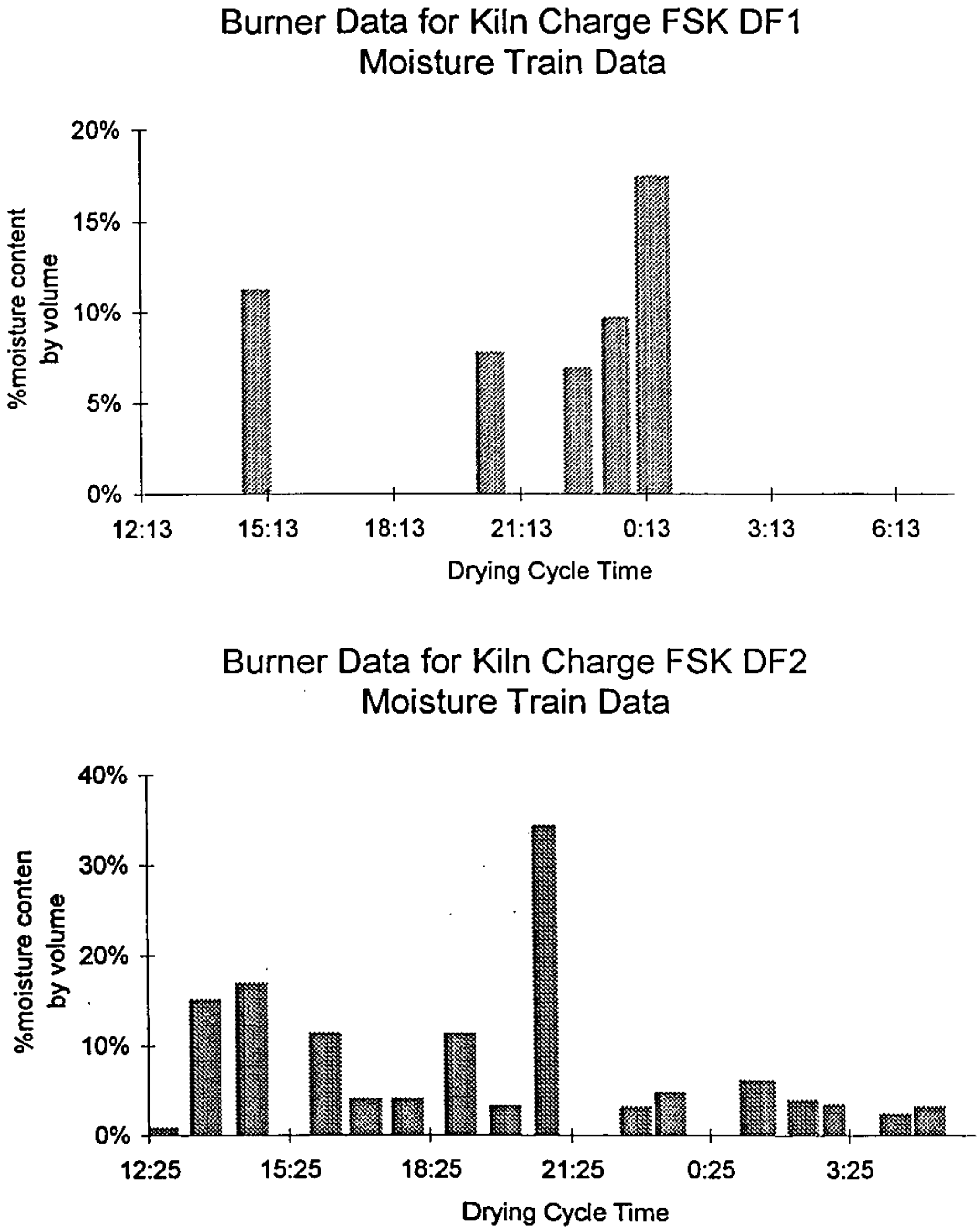
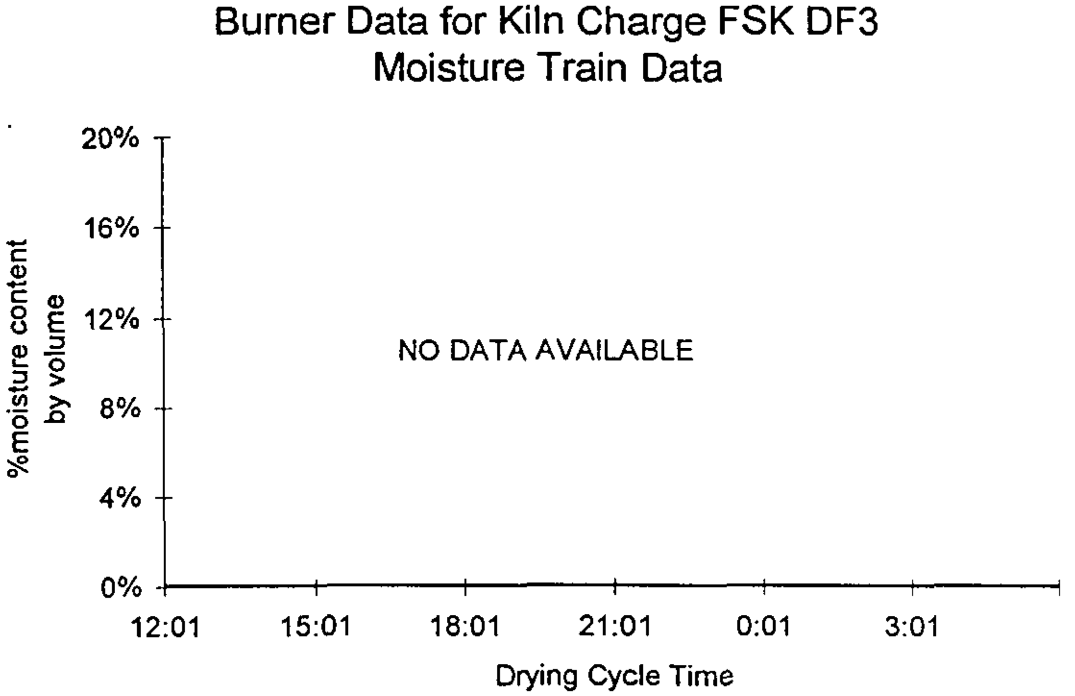


Figure X.4. Direct-Fired Burner Moisture Train Data for Kiln Charges FSK DF1 and DF2



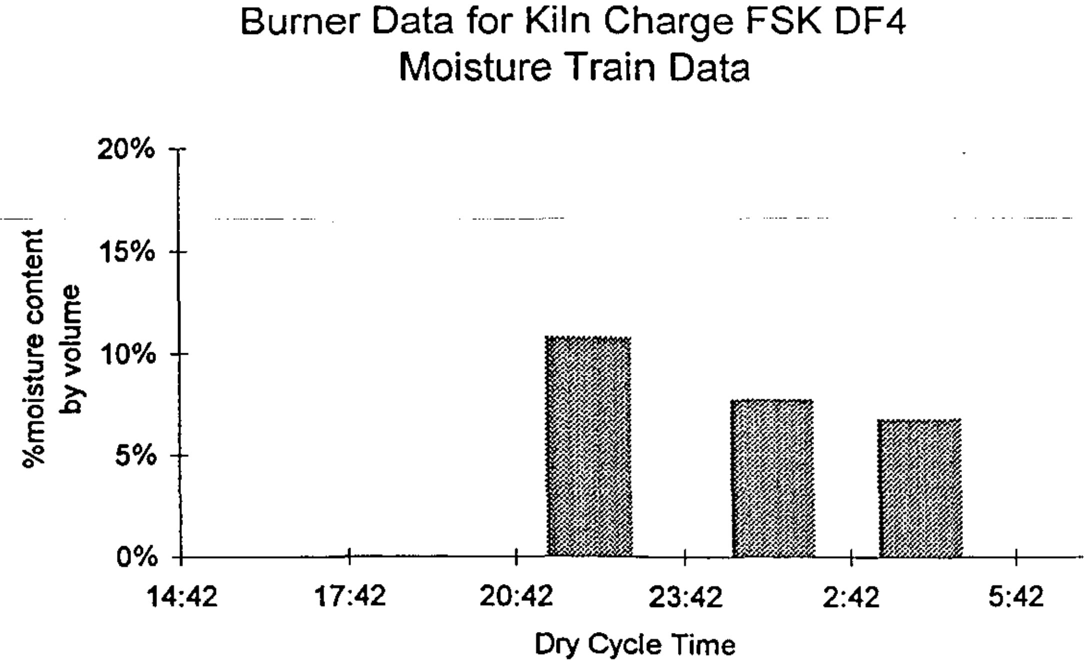
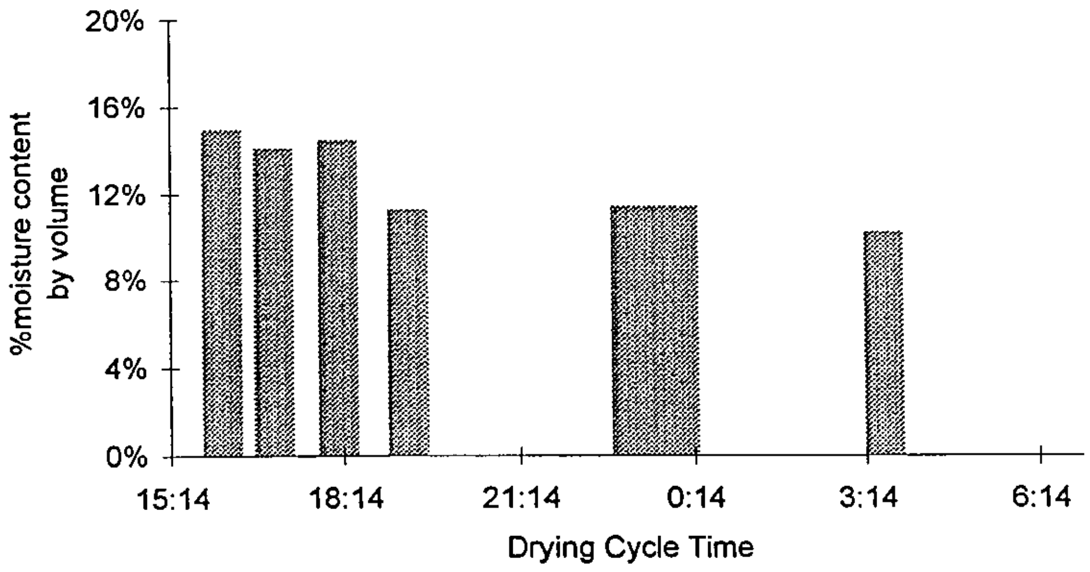
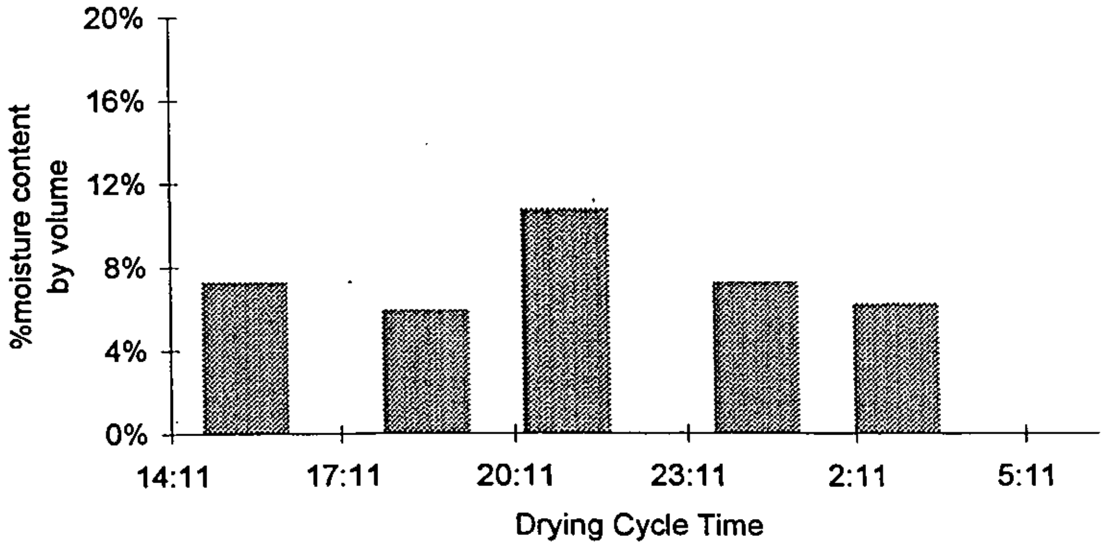


Figure X.5. Direct-Fired Burner Moisture Train Data for Kiln Charges FSK DF3 and DF4

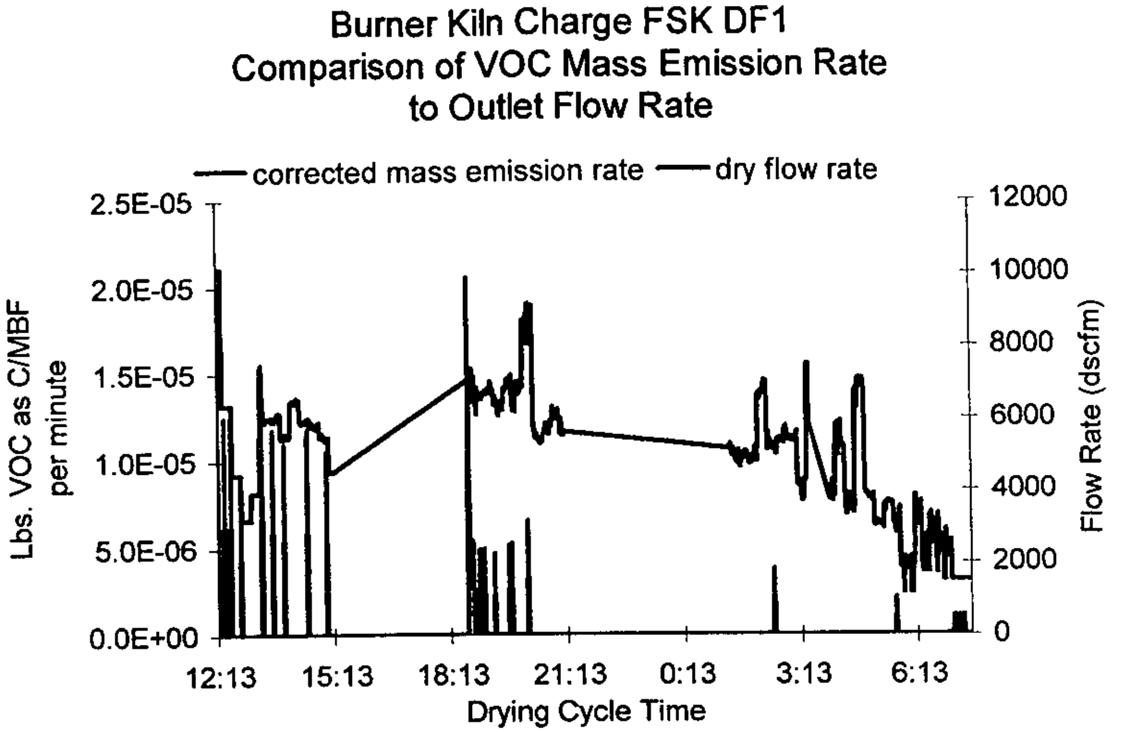


Burner Data for Kiln Charge FSK DF5
Moisture Train Data



Burner Data for Kiln Charge FSK DF6
Moisture Train Data

Figure X.6. Direct-Fired Burner Moisture Train Data for Kiln Charges FSK DF5 and DF6



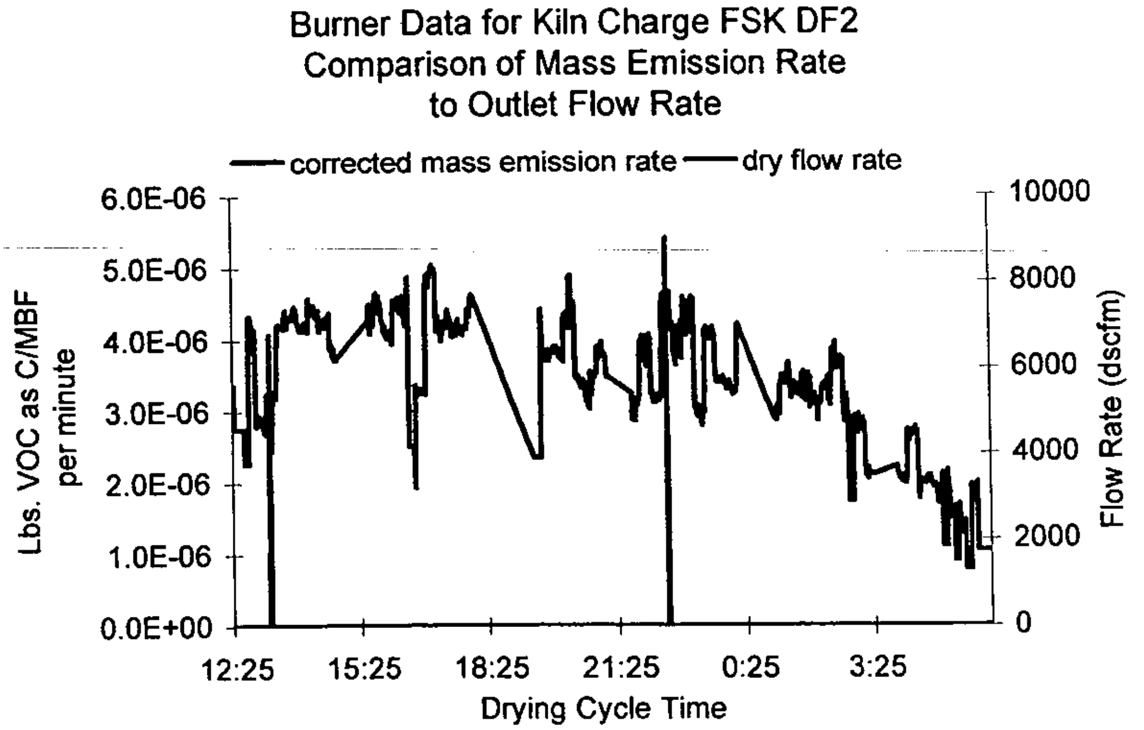
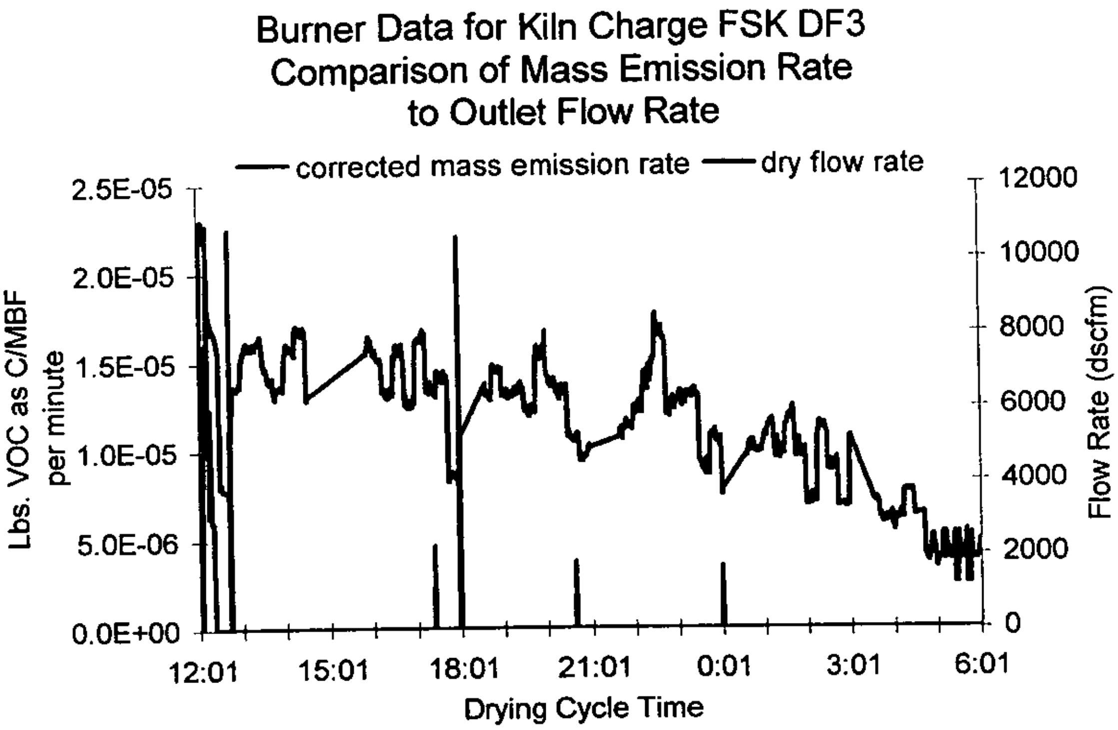


Figure X.7. Direct-Fired Burner VOC Mass Emission Rate for Kiln Charges FSK DF1 and DF2



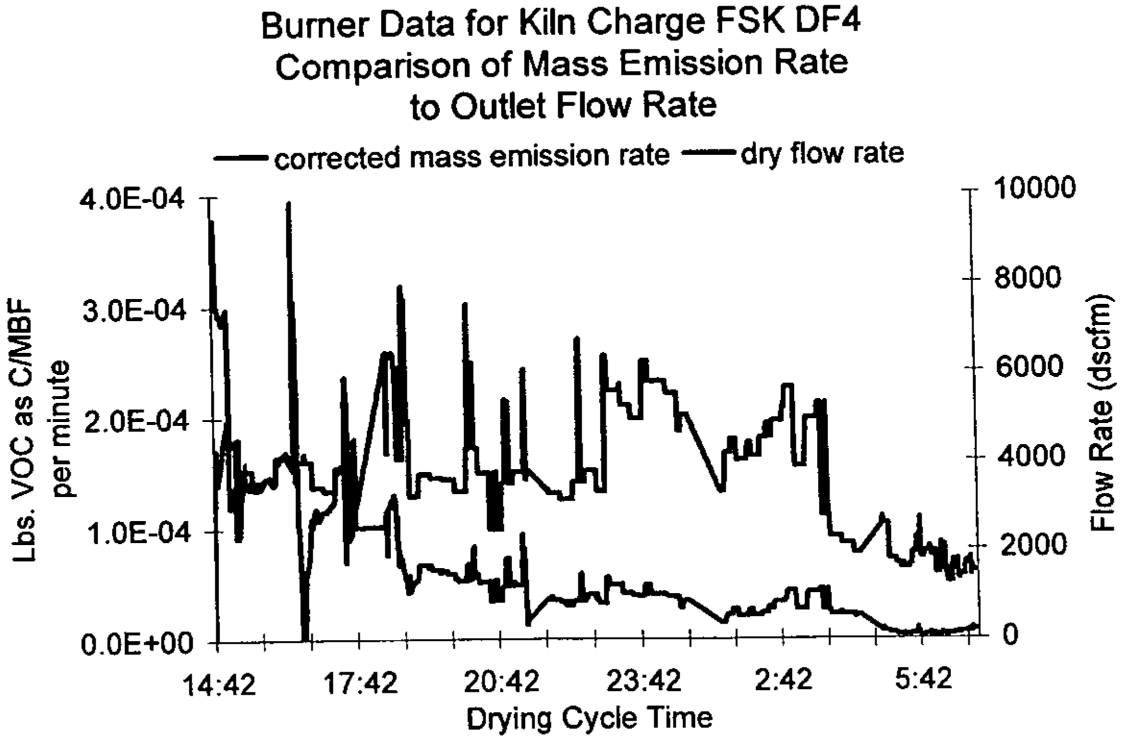
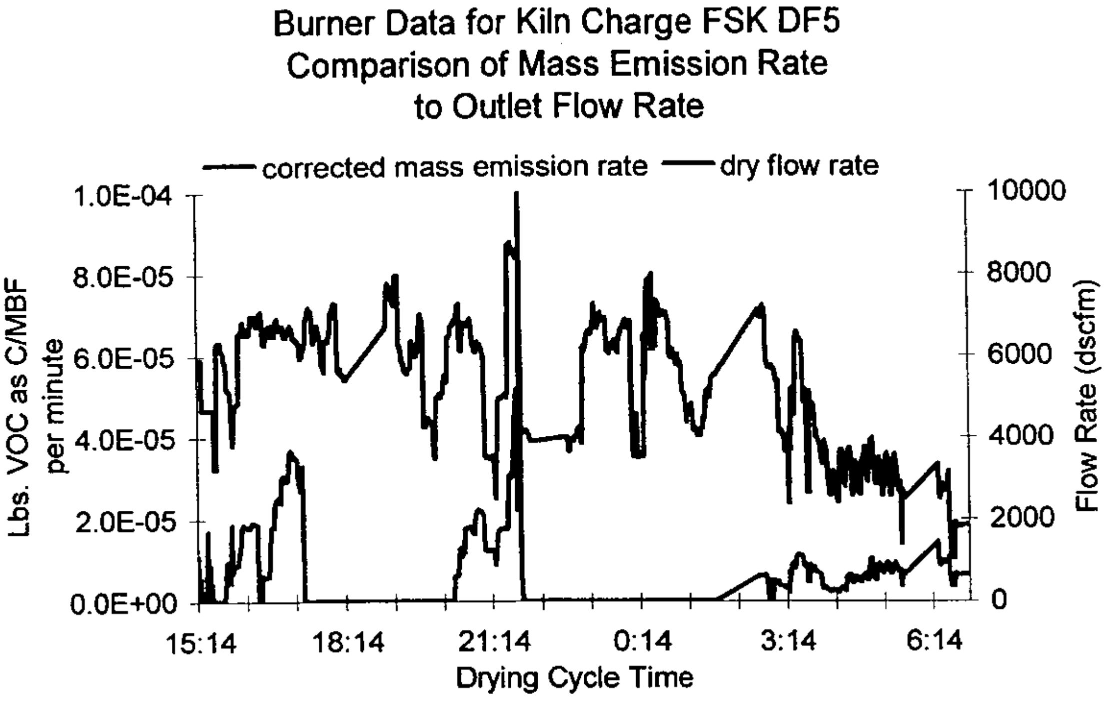


Figure X.8. Direct-Fired Burner VOC Mass Emission Rate for Kiln Charges FSK DF3 and DF4



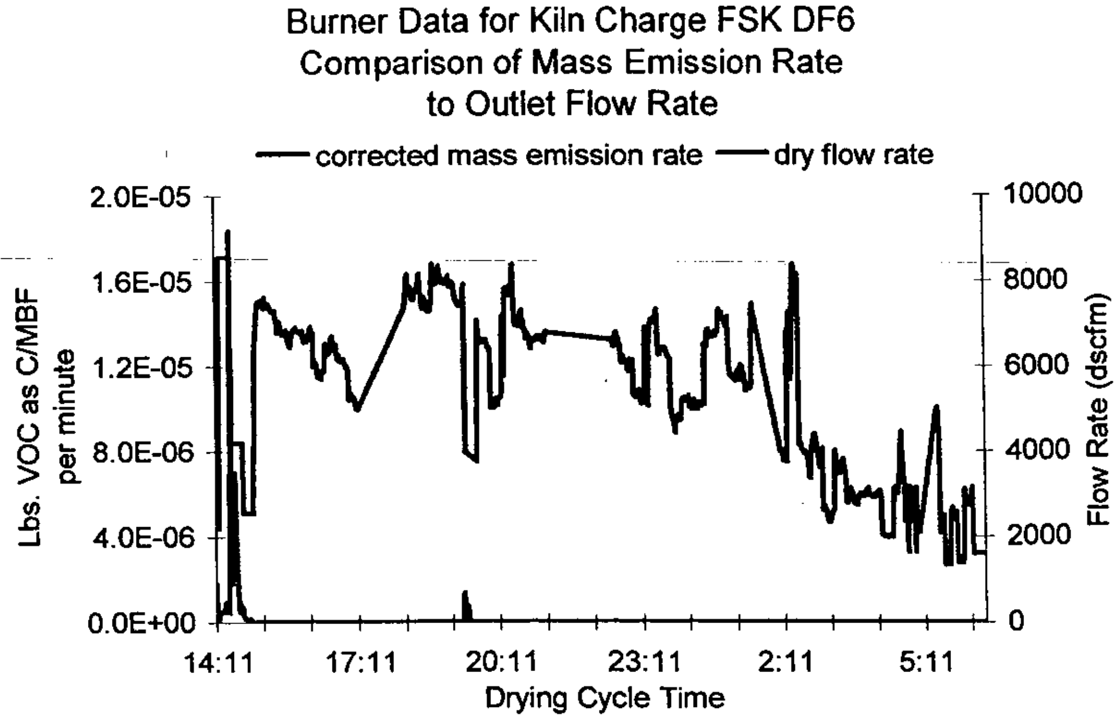


Figure X.9. Direct-Fired Burner VOC Mass Emission Rate for Kiln Charges FSK DF5 and DF6

Kiln Charge FSK DF1
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event		**4.19**
	%MC Wood	Per Sample Run:
Run 1		0.6892
Run 2		0.6671
Run 3		0.4754
Run 4		0.3657
Run 5		0.5580
Run 6		1.1905
Run 7	11.7%	0.2465

Kiln Charge FSK DF1
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	19.37	0.00	19.38

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
11.93	62%	7:07	

Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	0	0	180
Run 3	120	120	180
Run 4	97	77	180
Run 5	122	122	180
Run 6	217	217	263
Run 7	0	0	0

Table X.1. Burner Data for Kiln Charge FSK DF1

Kiln Charge FSK DF2
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event		**4.70**
	%MC Wood	Per Sample Run:
Run 1		0.5288
Run 2		0.7906
Run 3		0.7433
Run 4		0.8286
Run 5		0.7564
Run 6	15.5%	1.0562

Kiln Charge FSK DF2
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	17.72	0.00	17.73
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
14.55	82%	2:51	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	147	147	180
Run 2	149	0	180
Run 3	149	149	180
Run 4	149	129	180
Run 5	137	137	180
Run 6	162	162	164
Run 7	0	0	0

Table X.2. Burner Data for Kiln Charge FSK DF2

Kiln Charge FSK DF3 VOC Mass Emission Rate (Pounds of VOC as Carbon/MBF)		
		NCASI integrated value
Sum Total for the Sample Event:		4.22
	%MC Wood	Per Sample Run:
Run 1		0.5796
Run 2		0.5957
Run 3		0.5287
Run 4		0.5869
Run 5		0.8074
Run 6	12.6%	1.1222

Kiln Charge FSK DF3 Time Schedules			
Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	17.98	0.00	18.00
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
14.12	78%	3:33	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	150	150	180
Run 2	130	0	180
Run 3	148	148	180
Run 4	145	125	180
Run 5	146	146	180
Run 6	148	148	180
Run 7	0	0	0

Table X.3. Burner Data for Kiln Charge FSK DF3

Kiln Charge FSK DF4
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**2.90**
	%MC Wood	Per Sample Run:
Run 1		0.2718
Run 2		0.5244
Run 3		0.4437
Run 4		0.5666
Run 5		0.8075
Run 6		0.2844

Kiln Charge FSK DF4
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	16.18	0.00	16.22

Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
15.75	97%	0:28	

Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	169	169	180
Run 3	177	177	180
Run 4	177	177	180
Run 5	177	177	180
Run 6	64	64	73
Run 7	0	0	0

Table X.4. Burner Data for Kiln Charge FSK DF4

Kiln Charge FSK DF5
VOC Mass Emission Rate
(Pounds of VOC as Carbon/MBF)

		NCASI integrated value
Sum Total for the Sample Event:		**3.40**
	%MC Wood	Per Sample Run:
Run 1		0.4681
Run 2		0.6042
Run 3		0.4651
Run 4		0.6353
Run 5		1.0313
Run 6		0.2001

Kiln Charge FSK DF5
Time Schedules

Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	15.73	0.00	15.75
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
9.12	58%	6:38	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	178	178	180
Run 3	178	178	180
Run 4	178	178	180
Run 5	179	179	180
Run 6	35	35	45
Run 7	0	0	0

Table X.5. Burner Data for Kiln Charge FSK DF5

Kiln Charge FSK DF6 VOC Mass Emission Rate (Pounds of VOC as Carbon/MBF)		
Sum Total for the Sample Event:		NCASI integrated value
		3.59
	%MC Wood	Per Sample Run:
Run 1		0.3857
Run 2		0.6440
Run 3		0.4052
Run 4		0.7446
Run 5		1.0330
Run 6		0.3746

Kiln Charge FSK DF6 Time Schedules			
Rampup Time (hour)	Total reported sampling time based on data collection (hour)	Amount of time truncated to reach end of drying cycle (hour)	NCASI sampling time to reach end of drying cycle (hour)
3.00	16.27	0.00	16.28
Actual sampling time for the adjusted Sample Event (hour)	Percent of sampling time for the total adjusted drying cycle	Total calibration period during drying cycle (hour:min)	Duration of data loss during data collection (hour:min)
16.03	98%	0:15	
Run #	Reported duration of data collection by contractor (minutes)	Actual duration of data collection by contractor (minutes)	NCASI Extrapolated Sample Run (minutes)
Run 1	180	180	180
Run 2	179	179	180
Run 3	179	179	180
Run 4	178	178	180
Run 5	179	179	180
Run 6	67	67	77
Run 7	0	0	0

Table X.6. Burner Data for Kiln Charge FSK DF6

Burner Data for Kiln Charge FSK DF5 Pounds Formaldehyde and Methanol/MBF		
	Formaldehyde	Methanol
	0.00276	
Runs 1	3.66E-04	
Runs 2	1.32E-03	
Runs 3	6.53E-04	
Runs 4	2.45E-04	
Runs 5	1.47E-04	
Runs 6	3.56E-05	

Burner Data for Kiln Charge FSK DF5 F/M Time Schedules			
Rampup Time (hour)	Total reported sampling time based on the F/M data collection (hour)	Duration of the complete F/M Sample Event to ending % MC (hour)	Amount of time adjustment to ending % MC (hour)
3.00	15.15	15.73	0.58
Total time of data collection for the Sample Event (hour)	Percent of actual sample collection to Sample Event	Total amount of Meas. System turn around time required (hour)	Percent of Measurement system turn around time to Sample Event
8.48	54%	7.25	46%
Run #	Reported duration of data collection (minutes)	Reported duration of turn around time (minutes)	Extrapolated Sample Run time reported to 15% (minutes)
1	40	14	180
2	40	26	180
3	40	32	180
4	40	8	180
5	90	55	180
6	40	0	44

Table X.7. Burner Data for Kiln Charge FSK DF5

Table X.8.

Auburn Air Quality &
Industrial Hygiene Laboratory

Analysis Report

for Formaldehyde in Air Samples.

Client : NCASI
Weston W.O. : 10027-001-002-9999

Analyst : T Hodges
Date Analyzed : 26 May 1999

Sample Identification	Lab ID	Vol. (mL)	Dilution Factor	Abs.	CH_2O Conc. (µg/mL)	Total CH_2O (µg/Sample)
R1-C2/Kiln Outlet	CK 0990	43	1	0.218	1.36	59
R2-C2/Kiln Outlet	CK 0991	43	1	0.185	1.15	50
R3-C2/Kiln Outlet	CK 0992	43	1	0.389	2.44	105
R4-C2/Kiln Outlet	CK 0993	43	1	0.534	3.36	144
R5-C2/Kiln Outlet	CK 0994	43	1	0.584	3.68	158
R6-C2/Kiln Outlet	CK 0995	43	1	0.575	3.62	156
R7-C2/Kiln Outlet	CK 0996	43	1	0.458	2.88	124
R8-C2/Kiln Outlet	CK 0997	43	1	0.475	2.99	128
R9-C2/Kiln Outlet	CK 0998	43	1	0.353	2.22	95
R9-C2/Kiln Outlet Dup	CK 0998 Rep	43	1	0.351	2.20	95
R10-C2/Kiln Outlet	CK 0999	43	1	0.468	2.94	127
R11-C2/Kiln Outlet	CK 1000	43	1	0.563	3.54	152
R12-C2/Kiln Outlet	CK 1001	43	1	0.629	3.96	170
R13-C2/Kiln Outlet	CK 1002	43	1	0.545	3.43	147
R14-C2/Kiln Outlet	CK 1003	43	2	0.684	8.61	370
R15-C2/Kiln Outlet	CK 1004	43	1	0.401	2.52	108
R16-C2/Kiln Outlet	CK 1005	43	1	0.399	2.51	108
R17-C2/Kiln Outlet	CK 1006	43	1	0.706	4.45	191
R1-C2/Burner Exhaust	CK 1007	43	1	0.001	BDL	< 4.3
R1-C2/Burner Exhaust	CK 1007 Rep	43	1	0.001	BDL	< 4.3
R2-C2/Burner Exhaust	CK 1008	43	1	0.000	BDL	< 4.3
R3-C2/Burner Exhaust	CK 1009	43	1	0.001	BDL	< 4.3
R4-C2/Burner Exhaust	CK 1010	43	1	0.004	BDL	< 4.3
R5-C2/Burner Exhaust	CK 1011	43	1	0.008	BDL	< 4.3
R6-C2/Burner Exhaust	CK 1012	43	1	0.008	BDL	< 4.3
R7-C2/Burner Exhaust	CK 1013	43	0	0.000	BDL	< 4.3
R8-C2/Burner Exhaust	CK 1014	43	1	0.000	BDL	< 4.3
R91-C2/Burner Exhaust	CK 1015	43	1	0.001	BDL	< 4.3
R11-C2/Burner Exhaust	CK 1016	43	1	0.001	BDL	< 4.3
R11-C2/Burner Exhaust	CK 1016 Rep	43	1	0.000	BDL	< 4.3
R12-C2/Burner Exhaust	CK 1017	43	1	0.000	BDL	< 4.3
R13-C2/Burner Exhaust	CK 1018	43	1	0.002	BDL	< 4.3
R14-C2/Burner Exhaust	CK 1019	43	1	0.002	BDL	< 4.3
R15-C2/Burner Exhaust	CK 1020	43	1	0.008	BDL	< 4.3
R16-C2/Burner Exhaust	CK 1021	43	1	0.009	BDL	< 4.3
R17-C2/Burner Exhaust	CK 1022	43	1	0.011	BDL	< 4.3
R2-C3/Kiln Outlet	CK 1023	43	1	0.387	2.43	105
R2-C3/Kiln Outlet Dup	CK 1024	43	1	0.428	2.69	116
R3-C3/Kiln Outlet	CK 1025	43	1	0.563	3.54	152
R3-C3/Kiln Outlet	CK 1025 Rep	43	1	0.564	3.55	153
R3-C3/Kiln Outlet Dup	CK 1026	43	1	0.549	3.45	149
R4-C3/Kiln Outlet	CK 1027	43	1	0.582	3.66	157
R4-C3/Kiln Outlet Dup	CK 1028	43	1	0.631	3.97	171
R5-C3/Kiln Outlet	CK 1029	43	1	0.612	3.85	166
R5-C3/Kiln Outlet Dup	CK 1030	43	1	0.647	4.07	175
R6-C3/Kiln Outlet	CK 1031	43	1	0.503	3.16	136

Table X.9.

Auburn Air Quality & Industrial Hygiene Laboratory

Analysis Report

for Methanol by Modified USEPA Method 308

Client : NCASI
WESTON W.O. # : 10027-001-002-9999
Date Received : 24 May 1999
Analyst : B Benson
Detection Limit (µg/mL) : 0.5

Source ID	Vol. (mL)	Sample ID	Methanol (µg/mL)	Methanol (µg/Sample)
Kiln Outlet C2-R1	43	CK 0990	1.33	57
Kiln Outlet C2-R2	43	CK 0991	1.02	44
Kiln Outlet C2-R3	43	CK 0992	2.36	100
Kiln Outlet C2-R4	43	CK 0993	3.75	160
Kiln Outlet C2-R5	43	CK 0994	4.08	180
Kiln Outlet C2-R6	43	CK 0995	3.26	140
Kiln Outlet C2-R7	43	CK 0996	5.45	230
Kiln Outlet C2-R8	43	CK 0997	4.70	200
Kiln Outlet C2-R9	43	CK 0998	4.75	200
Kiln Outlet C2-R10	43	CK 0999	7.01	300
Kiln Outlet C2-R11	43	CK 1000	8.00	340
Kiln Outlet C2-R12	43	CK 1001	8.38	360
Kiln Outlet C2-R13	43	CK 1002	10.72	460
Kiln Outlet C2-R14	43	CK 1003	11.14	480
Kiln Outlet C2-R15	43	CK 1004	13.44	580
Kiln Outlet C2-R16	43	CK 1005	14.39	620
Kiln Outlet C2-R17	43	CK 1006	13.95	600
Burner Exhaust C2-R1	43	CK 1007	0.00	<21.5
Burner Exhaust C2-R2	43	CK 1008	0.39	<21.5
Burner Exhaust C2-R3	43	CK 1009	0.00	<21.5
Burner Exhaust C2-R4	43	CK 1010	0.00	<21.5
Burner Exhaust C2-R5	43	CK 1011	0.00	<21.5
Burner Exhaust C2-R6	43	CK 1012	0.00	<21.5
Burner Exhaust C2-R7	43	CK 1013	0.29	<21.5
Burner Exhaust C2-R8	43	CK 1014	0.00	<21.5
Burner Exhaust C2-R9	43	CK 1015	0.00	<21.5
Burner Exhaust C2-R11	43	CK 1016	0.00	<21.5
Burner Exhaust C2-R12	43	CK 1017	0.00	<21.5
Burner Exhaust C2-R13	43	CK 1018	0.00	<21.5
Burner Exhaust C2-R14	43	CK 1019	0.00	<21.5
Burner Exhaust C2-R15	43	CK 1020	0.00	<21.5
Burner Exhaust C2-R16	43	CK 1021	0.00	<21.5
Burner Exhaust C2-R17	43	CK 1022	0.00	<21.5
Kiln Outlet C3-R2	43	CK 1023	1.51	65
Kiln Outlet Dup C3-R2	43	CK 1024	1.62	69
Kiln Outlet C3-R3	43	CK 1025	2.00	86
Kiln Outlet Dup C3-R3	43	CK 1026	2.63	110
Kiln Outlet C3-R4	43	CK 1027	3.62	160
Kiln Outlet Dup C3-R4	43	CK 1028	3.74	160
Kiln Outlet C3-R5	43	CK 1029	3.81	160
Kiln Outlet Dup C3-R5	43	CK 1030	4.27	180
Kiln Outlet C3-R6	43	CK 1031	3.33	140
Kiln Outlet Dup C3-R6	43	CK 1032	4.59	200
Field DI Blank	43	CK 1033	0.00	<21.5

Table X.10.

Auburn Air Quality & Industrial Hygiene Laboratory

Analysis Report

for Methanol by Modified USEPA Method 308

Client	:	NCASI
WESTON W.O. #	:	10027-001-002-9999
Date Received	:	9 August 1999
Analyst	:	B Benson
Detection Limit (µg/mL)	:	0.5

Source ID	Vol. (mL)	Sample ID	Methanol (µg/mL)	Methanol (µg/Sample)
NCASI Kiln West Run 1	43	CK 1675	2.58	110
NCASI Kiln West Run 2	43	CK 1676	7.79	330
NCASI Kiln West Run 2 Dup	43	CK 1677	7.38	320
NCASI Kiln West Run 3	43	CK 1678	9.81	420
NCASI Kiln West Run 4	43	CK 1679	10.93	470
NCASI Kiln West Spike	86	CK 1680	4.37	380
NCASI Kiln West Spike	43	CK 1681	3.34	140
NCASI Burner Spike	43	CK 1682	9.14	390
NCASI Kiln East Spike	43	CK 1683	4.61	200
NCASI Field Spike	43	CK 1684	9.74	420
NCASI Trip Spike	43	CK 1685	10.23	440
DI Blank	43	CK 1686	0.00	<21.5
NCASI Kiln East Run 1	43	CK 1687	0.63	27
NCASI Kiln East Run 2	43	CK 1688	1.67	72
NCASI Kiln East Run 3	43	CK 1689	2.64	110
NCASI Kiln East Run 4	43	CK 1690	5.84	250
NCASI Kiln East Run 4 Dup	43	CK 1691	4.44	190
NCASI Kiln East Run 5	43	CK 1692	6.06	260
NCASI Kiln East Run 5 Dup	43	CK 1693	5.15	220
NCASI Kiln East Run 6	43	CK 1694	7.64	330
NCASI Kiln East Run 7	43	CK 1695	13.65	590
NCASI Kiln East Run 8	43	CK 1696	15.09	650
NCASI Burner Run 1	43	CK 1697	0.25	<21.5
NCASI Burner Run 2	43	CK 1698	0.00	<21.5
NCASI Burner Run 3	43	CK 1699	0.00	<21.5
NCASI Burner Run 4	43	CK 1700	0.00	<21.5
NCASI Burner Run 5	43	CK 1701	0.00	<21.5
NCASI Burner Run 6	43	CK 1702	0.00	<21.5
DI Water Blank	43	CK 1703	0.00	<21.5
DI Water Blank	43	CK 1704	0.00	<21.5
NCASI Burner Run 6 Dup	43	CK 1705	0.00	<21.5