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NATIONAL COUNCIL OF THE PAPER INDUSTRY FOR AIR AND STREAM IMPROVEMENT, INC., 260 MADISON AVENUE, NEW YORK, N.Y. 10016

A STUDY OF ORGANIC COMPOUND EMISSIONS FROM VENEER DRYERS AND MEANS FOR THEIR CONTROL

TECHNICAL BULLETIN NO. 405

AUGUST 1983

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TECHNICAL BULLETIN No. 405

August 24, 1983

A STUDY OF ORGANIC COMPOUND EMISSIONS FROM VENEER DRYERS AND MEANS FOR THEIR CONTROL

For the past three years the National Council's technical study program has been actively engaged in determining the level of volatile organic compound (VOC) emissions from sources in the forest products industry, and effectiveness of in-place control technology. Technical bulletins on VOC emissions from kraft recovery furnaces, Western wood-fired power boilers, lime kilns, heavy black liquor oxidation systems and the coating and printing of paper have already been issued. Currently, VOC emissions from TPM pulping, southern wood-fired power boilers, various unit processes in sulfite pulping and particle board manufacture are under study. Technical bulletins on the first two subjects under study are scheduled for distribution in late 1983.

The attached technical bulletin deals with the control of volatile organic emissions from veneer drying and means for their control. The investigative work on the West Coast was directed by Victor J. Dallons, Research Engineer, assisted by Mr. Dean R. Hoy and Ronald Messmer, all located at the West Coast Regional Center. In the South, the investigative work was directed by Mr. Charles G. Simon, Research Chemist, assisted by Mr. Van H. Dozier and Mr. Michael D. Marks, all at the Southern Regional Center. Mr. Dallons, assisted by Mr. Simon, prepared the technical bulletin.

The bulletin contents provide background material on the characteristics of veneer dryer emissions and the objectives of emission control technology currently applied at these sources. It goes into some depth in describing the principal source test methods used to characterize VOC emissions from these sources, as well as the capabilities and limitations of each.

During the course of this study emission factors for uncontrolled veneer dryer emission sources were developed. A description of several control technologies currently applied at

this source are described. The information available, and that generated during this study on the effectiveness of this technology for control of the various emission fractions, is then presented.

Total organic compound emissions from uncontrolled steam heated veneer dryers were found to vary substantially, as were the noncondensible and condensible fractions. This variability was found to be a function of the wood species being dried, dryer temperature, and amount of air passing through the dryer. The noncondensible fraction of organic compound emissions from wood residue fired direct heat dryers was found to be greater than those from steam heated dryers.

Your comments and questions on this technical bulletin are solicited, and should be directed to me, Mr. Victor J. Dallons at the NCASI West Coast Regional Center, P.O. Box 458, Corvallis, Oregon 97339 (503-754-2015), or Mr. Charles G. Simon, NCASI Southern Regional Center, P.O. Box 14483, Gainesville, Florida 32604 (904-377-4708).

Yours very truly,

Russell O. Blosser
Technical Director

ROB:gs
Attach.

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A STUDY OF ORGANIC COMPOUND EMISSIONS FROM VENEER DRYERS AND MEANS FOR THEIR CONTROL

I INTRODUCTION

The highly visible nature of veneer dryer plumes earlier triggered the interest of state regulatory agencies and led the forest products industry to study control options, particularly in the Northwest Region of the United States. Emission controls installed to meet the resulting state regulatory requirements were designed primarily to reduce plume opacity. Methods for measuring veneer dryer emission composition were designed to quantify those constituents responsible for the plume opacity. These constituents were solid particulates and aerosols formed by condensation of gaseous organic compounds as the emissions cooled after leaving the stack. The advent of air quality management programs in the form of regulations governing ambient air quality limited areas and point source permitting requirements to deal with the prevention of significant deterioration (PSD) regulations in areas of satisfactory air quality, expanded interest in veneer dryer emissions. EPA has developed background information for the development of a new source performance standard (NSPS) for plywood manufacturing. As the result of an array of emerging regulatory programs the forest products industry identified a need for emission factors for particulate and condensible organic compounds, and for gaseous organic compounds from veneer drying. Consequently, the NCASI study program was designed to include a task which embodied (a) a review and analysis of previous studies and measurement procedures used for characterizing veneer dryer emissions, (b) evaluation and adoption of procedures suitable for the measurement of particulate and condensed aerosols, if necessary, and volatile organic compounds (VOC), (c) establishment of a range of emissions possible from veneer dryers representative of current operation, and (d) organization of existing and generation of new information on existing veneer dryer emission control systems.

Organic materials which have condensed at the point of discharge or soon thereafter and nonorganic particulate are responsible for the opacity associated with veneer dryer emissions. These materials are believed to impact particulate concentrations in adjoining airsheds. The national primary ambient air quality standards for particulate are 75 ug/m^3 annual average and 260 ug/m^3 24-hour duration not to be exceeded more than once per year (1). Gaseous nonmethane organic compounds in the emissions may lead to the formation of ozone in the atmosphere. Nonmethane organics were once designated as criteria pollutants by EPA. The Agency issued primary and secondary ambient air quality standards for nonmethane organics which were 0.24 ppm 3-hour average between 6 and 9 a.m. not to be exceeded more than twice per year (1) for use as a guide to achieve the ozone ambient air quality standard. These regulations were later revoked, and the ozone ambient air standards remain in effect (2).

Since veneer dryer emissions are known to consist of varying amounts of normally solid particulate, organic compounds that condense at ambient temperature to form aerosols, and organic compounds that do not condense at ambient temperatures, appropriate sampling procedures need to be identified for use in developing emission factors. EPA reference methods for particulate matter (EPA Method 5) or VOC (EPA Method 25) do not distinguish between solid particulate, condensible organics, and noncondensible organics present in veneer dryer emissions. The Oregon Department of Environmental Quality (ODEQ) Method 7, a modification of EPA Method 5, was examined for measurement of particulate and organic material that condense at ambient temperatures. Modifications of EPA Method 25 to exclude particulate and organic material that condense at ambient temperature were examined for capability to quantify noncondensible organic emissions from veneer dryers. The sampling procedures used to gather emission data reported in this bulletin yielded emission factors for (a) volatile organic compounds (VOC) or total gaseous nonmethane organics (TGNMO) emissions, (b) noncondensible organic emissions, and (c) particulate and condensible organic emissions. Note that the terms VOC and TGNMO may be used interchangeably in this bulletin. Both represent the same fraction when measured using EPA Method 25 with the former now being the preferred expression.

Due to a wide variability in veneer dryer emission levels resulting from differences in dryer design, wood species dried, dryer operating parameters, and the variety of emission control devices available, determining emission factors for controlled emissions was not accomplished in this study. Emission factors were developed for uncontrolled emissions taking process variability into account. Emission control practices studied included wet scrubbers and incineration in power boilers. They were examined for their removal efficiencies and limitations in application.

This technical bulletin should be considered as a progress report in the total assembly of pertinent information on characteristics of plywood veneer drying emissions, their form in the ambient air, and the expectations of various control technology applications. The previously unreported data in this bulletin came from a number of sources. NCASI generated all EPA Method 25 data. Data from ODEQ Method 7 or modifications of EPA Method 5 were (a) generated by NCASI, (b) provided by member companies, (c) obtained from ODEQ files, or (d) generated as part of an EPA contract.

II VENEER DRYER PROCESS DESCRIPTIONS

A. Theory and Practice of Veneer Drying

Veneer used for the manufacture of plywood is dried to permit the glue to adhere to the wood surface and result in a pre-dried dimensionally stable product. Glues used for manufacturing plywood are usually phenol formaldehyde resins requiring heat to set. The glues are spread on the veneer, the veneer laid up to produce a plywood sheet of desired thickness and then pressed at 115 to 148°C (240 to 300°F) and pressures up to 1030 KPa (150 psi) for

2 to 7 minutes to set the glue. Residual moisture in the wood will form steam under these high pressure and temperature conditions. When the presses open, any steam formed inside the plywood will separate the layers of veneer, causing what is referred to in the industry as "blows".

To prevent blows, promote optimum gluing characteristics of the veneer surface, and to manufacture dimensionally stable plywood sheets, veneer is typically dried to 3 to 5 percent moisture content. Overdrying scorches the wood and product surface, and adversely affects the strength of the bond between wood surfaces. Veneer that is too wet can be redried, but veneer that is scorched cannot be used for making plywood. Scorching is prevented by operating the dryer to reject 10 to 15 percent of the veneer due to high moisture content. Conductivity detectors at the dryer exit are used to identify and mark insufficiently dried veneer. Veneer rejected for high moisture content is redried.

(1) Dryer Types and Operation - Veneer dryers are long rectangular heated chambers. Veneer is continuously fed to the dryer in 4 to 7 layers known as decks, and moved through the dryer on rollers. The sides of the dryers are a series of 6 ft wide doors that allow access to all areas to easily clear veneer jams. To prevent fugitive emissions and/or air leakage, the doors must be well sealed. Each door represents a section. At the discharge end of the dryer a cooling section circulates ambient air around the veneer to allow hand sorting of the dried veneer. Some dryers have a sealing section at the feed end to reduce fugitive emissions from entering the workspace. Prevention of fugitive emissions from the dryer feed can also be accomplished by adjusting the dryer fans and dampers to create a slight vacuum at the feed section.

Dryers are often separated into 1 to 3 drying zones. Air temperature and humidity in each zone is controlled to obtain optimum drying conditions. Higher temperatures allow faster drying but can result in scorching. Usually, more heat is delivered to the first zone where the wood is wettest. Less heat is delivered to the latter zones where final drying occurs.

Air flow through veneer dryers is either longitudinal or cross-flow. Longitudinal dryers have fans that circulate air either concurrent or counter-current to the direction the veneer travels. Heat is added to the air in the plenum above the veneer either indirectly by steam heating coils, or directly by mixing combustion gases from wood-residue or gas firing with recirculated dryer air. In cross-flow dryers, fans blow air perpendicular to the direction of veneer movement. In both designs, air circulates between the veneer layers which are supported on rollers. Figure 1 shows typical dryer layouts.

In jet dryers heated air is impinged on the veneer from tubes with drilled holes that extend between the decks as illustrated in Figure 2. This method of air contact has been reported to improve heat transfer.

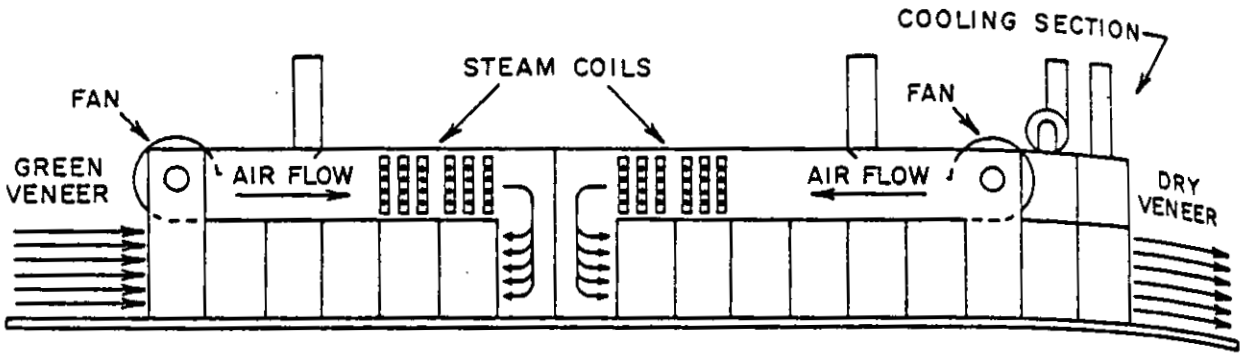

FIGURE 1

TWO ZONE LONGITUDINAL FLOW VENEER DRYER WITH COOLING SECTION

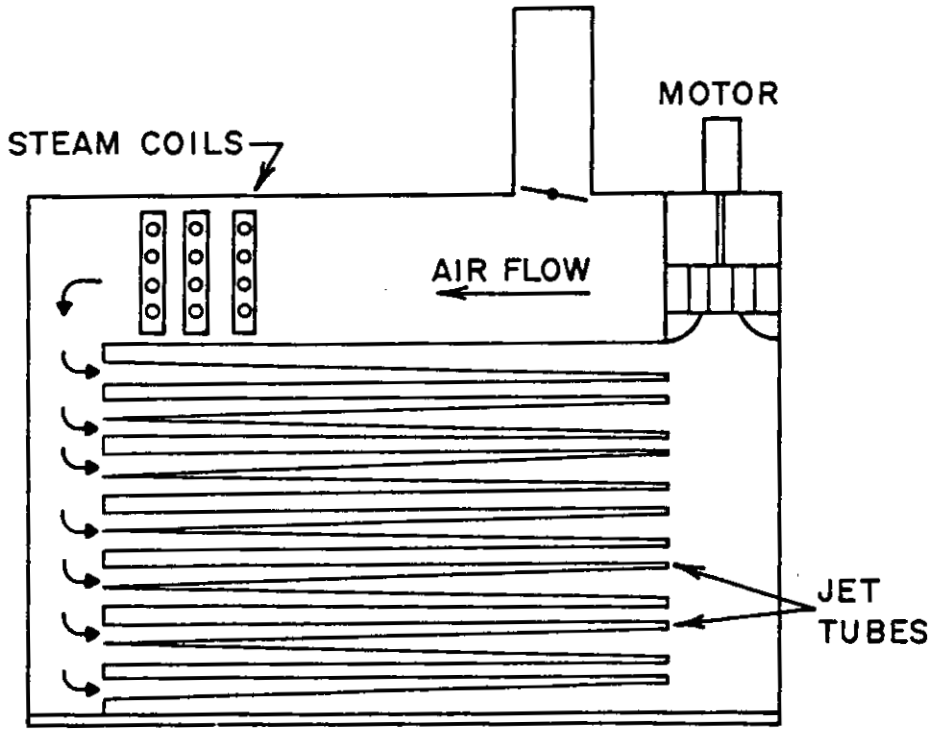

FIGURE 2

CROSS SECTIONAL VIEW OF A STEAM HEATED CROSS FLOW JET DRYER

(2) Veneer Dryer Energy - The moisture content of veneer being fed to a dryer is the dominant factor in determining the amount of heat required. Other factors are the dryer temperature and air exhaust rates. Moisture content of wet veneer varies with species, sapwood or heartwood, season, type of log conditioning for peeling, storage time of undried veneer, and previous drying of the veneer. Typical moisture contents of green veneer varies widely and are listed in Table 1 for several species.

TABLE 1 VENEER MOISTURE CONTENT

Species	Percent Moisture, Dry Basis	
	Average	Range
Douglas Fir, Sapwood	70	45 - 95
Douglas Fir, Heartwood	37	32 - 58
Southern Pine	97	82 - 121
White Fir	89	--
Ponderosa Pine	151	132 - 171

Heat is delivered to a dryer at a constant rate, limited by the capacity of the delivery system. The proper application of heat to dry the veneer is controlled by the rate the veneer passes through the dryer. Feed rates for high moisture content veneer are slower than those for low moisture veneer. To predict dryer operation and set proper dryer speeds, wet veneer is sorted according to moisture content and often by wood species before drying. An effort is made to adjust dryer speed to reject 10 to 15 percent of the product for excessive moisture.

Veneer dryers are seldom completely sealed and are normally operated with a small internal vacuum to reduce emissions entering the workspace. This results in ambient air being drawn into the dryer. The air drawn through the dryer carries moisture and other volatiles emitted from the veneer. Dryers have areas of positive and negative pressure. Compared to ambient conditions, pressure at the circulation air fan inlet is negative, whereas pressure at the fan exit is positive. Pressures in longitudinal dryers can be balanced so that a slight vacuum exists at the dryer feed section to prevent fugitive emissions.

The total heat input to a dryer can be calculated from the veneer moisture content, the flow and temperature of the gases leaving the dryer, and radiant heat losses. Results of such calculations are presented in Figure 3. These calculations show approximate heat requirements between 0.6×10^6 Btu/MSF on a 3/8 in basis for Douglas fir heartwood veneer at low air exhaust rates from the dryer to 1.7×10^6 Btu/MSF for hemlock and white fir at high air exhaust rates. Veneer dryers typically operate at air exhaust rates between 15,000 to 75,000 DSCF/MSF.

The major energy requirement in a veneer dryer is for evaporation of water in the veneer. The second most significant energy requirement is to heat the ambient air supplied to the

dryer. Radiant losses from uninsulated dryers are from 0.1 to 0.3×10^6 Btu/MSF depending on production rates and dryer temperature. The dryer energy requirements shown in Figure 3 are approximate because of the high variability in wood moisture. In addition to the energy requirements for drying veneer, energy is required to operate the plywood lay up presses and log conditioning operations.

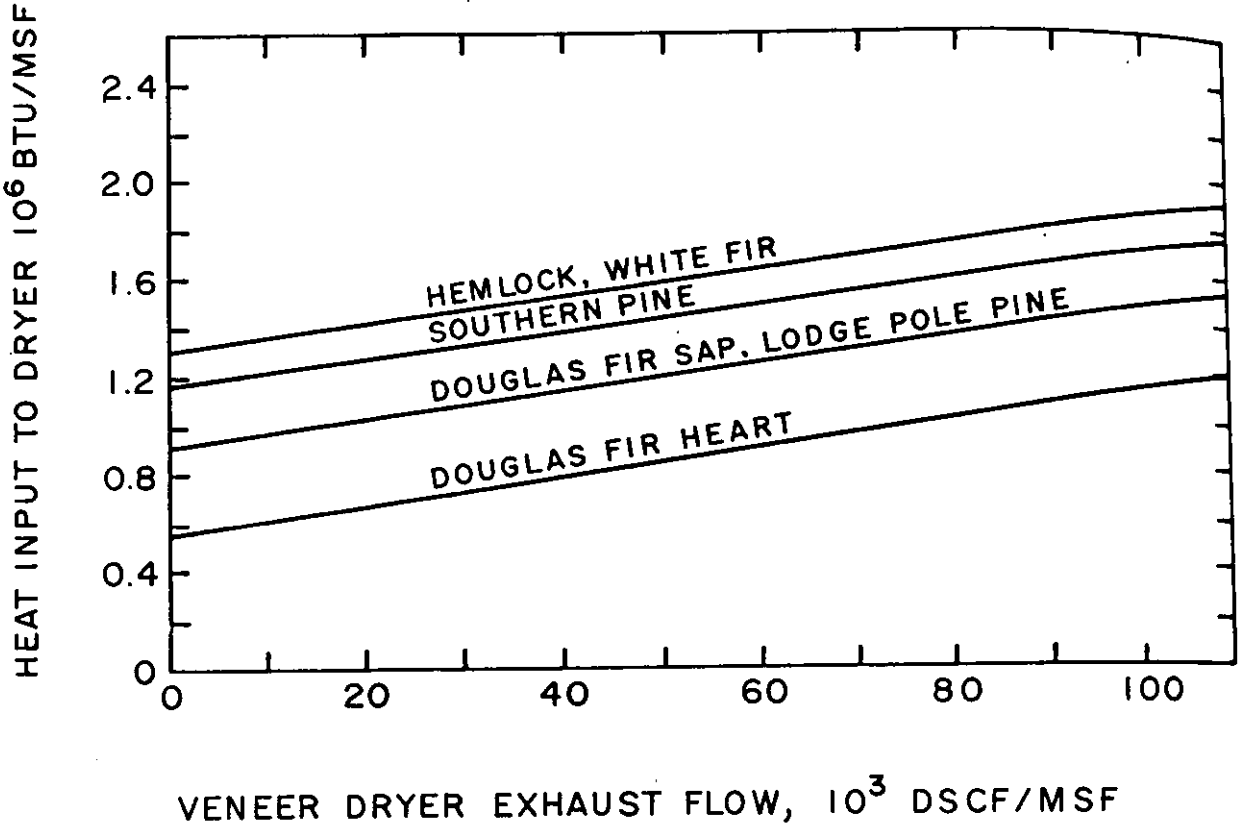

FIGURE 3

APPROXIMATE ENERGY REQUIRED TO DRY VENEER AS A FUNCTION OF AIR FLOW THROUGH A DRYER AND WOOD SPECIES AT A DRYER TEMPERATURE OF 325°F

(3) Direct and Indirect Heated Dryers - Dryers are heated either indirectly by steam or directly by gas or wood-residue fired heat cells. For indirect heated veneer dryers, a steady supply of heat is delivered to the dryer by steam coils placed in the internal air flow ducts in the dryer. Recirculating air is heated by steam coils and is blown around the veneer.

In gas-fired direct heated dryers, heat is delivered directly to the circulating air by combustion in the air. Gas burners are placed inside the dryer air circulating ducts. Combustion products from burning gas are mixed with the circulating air to control the dryer operating temperature. For direct heated wood-residue fired dryers, fuel is burned using fresh combustion air in a variety of burner types. The hot gases are then blended with recirculated air from the dryer to reduce the combustion gas temperature to between 400 and 650°C (750 to 1200°F). These gases are delivered to the dryer and are cooled further in the dryer plenum.

Heat delivery to the dryer can be controlled within narrow limits, but is normally at a constant level. The air exhaust rate from a direct fired dryer is controlled by the amount of air required for combustion. Although optimum combustion for heat recovery in a conventional boiler produces an emission with 14 percent CO_2, direct heated veneer dryer burners are operated with much higher excess air. High excess air is required to cool the flame temperature to prevent melt down of the combustion equipment. Normal air required for wood-residue firing in fuel cell type burners is about 37,000 DSCF/10^6 Btu to give CO_2 concentration in the dryer of 5 percent. Many systems operate with lower CO_2 concentrations due to additional air drawn in at the dryers.

III LITERATURE REVIEW

The choice of proper sampling procedures for a source requires knowledge of the stack gas constituents likely to be encountered and their influence on the results. It is of utmost importance that the sampling results reflect the objectives of the study. The constituents of interest in veneer dryer emissions are those responsible for a contribution to the ambient particulate load and those responsible for the formation of ozone through photo-chemical reactions. This section reviews: (a) the chemical and physical nature of veneer dryer emissions, (b) their potential to form particulate matter and ozone in the atmosphere, (c) current sampling procedures used to measure particulate matter and ozone precursors, (d) further development of sampling procedures to make them applicable to veneer dryer emissions, and (e) the precision and accuracy of the sampling procedures.

A. Background and Information on Veneer Dryer Emission Characteristics

(1) Chemical Composition of Veneer Dryer Emissions - Emissions from steam heated veneer dryers are composed of organic compounds vaporized from veneer during the drying process and wood dust. Most of these compounds originate from the extractable portion of the wood. Emissions from direct fired dryers will also contain products of combustion and wood ash. Wood extractives are classified into three major categories: (a) neutrals, comprising

saponified fatty acids and di- and tri-terpenes, (b) free acids comprising fatty and resin acids, and (c) volatiles, comprising terpene-like materials. The amount of material in each classification group differs among wood species.

Information on the nonvolatile constituents of wood extractives in a number of North American species of wood can be found in work by Rogers et al. (3), Zinkel and Foster (4), Zinkel (5), and Foster et al. (6). These works indicate that between 50 to 80 percent of the nonvolatile extractives in West Coast tree species consist of oleic and linoleic acids. The balance consisted of resin and other fatty acids. Fatty acids contained in southern species were found to consist primarily of oleic and linoleic acids. The resin acids were principally levopimaratic, palustractic, and abietic acids.

Organic compouds in veneer dryer emissions have been found to be comprised of terpenes, and resin and fatty acids similar to those found in wood. Monroe et al. (7) and Cronn et al. (8) studied the noncondensible fraction of veneer dryer emissions from West Coast and Southern veneer dryers. Dryers operating on Western species of wood emitted primarily α and β-pinene and minor amounts of Δ^3-Carene, β-phellandrene and d-lemonene. Dryers operating on southern wood species emitted primarily α and β-pinene and minor amounts of d-limonene, myrene, β-phellandrene and camphene. The terpenes comprise between 30 to 90 percent of the total organic emissions from uncontrolled dryers depending upon the species of wood and the amount of air passing through the dryer (8).

Analysis of the condensible fractions of veneer dryer emissions have been conducted by Cronn et al. (8) and Fraser and Swan (9). The same fatty and resin acids found in wood extractives were found in the veneer dryer emissions as well as some sesquiterpenoids. The amount of each chemical species varied greatly depending upon the wood species dried and the point at which the dryer was sampled. Slightly more resin acids than fatty acids were found in most of the samples.

Most of the non-terpene compounds identified in veneer dryer emissions have boiling points greater than the normal operating temperature of dryers. Veneer dryers operate at temperatures between 180° to 200°C (256-392°F). Terpenes have boiling points greater than 155°C (311°F). Fatty acids have boiling points between 320°C to 370°C (608-698°F). Resin acid boiling points are higher yet. However, these materials have significant vapor pressures at veneer dryer temperatures, leading to their vaporization. Figure 4 shows vapor pressure data for some terpenes, fatty acids, and resin acids for temperatures between atmospheric and veneer dryer operational temperature. Since testing procedure results for total organic compound emissions developed by EPA Method 25 are expressed as ppm methane equivalent, it is useful to show the vapor pressure of these materials in terms of ppm equivalent methane as shown in Figure 5. Based on the vapor

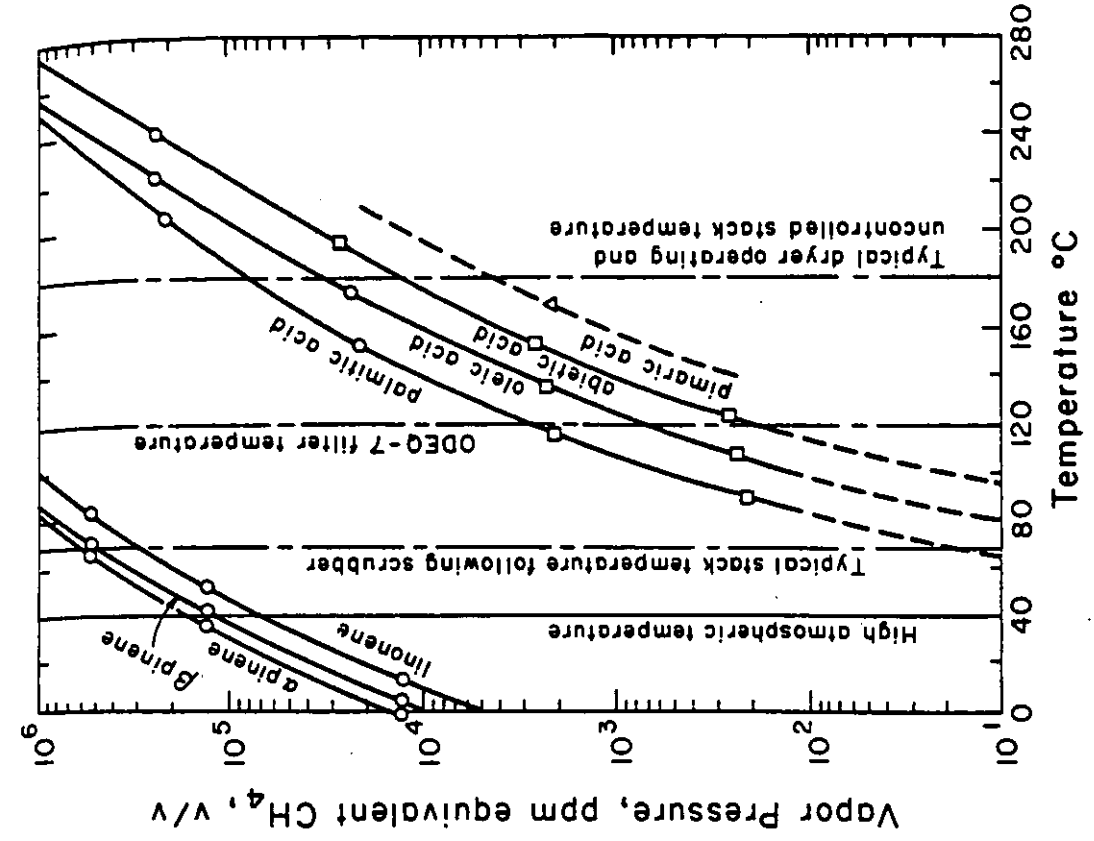

FIGURE 5

VAPOR PRESSURE OF VENEER DRYER ORGANIC EMISSION CONSTITUENTS EXPRESSED AS EQUIVALENT METHANE

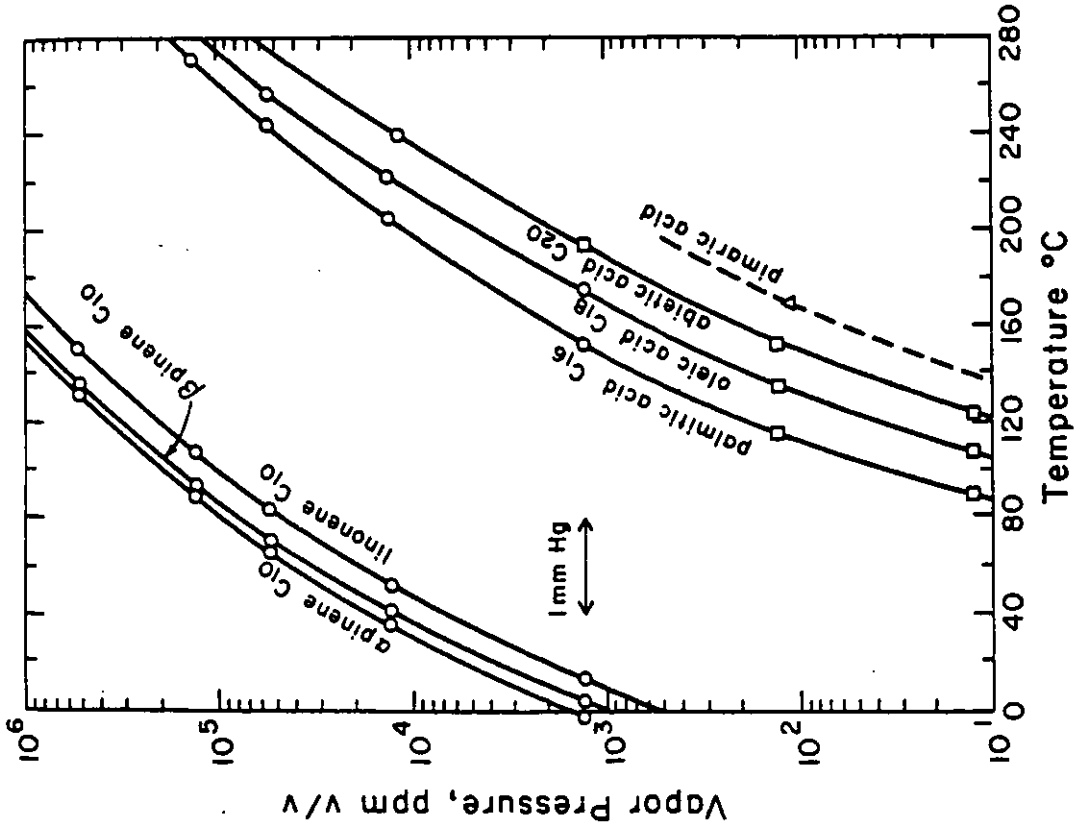

FIGURE 4

VAPOR PRESSURE OF VENEER DRYER ORGANIC EMISSION CONSTITUENTS

pressures of the organics found in veneer dryer emissions at typical dryer operating temperatures. The presence in dryer vent gases might be expected to be higher than what has been measured in dryer stack. The lower concentrations found may be accounted for by the affinity of these compounds for wood.

Nearly all the turpentine material contained in the green veneer should be removed during drying since their boiling points are below the dryer air temperature. Turpentines have been shown to be a major component of the organic emissions from veneer dryers (8). Table 2 lists the turpentine content from numerous United States and Canadian wood species both in terms of gallons of turpentine per ton dry wood and in pounds CH_4 per thousand square feet of green veneer on a 3/8 in. basis. Turpentine found in the wood ranged from nondetectable levels in hemlock, cedar, and white fir to over 20 lb/MSF for some southern pine species.

TABLE 2 TURPENTINE CONTENT OF WOOD SPECIES (9)

Species	Turpentine gal/ton dry wood	Turpentine as CH_4 lb/MSF
Bahama Pine	1.09	4.6
Balsam Fir	0.93	3.1
Black spruce	0.08	0.3
Douglas fir (Washington)	1.05	4.5
Douglas fir (Canada)	0.19	0.8
Eastern white pine	1.05	4.5
Engelman spruce	0.18	0.7
Grand fir	ND	ND
Jack Pine	0.81	4.3
Hemlock, Eastern	ND	ND
Hemlock, Mountain	ND	ND
Hemlock, Western	ND	ND
Loblolly pine	0.97	5.1
Lodgepole pine	0.54	2.3
Long leaf pine	4.06	21.5
Pacific silver fir	ND	ND
Noble fir	ND	ND
Pitch pine (yellow or Southern pine)	1.12	5.9
Pond pine	0.92	3.9
Ponderosa pine	0.98	4.2
Red pine	0.99	4.2
Sand pine	0.48	2.0
Short leaf pine	0.89	4.7
Sitka spruce	0.12	0.4
Slash pine	1.40	7.4
Spruce pine	1.17	5.0
Subalpine fir	0.15	0.5
Sugar pine	0.66	2.8
Tamarack	0.12	0.5
Virginia pine (scrub pine)	5.86	31.0

TABLE 2 (Con't.)

Species	Turpentine gal/ton dry wood	Turpentine as CH_4 lb/MSF
White fir	ND	ND
Western larch	0.66	2.8
Western red cedar	ND	ND
Western white pine	0.24	0.9
White spruce	0.16	0.6

ND Quantities found were below the detection level of the procedure.

Measurement of veneer dryer volatile hydrocarbon emissions by a gas chromatograph procedure gave the values listed in Table 3 (7). These volatile organics were determined to be mostly turpentines. The values reported in Table 3 have been corrected for calculation errors in the referenced data and converted to methane equivalent. The values reported are somewhat lower than the quantity of turpentine found in chipped wood. These lower emission values may be due to loss of turpentine during storage of peeled veneer. A 50 percent loss in turpentine yield in 1 week was reported during storage of chips in an open pile (10).

TABLE 3 VOLATILE HYDROCARBON EMISSIONS FROM VENEER DRYERS (7)

Wood Species	Turpentine Emissions lb as Methane/MSF, 3/8 in basis Average	Range
Douglas fir, heartwood	0.83	0.21 - 2.50
Douglas fir, sapwood	0.40	0.23 - 0.59
Southern pines	2.35	1.28 - 3.86
Larch	0.19	0.09 - 0.27
Hemlock	0.31	--
Ponderosa pine	2.36	--
White pine	0.87	--

CORRECTED VALUES FOR MONROE DATA

B. Aerosol Formation in Veneer Dryer Plumes

A portion of the organic material in veneer dryer emissions form aerosols upon cooling. Aerosol particle sizes measured a few feet above uncontrolled veneer dryer stacks were between 0.1 and 0.3 um (8,11). Little or no aerosol has been found inside

uncontrolled veneer dryer stacks. These particles originate from condensation nuclei and grow rapidly as the gases are cooled by mixing with ambient air.

The size of the smallest areosol particle possible is given by the equation (12):

$$d_p = \frac{4\ \sigma\ \bar{v}}{RT\ \ln\ S}$$

where:

d_p = smallest stable aerosol particle size

σ = surface tension of compound

$\bar{v}$ = molar volume of compound

R = gas law constant

T = absolute temperature

S = degree of supersaturation. This can be taken as the actual vapor pressure of the material in the gas divided by the vapor pressure of the material over a flat surface.

Particles smaller than d_p will tend to evaporate while particles larger than d_p will tend to grow in a supersaturated gas stream. Figure 6 shows the theoretical minimum particle size produced at different degrees of supersaturation for oleic acid. Rapid cooling of veneer dryer emissions either by mixing with ambient air or by cooling with water sprays should produce high supersaturations and thereby produce particles in the range of 0.005 to 0.04 um. Cronn et al. (8) showed the largest number of particles in untreated veneer dryer emissions at a distance 5 ft above the exhaust stack to be about 0.005 um in diameter.

Once the veneer dryer emissions have been cooled and condensation has taken place, the supersaturation of the organics will be reduced because of transfer of material from the gas phase to the solid phase. Small particles formed under high supersaturation are no longer stable. They will revaporize and the organics evaporated will tend to recondense on larger particles (12).

The vapor pressure of a material in a very small diameter particulate is much higher than the vapor pressure of that same material over a flat surface. This is known as the Kelvin effect. A relationship between vapor pressure of a small particle to the vapor pressure over a flat surface is given by (12):

$$\ln\ \frac{P_d}{P_s} = \frac{4\ \bar{v}\ \sigma}{d_p\ RT}$$

where p_d and p_s are the vapor pressures of the material of the particle and over a flat surface, respectively. Figure 7 shows the Kelvin effect for various particle sizes and temperatures for oleic acid. Reference to Figure 6 will show that it is unlikely that any particles less than 0.003 um will form.

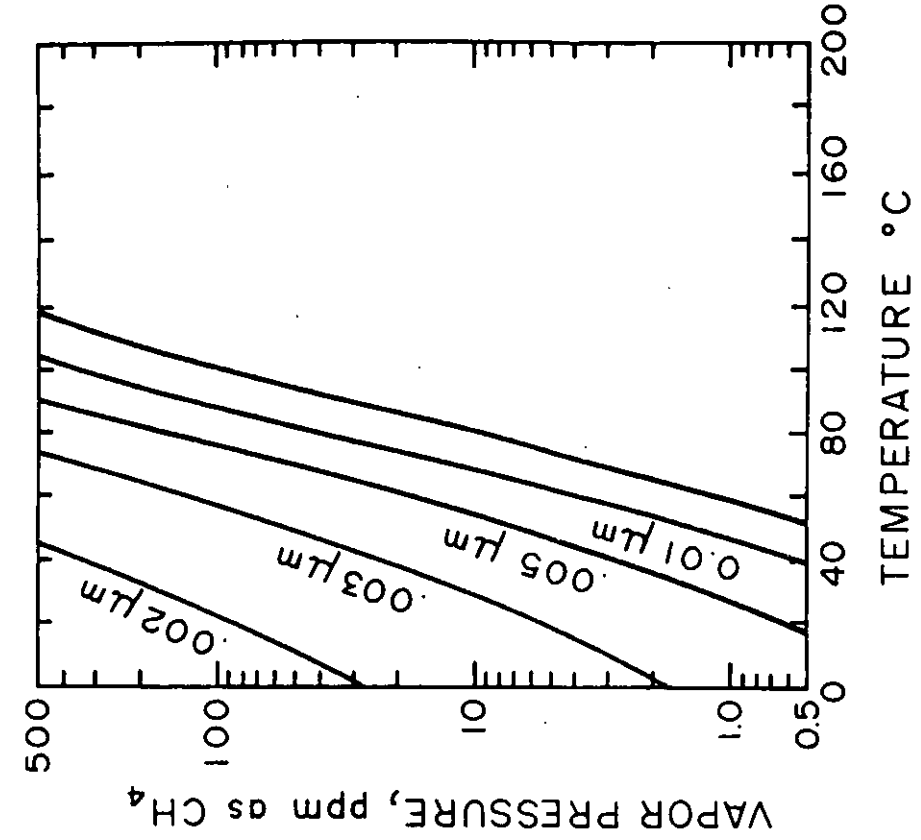

FIGURE 7

VAPOR PRESSURE OF SMALL PARTICLES OF OLEIC ACID BY THEORETICAL CALCULATION

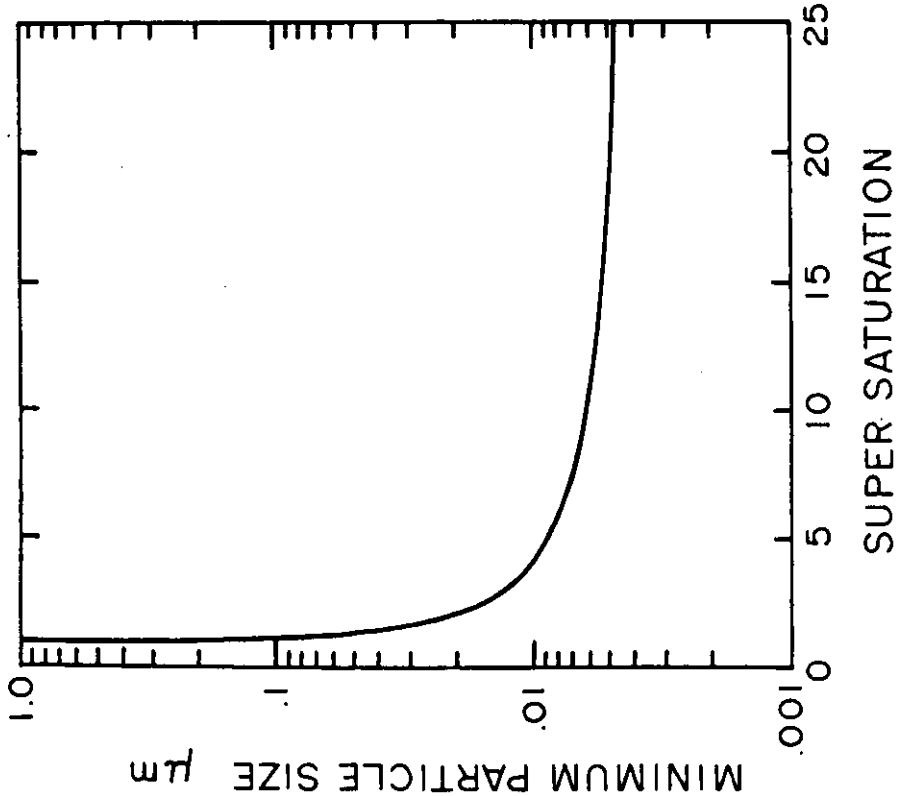

FIGURE 6

MINIMUM PARTICLE SIZE FORMED FOR OLEIC ACID AT VARIOUS SUPERSATURATIONS, BY THEORETICAL CALCULATION

The behavior of small aerosols as they enter the atmosphere is important. Extremely small aerosols are likely to revaporize due to their significantly higher vapor pressures. Larger aerosols would be expected to exist for much longer time periods allowing for coagulation, agglomeration, and surface chemcial oxidation effects to take place. No studies have been undertaken to determine the fate of these aerosols in the atmosphere. More information is needed on veneer dryer emission particle size distributions from controlled sources to comment on the possiblity of revaporization of small aerosols. Aerosol behavior in the stack bears no relationship to what might be expected to occur in the atmosphere.

C. Reactions of Veneer Dryer Emissions in the Atmosphere

(1) Photochemical Reactions of Terpenes - Terpenes have been shown to react rapidly in the presence of NOx and ultraviolet light to form ozone (13,14). They are among the most photochemically reactive compounds. However, they are inefficent ozone producers. Secondary reactions with ozone result in oxidation of terpenes and consequent aerosol formation (13,15), thus blocking further photochemical reactions.

Rate constants for the formation of ozone have been reported as 7.8×10^3 L/mole sec for the reference compound, propylene, and 8.5×10^4 to 2×10^5 L/mole sec for α-pinene, 2.2×10^4 for β-pinene, and 3.9×19^5 L/mole sec for limonene (13). Rate constants for most anthropogenic olefins are between 10^3 to 10^5 L/mole sec and are nearly zero for paraffins and aromatics (14). Although the reaction rates for terpenes are high, the ozone yield per carbon molecule is low. Ozone yields for terpenes were about half those of propylene (13), but similiar to other anthropogenic organics (14). Maximum ozone yields from α-pinene were found to be 0.1 mole ozone/mole carbon at levels of 190 ppb C and a 16:1 carbon/NOx ratio (13). Once ozone had formed it was shown to react with the remaining terpenes to form non-photochemically reactive aerosols.

Shulte (13) indicated that 50 percent of the terpenes in a smog chamber were consumed by aerosol formation. Aerosols formed from the reaction of terpenes with ozone were a result of the higher vapor pressure of the reaction products. Reactions of ozone with terpenes result in ring opening and formation of difunctional end groups of aldehydes, ketones, alcohols, or acids (15). A lower threshold concentration at which aerosol formation begins to occur has not been established for these materials. Aerosols were formed from the photochemical reaction of 1,6-heptadiene at concentrations of 50 ppb, the lowest concentration tried, or greater (16).

No studies have been conducted on the photo-reactivity of the resin and fatty acids. These compounds would likely remain in aerosol form in the atmosphere due to their extremely low vapor pressure and not be available for photochemical reactions.

Resin acids are known to oxidize and polymerize easily, resulting in even lower vapor pressure compounds. More information is needed on the behavior of these compounds in the atmosphere.

D. Historic Sampling Procedures

(1) ODEQ-7 - Veneer dryer emissions have been sampled by a number of procedures. The earliest applied test was visual opacity. In order to quantify the materials responsible for opacity in veneer dryer emissions the Oregon Department of Environmental Quality adopted a procedure known as ODEQ-7. This procedure is the EPA Method 5 particulate sampling train modified to include a filter maintained at ambient temperature between the third and fourth impingers. Organic materials caught in the impingers and impinger water are extracted, dried and weighed, and the weights added to the probe wash, front filter, and back filter weights. The complete procedure is presented in Appendix A. The intent of this procedure is to measure those constituents in the emissions responsible for the formation of particulate matter once the emissions have cooled to ambient temperature.

(2) WSU Procedure - Washington State University undertook a study sponsored by the American Plywood Association and the U.S. Environmental Protection Agency to determine the physical and chemical nature of emissions from veneer dryers during the drying of various wood species under normal veneer dryer operating conditions. Determinations were made of volatile and condensible hydrocarbon emissions.

Condensible hydrocarbons were sampled by drawing veneer dryer stack gases through an in-stack fritted glass filter followed by an ice cooled glass condenser with a vacuum pump. A rotameter between the condenser and vacuum pump measured gas flow. The samples collected were dried in a rotary evaporator at 40°C under 27 in Hg. These dried samples were weighed and prepared for further analysis by gas chromatography and thin layer liquid chromatography (7).

In a later study by the same investigators (17), this apparatus was shown to give a result that was 54 percent of the result from a simultaneously drawn ODEQ-7 sample. An investigation of the WSU procedure showed sample losses resulted from: (a) aerosol escaping the cold trap, and (b) losses during evaporation of the water and solvents during analysis (17).

Volatile organic emissions in veneer dryer emissions were measured by a flame ionization detector (FID) placed in the sampling system following the ice water condenser. The FID was calibrated with hexane. In addition, samples were taken for gas chromatograph analysis.

organic losses would be expected to be similar to those experienced in the atmosphere. The ODEQ-7 procedure should give a measure of those organic materials that are likely to remain condensed in the atmosphere.

The WSU procedure for determining volatile organic compounds may also be inadequate on two counts: (a) the response of an FID detector to all compounds is not the same, and (b) some of the volatile organic compounds condense in the cold trap and do not reach the FID. The response factor of terpenes and other possible organic constituents of veneer dryer emissions should be assessed before this approach is used. Compounds that condense during sampling but evaporate during the solvent evaporation step in the laboratory procedure are likely to be volatile in the atmosphere and should be measured as gaseous organic compounds.

EPA Method 25 will convert all organics captured to methane so that all carbon atoms are counted equally. The method appears to be a suitable choice on which to base measurement of the organic materials in veneer dryer emissions. However, in order to meet the objective of differentiating between organic emissions that may condense to form aerosols or remain in a gaseous state in the atmosphere, modifications to the sampling procedure to exclude particulate and condensible organics will be required.

A. Organic Losses in ODEQ Method 7

A material balance was performed around the ODEQ-7 sampling train using EPA Method 25 sampling trains as references to determine possible sample losses due to evaporation during the ODEQ Method 7 laboratory analysis. Conversely, the ODEQ-7 train was also used to evaluate EPA Method 25 with the option of being preceded with a filter held at 120°C (250°F) and 21°C (70°F) and with the sample drawn under isokinetic conditions. Both uncontrolled and sand filter controlled veneer dryer emissions from a steam heated dryer were sampled.

To conduct the material balance, EPA-25 sampling trains were connected to an ODEQ-7 train in two places: (a) following the 120°C (250°F) filter in the oven, and (b) following the backup filter between the third and fourth impingers. This sampling train was modified to measure filter temperature rather than oven temperature. The first filter was held at 120°C (250°F). Two additional EPA-25 trains operated simultaneously measured emissions directly from the stack. Both of the latter EPA-25 trains were fitted with in-stack filters made of quartz wool stuffed in a ½ in. stainless steel fitting to prevent particulate material from entering the EPA-25 sample train. These were built to be heated to 600°C (1110°F) to recover and measure the organics caught on the filters to provide an estimate of the amount of particulate organic material in the emissions at stack conditions. To balance the effects of nonisokinetic EPA Method 25 sampling, one filter was directed into the flow and the other directed perpendicular to the flow at both sample locations. All samples were taken simultaneously.

(3) EPA Method 25 - The objective of EPA Method 25 is to measure those organic compounds emitted to the atmosphere that may be involved in photochemical reactions that lead to the formation of ozone. The method is designed to exclude organic compounds which do not react to form ozone, methane being the only one of consequence in veneer dryer emissions.

Total gaseous nonmethane organics (TGNMO) emissions from sources other than veneer dryers have been measured using EPA Reference Method 25. The principle of the procedure is to separate the compounds at the time of collection into a high and low molecular weight fraction using a cold trap (-78°C). The low molecular weight components are captured in an evacuated tank. The trap containing condensed organics is burned to convert organics to CO_2 for analysis in the laboratory. The light and unreactive organics captured in the evacuated tank are separated on a chromatographic column yielding concentrations for CO, CH_4, CO_2, C_2H_6 and C_2H_4. All other organics are eluted in one peak. Summation of the trap and tank nonmethane organic results gives TGNMO stack concentrations. All results are reported as methane.

The National Council has modified the procedure as published in the Federal Register (18) to include a filter to remove particulate material that may interfere with the test. Appropriate temperatures at which the filter should be maintained during sampling is discussed in a later section. Corrections for a carbon dioxide interference to the analytical procedure when sampling combustion sources can be made according to work published in Atmospheric Quality Improvement Technical Bulletin No. 109 (19). Procedures for sampling and analysis by EPA Method 25 as conducted by the NCASI are given in Appendix B.

IV SAMPLING PROCEDURE EVALUATION

Procedures for sampling veneer dryer emissions were compared to assess their capability to achieve two objectives: (a) determine emissions of particulate and organic materials that would condense to form particulate in the atmosphere, and (b) determine emissions that would be expected to remain in gaseous form in the atmosphere. The ODEQ-7 procedure was designed to specifically measure the first objective and appears in principal to satisfy that objective. The WSU procedure falls short of measuring condensible organics because of losses due to aerosols escaping the trap during sample collection and losses during sample evaporation in the laboratory. Although a filter to catch aerosols can be inserted into the WSU sampling train and the condensates handled according to the ODEQ-7 analysis procedure to reduce sample loss through evaporation, the method is incapable of isokinetic sampling. Isokinetic sampling may be required following a wet scrubber control device where condensible organics are in particulate form. The losses experienced during the WSU analysis indicate evaporative sample loss may also occur during the ODEQ-7 sample analysis. Since the ODEQ-7 drying steps in the analysis take place at ambient temperature, the evaporative

(1) Units Conversion Between Sampling Method Results - Comparative sampling with ODEQ Method 7 and EPA Method 25 requires conversion of sampling results from each sampling method to a common set of units. The ODEQ-7 method reports results as weight per volume of sampled gas. The weight is determined gravimetrically. The EPA-25 method reports results as ppm methane equivalent. To compare results of one method to the other a conversion factor from gr/DCSF to ppm methane equivalent or visa-versa is needed.

The ODEQ-7 train weight results are a composite of 6 weighings: (a) the front filter catch, (b) probe washings, (c) impinger water extraction, (d) impinger water solids, (e) impinger wash, and (f) back-half filter catch. The conversion factor for the organics captured in each section of the ODEQ-7 train may be different. Organic catches from different sections of the ODEQ Method 7 train were weighed, burned to CO_2, reduced to methane and measured to produce conversion factors from gr/DSCF to ppm methane. The probe washings were assumed to be identical in composition to the front filter catch. Insufficient sample material on the back filter prevented the generation of a factor for that portion of the ODEQ-7 train catch.

The conversion factors from gr/DSCF to ppm methane equivalent were different for each section of the ODEQ-7 analysis. The average conversion factors for uncontrolled veneer dryers were: (a) 3100 ppm/gr/DSCF for the front filter catch and probe rinse, (b) 2550 ppm/gr/DSCF for the impinger rinse, (c) 2010 ppm/gr/DSCF for the impinger water extract, and (d) 400 ppm/gr/DSCF for the dried impinger water. Average conversion factors for the sand filter controlled veneer dryer emissions were: (a) 2020 ppm/gr/DSCF for the front filter catch and probe rinse, (b) 2950 ppm/gr/DSCF for the impinger rinse, and (c) 3440 ppm/gr/DSCF for the impinger extract. The conversion factor obtained from the impinger water dried solids was low and erractic. This was judged to be caused by water bound with the solids. The dry solids from the impinger water (those left behind after dissolving in ether) were not soluble in acetone, and were therefore redissolved with water for loading into the cartridges for subsequent analysis.

The conversion factors are substantially lower than the theoretical conversion factor of 3374 ppm/gr/DSCF based on the assumption that the organics caught were mainly abietic acid. It is possible that a portion of the weight measured by the ODEQ-7 procedure consisted of water associated with the organics. This water is more tightly held by the organics than by the desiccants in the desiccators. This work indicated that the conversion factors can change substantially from sample to sample, casting doubt on the ability to compare ODEQ-7 and EPA-25 results. Nonetheless, ODEQ-7 data reported on in this work was converted to ppm as CH_4 with these conversion factors to allow material balance calculations to be made in consistent units.

(2) Sampling Results at a Veneer Dryer with Uncontrolled Emissions - Results from sampling with different ODEQ-7 and EPA-25 configurations at a veneer dryer with uncontrolled emissions are presented in Table 4. The entries in this table are arranged in three sections to show material balances over: (a) the front-half, (b) the back-half, and (c) total ODEQ-7 train using EPA-25 as a reference.

TABLE 4 ODEQ-7 AND EPA-25 COMPARISONS FROM A VENEER DRYER WITH UNCONTROLLED EMISSIONS

	Run Number	Results in ppm TGNMO as Methane			
		1118-1	118-2	1216-1	1216-2
(1)	EPA-25 from Stack	760	705	534	475
(2)	EPA-25 after 250°F Filter	506	442	495	424
(3)	Organics Removed by 250°F Filter (1)-(2)	254	263	39	51
(4)	ODEQ-7 Front-Half	249	217	113	86
(5)	Organics Unaccounted for	5	46	-74	-35
(6)	EPA-25 After Ambient Filter	206	367*	119	80
(7)	Organics Removed in Back-Half of ODEQ-7 (2)-(6)	300	75	376	344
(8)	ODEQ-7 Back-Half	156	156	124	148
(9)	Organics Unaccounted For (apparent loss due to evaporation)	144	-81	252	196
(10)	Organics Captured by ODEQ-7 (1)-(6)	554	338	415	395
(11)	ODEQ-7 Total (4)+(8)	405	373	237	234
(12)	Organics Unaccounted For (10)-(11)	149	-35	178	161

* This value appears to be an outlier. Use of this number appears to effect the subsequent results from sample 1118-2. Data from 1118-2 was not used in computing average losses of organics.

Organic material caught in the probe and filter of the ODEQ-7 train was measured by: (a) weight of acetone soluable material caught in that portion of the train, and (b) the difference between the EPA-25 results from samples taken directly from the stack and immediately following the heated ODEQ-7 train filter. In-stack filters were used on the EPA-25 train drawing a sample from the stack. The quantity of organics caught in the front-half of the ODEQ-7 train as measured by the ODEQ-7 procedure averaged 15 ppm less than the measurement by difference of EPA-25 samples, and ranged between a loss of 74 ppm to a gain of 46 ppm. The values reported by the two procedures were considered equivalent because of the large variance in analytical results. EPA-25 results have a precision of roughly ±15 percent estimated from experience with duplicate samples taken on other sources. The individual EPA-25 results for in-stack and after the 120°C (250°F) filter may be in error by ±80 ppm, thus the value reflected in the results obtained by taking the difference between the two EPA results may also produce an error of ±80 ppm.

Organic material caught in the impingers and back filter of the ODEQ-7 train were measured by: (a) weight of the material captured in that portion of the train, and (b) the difference between EPA-25 results from samples taken immediately following the heated filter and immediately following the filter between the third and fourth impingers. This mass balance on the back-half of ODEQ-7 showed an average loss of 150 ppm (calculated using 3 data points), a value that is higher than the variability of EPA-25. The losses across the ODEQ-7 train represents a loss of between 25 to 45 percent of the organic material captured by the ODEQ-7 train.

This loss was judged to result from the vaporization of terpenes or slightly volatile compounds during the drying of the ODEQ-7 samples. Some terpenes may be dissolved with the less volatile organics caught in the impingers.

(3) Sampling Results from a Veneer Dryer with Emissions Controlled by a Sand Filter - Results from sampling with different ODEQ-7 and EPA-25 configurations at a veneer dryer with emissions controlled by a sand filter are presented in Table 5. The first set of entries show: (a) results of EPA-25 anisokinetically drawn in-stack filter catch, (b) the EPA-25 trap and tank catch, and (c) the total organics by sum of (a) and (b). The remainder of the table is arranged to show material balances over the (a) front-half, (b) the back-half, and (c) the total ODEQ-7 train using EPA-25 as a reference.

Differences in the results for probes directed parallel into the stack gas flow and for probes directed perpendicular to the stack gas flows can be attributed to nonisokinetic collection of particulate organics. The glass wool filters used were intended to remove wood fiber from the samples and were not efficient at removal of submicron sized particulate. These results indicated the necessity of isokinetic sampling when aerosols are present, such as following wet scrubbing devices.

TABLE 5 ODEQ-7 AND EPA-25 COMPARISONS FOLLOWING A SAND FILTER

	Sample Number	Results in ppm TGNMO as Methane				
		0013	0120A	0120B	127A	0127B
EPA-25						
(a)	Filter catch filter parallel to flow	119	130	77	148	87
	Filter perpendicular to flow	204	131	249	132	149
	Average	162	130	163	140	118
(b)	Trap and tank catch filter parallel to flow	94	609	164	488	499
	Filter perpendicular to flow	108	314	306	264	470
	Average	101	462	235	376	485
(c)	Total parallel to flow	213	739	241	636	586
	Total perpendicular to flow	312	445	555	396	619
	EPA-25 Total Average	263	592	398	516	603
ODEQ-7						
(1)	EPA-25 after 250°F filter	274	785	288	364	595
(2)	Organics removed by 250°F filter (c)-(1)	+11	+193	-110	-152	-8
(3)	ODEQ-7 front-half	40	60	43	37	49
	Difference	gain 51	gain 253	loss 67	loss 115	loss 41
(4)	EPA-25 after second filer	131	309	340*	591*	1135*
(5)	Organics removal by back-half of ODEQ-7 (1)-(4)	143	476	-52	-	-
(6)	ODEQ-7 back-half	42	105	70	82	174
	Difference	101	371	-	-	-
(7)	ODEQ Total	71	166	113	119	224
(8)	ODEQ Total + EPA-25 back-half	202	475	453	710	1359
(9)	Organics Unaccounted for	61	117	-	-	-

* These results are unreasonablly high. Their high values are possibly due to residual actone in ODEQ-7 train from previous cleanup or vacuum grease on the back-half used on these three samples only. Precautions were taken to avoid acetone residues in the ODEQ-7 train prior to sampling.

The mass balance across the ODEQ-7 front-half was poor. Anisokinetically drawn EPA-25 samples may have given an inadequate representation of the total particulate and gaseous organics present. Capture of organic particulates on the filter maintain at 120°C (250°F) was always less than capture on the in-stack filters at the stack temperature of 71°C (160°F), indicating revaporization of organic aerosol on the 120°C (250°F) filter. Revaporization of particulates from the 120°C (250°F) filter resulted in an increase in the result from EPA-25 train following the hot filter of 11 to 120 percent. The revaporization of particulates on the 120°C (250°F) filter and the poor material balances obtained across the 120°C (250°F) filter underscore the need for isokinetic sampling when organic particulates are present.

Poor material balances were also observed across the back-half of ODEQ-7 train. Three of the EPA-25 samples taken after the second filter showed higher results than the EPA-25 results taken after the 120°C (250°F) filter. This could only result from organic contamination of the sampling train. One possible source of organic contamination was the acetone wash used to clean the sampling train after each use. The sampling trains were washed with water after cleaning with acetone and dried prior to use. TOC determinations on the distilled water added to the impinger showed no organics. Another source of contamination may have been vacuum grease used on the three runs with the high results to seal leaks where the EPA-25 trains were connected to the ODEQ-7 train following the second filter.

Comparison of the ODEQ-7 back-half sample weight and the differences of EPA-25 samples drawn after the first and second filters for the two samples that were not contaminated showed a loss of organic material from the back-half ODEQ-7 samples of 140 ppm. This represents a loss of between 20 to 45 percent of the organic material captured by the ODEQ-7 train.

It was also shown that ODEQ-7 procedure yields results that are less than EPA-25 results. The difference in results between the two procedures was greater when sampling a scrubber outlet than when sampling uncontrolled emissions. The lower values measured resulted from escape of the more volatile materials which were captured by EPA Method 25. The removal of particulate and organic aerosol by the scrubber increases the ratio of volatile to condensible organics in the emissions. This ratio would also be expected to be influenced by the turpentine content of the wood.

B. Formulation of a Sampling Procedure

Sampling procedures were needed to measure three parameters in veneer dryer emissions: (a) particulate and organic material that would condense to form aerosols in the environment, (b) total organic compounds, and (c) gaseous organic compounds that would be expected to remain in a gaseous state in the atmosphere. These sampling procedures should be capable of giving comparable

results for each parameter for different dryer types and for controlled and uncontrolled emissions. Emission components that change form, i.e. gaseous to aerosols, as they pass through control devices should be measured on a consistent basis. These sampling procedures should be capable of consistent performance at stack moisture contents of up to 60 percent and in the presence of entrained water. The sampling procedures should be based on existing or modifications of EPA reference methods.

(1) Particulate and Condensible Organic Compounds - The ODEQ-7 test was designed to measure particulate and organic compounds that are likely to condense in the atmosphere to form aerosols that are largely responsible for the blue haze associated with veneer dryers. The work described above showed a loss of organic material upon drying ODEQ-7 back-half samples. ODEQ-7 samples are dried at room temperature, except for the extracted impinger water which is dried at 105°C (220°F). The quantity of organics left in the impinger water is small compared to what has been extracted; little loss would be expected to occur from drying the impinger material after ether extraction. Organics evaporated upon drying of ODEQ-7 samples would be expected to evaporate from condensed organics emitted to the atmosphere. The losses of organic material from the sample during analysis are not a constituent of the parameter being measured, therefore, the ODEQ-7 procedure cannot be questioned on this account. It was judged to produce data that were an accurate measurement of particulate matter and organics that condense in the atmosphere when applied to veneer dryer emissions.

(2) Total Nonmethane Gaseous Organic Compounds - EPA Method 25 has been designed to measure total nonmethane gaseous organic compounds. The method does not have provisions for a filter to remove particulate material from the sample. Since particulate material in veneer dryer emissions may interfere with the measurement, use of a filter is recommended. However, some of the organic material in veneer dryer emissions condense into aerosols when cooled by wet collection devices intended for their removal and escape the collection device. A filter held at stack temperature following a scrubber will exclude these condensed organics from the sample. If a true evaluation of a scrubber device to remove total organics is desired, the organic compounds should be compared on the basis of the organic materials being in a gaseous state. The organic material condensed while passing through the scrubber and not captured should be reevaporated by the sampling train so that only nonvolatile particulate are removed from the sample by filtration. Isokinetic sampling will be required to prevent a disproportionate collection of aerosols. The filter removing particulate from the sample stream should be maintained at a temperature equivalent to the uncontrolled emissions. A filter temperature of 150°C (300°F) is recommended for this purpose.

(3) Noncondensible Organic Compounds - Noncondensible organic compounds are those organic constituents in the emissions that are unlikely to condense in the atmosphere to form aerosols. The

EPA Method 25 procedure can give a carbon equivalent measure of the noncondensible organic compounds after conditioning the sample to remove the organics that may condense in the atmosphere. Many factors must be considered in choosing sampling procedures for this purpose that provide consistent results while sampling emission sources under a variety of conditions.

A separation between those organic materials which may condense in the atmosphere and those which may not can be achieved by placing a filter in the sample line that is held at a specified temperature. The filter temperature is chosen so that organic material that may condense in the atmosphere will be retained by the filter. The sampled gas should be brought to the filter temperature prior to filtering to allow the condensible organics to condense if the sampled gas is hotter than the filter or evaporate if the sampled gas is cooler than the filter temperature. Factors that affect the choice of the filter temperature are discussed.

A potential choice for the filter temperature would be at the standard ambient temperature of 20°C (70°F). Experience with losses of organic material during laboratory analysis of ODEQ-7 samples indicated that a portion of the organic material removed by a filter maintained at ambient temperature would likely be gaseous in the atmosphere. Choice of a higher filter temperature is indicated. This presents potential difficulties with condensing moisture. Veneer dryer emissions have high moisture contents, on occasion as high as 60 percent. Moisture condensing in the sample train and on the filter could plug the filter and hinder sampling. This requires that the filter and gas conditioning system be maintained at a temperature above the dew point of the highest humidity emissions likely to be encountered. The dew point of 60 percent moisture air is 86°C (187°F). A filter maintained at this temperature will likely pass organic material that will condense in the atmosphere. As the filter temperature is increased over the dew point, greater quantities of the condensible organics will pass the filter. A filter temperature that is 2°C (3°F) above the highest dew point likely to be encountered is recommended, that is 88°C (190°F).

Some organic material that may condense at atmospheric conditions may pass through a filter maintained at 88°C (190°F) as a result of the significantly higher vapor pressure of the organic material at this temperture as compared to atmospheric conditions. See Figure 5. Some condensible organics may pass the filter because of inefficient filtration of aerosols in the 0.1 to 0.5 range. The condensible organics passing the filter will bias the noncondensible organic measurements to the high side.

(4) Study on Over Estimation of Noncondensible Organics - The amount of organics found in the back-half of the ODEQ-7 train should give a good estimate of condensible organics measured by an EPA-25 train preceded by a 88°C (190°F) filter. Several samples were taken with the ODEQ-7 train with an EPA-25 train

attached following the front filter held at 88°C (190°F). The methane equivalent of the ODEQ-7 back-half catch as well as the EPA-25 train are presented in Table 6. These results indicated that an EPA-25 sampling train preceded by a filter held at 88°C (190°F) will over estimate the noncondensible organic emissions from veneer dryers by 10 to 30 percent.

TABLE 6 ODEQ-7 BACK-HALF AND EPA-25 FOLLOWING 190°F FILTER RESULTS

Source	ODEQ-7 Back-Half ppm	EPA-25 After 190°F Filter, ppm	Percent Condensible Organics in EPA-25 Sample
Uncontrolled Emissions from Douglas fir	70	311	23
Uncontrolled Emissions from Hemlock and White Fir, Direct Fired Dryer	47	156	30
Uncontrolled Emissions from Lodgepole Pine	125	1153	11
Wet Scrubber Controlled Emissions from Douglas Fir	94	475	23
Uncontrolled Southern Pine	259	2460	11

(5) Evaporation of Condensed Organics - To determine the volatility of organics caught on a filter held at 88°C (190°F) when sampling veneer dryer emissions, two such filters were placed in filter holders while 250 cc/min clean air was passed through them for a period of 15 days. A loss of 4.8 percent was measured. The filters were then placed in direct sunlight with the same air flow through them for 16 days. A loss of 1 percent was measured. From the results of this study it was concluded that organic material caught on a 88°C (190°F) filter preceding an EPA-25 sampling train are not volatile at ambient conditions.

C. Precision

The precision of the EPA Method 25 tests for sampling veneer dryer emissions was determined by analysis of a series of simultaneously drawn samples by three laboratories. Three sets of six samples drawn from veneer dryer emissions before and after a wet scrubber were analyzed in pairs by three laboratories. All of the samples were drawn from behind a filter maintained at 350°F in an EPA Method 5 particulate sampling train oven. The samples were drawn isokinetically by the EPA-5 train. Individual sample results are shown in Table 7.

TABLE 7 RESULTS OF EPA-25 ANALYSIS IN ppm C

Source	Laboratory	Test Day 1	2	3
	A	1292	1594	1304
		1128	995	1365
Inlet	B	803	1324	1206
		906	1460	996
	C	1186	1452	2116
		1246	1309	2159
	A	1292	1294	1018
		1321	1148	829
Outlet	B	1909	1033	712
		1168	851	1094
	C	1664	1484	686
		1886	1887	1028

(1) Precision of Each Laboratory - An estimate of the variance of the EPA-25 test method for each of the laboratories can be obtained from a 2 x 6 Analysis of Variance (ANOVA) on the paired samples. The estimate of s^2 is given by the mean square of the residual. The standard deviations calculated in this manner were 188, 258, and 172 ppm, resulting in relative standard deviations of 0.156, 0.221, and 0.114 for laboratories A, B, and C, respectively. The NCASI West Coast Regional Center is laboratory A.

(2) Comparison of Laboratory Pairs - A students "t" test comparing the total average of each laboratory's results can be used to determine if the laboratories are reporting the same statistical values. t_2 is calculated by:

$$t_2 = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{(n_x-1)S_x^2 + (n_y-1)S_y^2}{n_x + n_y - 2}} \sqrt{\frac{1}{n_x} + \frac{1}{n_y}}}$$

The comparisons are listed in Table 8. Since t_2 is greater than $t_{\alpha/2:5}$ for the laboratory comparisons B-C, laboratory C's results were significantly different than laboratory B's at the 90 percent confidence level.

TABLE 8 INTERLABORATORY COMPARISONS OF AVERAGE RESULTS

Laboratory Comparisons	$\bar{x} - \bar{y}$	t_2	$t_{0.05:5}$
A - B	147	1.42	2.0
A - C	169	1.54	2.0
B - C	316	2.42	2.0

(3) Summary - These analyses show that: (a) Results from laboratory A and B were not statistically different from each other, and results from laboratory C was statistically different from laboratory B. (b) Laboratory C produced the highest results and laboratory B produced the lowest. (c) Laboratory C had the best precision and laboratory B had the poorest precision. Other researchers may use other statistical methods to analyze the data from these tests and thereby arrive at somewhat different conclusions.

From these comparisons of EPA-25 results from different laboratories it appears that the method is prone to poor accuracy. Although each laboratory adheres to strict quality control procedures, results from one laboratory may be as much as twice those from another. This difference suggests that additional quality control procedures are necessary. Possibly a field sample of an audit gas should be incorporated into the quality control procedures.

D. Summary and Conclusions

(1) These studies showed that isokinetic sampling of veneer dryer source emissions containing organics in particulate form is necessary when measuring gaseous organic emissions. Particulate organics are likely to occur in the gas stream following control devices that cool the gas stream. Possible enrichment of the particulate catch by nonisokinetic sampling conditions could

result in a high analytical result for gaseous organics. If there are no particulates in the emissions sampled, isokinetic sampling is not necessary for gaseous organics emission measurement.

(2) There are potential losses of volatile organics in the back-half analysis of the ODEQ-7 procedure. These losses may result from evaporation of volatile constituents in the impinger and second filter catch during drying of these materials for weighing. This loss amounted to between 20 to 46 percent of the organic material captured by the ODEQ-7 train.

(3) Three sampling procedures were outlined that would allow full characterization of veneer dryer emission constituents. These procedures would give values for: (a) total particulate and condensible organic compounds, (b) total nonmethane organic compounds, and (c) noncondensible nonmethane organic compounds. Condensible organic compounds refer to those organic compounds in the emissions that would likely condense and remain condensed at ambient conditions. The ODEQ-7 procedure was found to give results acceptable to be used for particulate and condensible organic compounds. EPA Method 25 with a pre-filter held at 150°C (300°F) was selected to provide results for total nonmethane organics. EPA Method 25 with a pre-filter held at 88°C (190°F) was selected to provide results for noncondensible organic compounds. Results from this latter method were found to give a result for noncondensible organic compounds that was 10 to 30 percent high. This overestimation of noncondensible organic material results from condensible organics passing the pre-filter held at a temperature higher than necessary to separate condensible and noncondensible organics, but at a temperature high enough to avoid sampling problems resulting from the condensation of moisture.

(4) Condensed organic material from a veneer dryer emissions caught on a filter held at 88°C (180°F) preceding an EPA-25 sampling train are not volatile at ambient conditions.

V VENEER DRYER EMISSION FACTORS

Hourly average emission factors for uncontrolled veneer dryers emissions were developed from results of studies conducted during this project and from historical data. These emission factors are representative of the process when operating at full capacity. Emission factor data for total organic emissions and noncondensible organic emissions were derived from NCASI conducted studies using variations of EPA Reference Method 25 described in the previous section. Emission factors for particulate and condensible organic materials were derived from NCASI conducted studies and historical data produced from measurements with ODEQ-7. The NCASI test results along with descriptions of the dryers and test procedures are contained in Appendix C as individual mill test reports.

For the purpose of this section: (a) total organic compounds are defined as results of EPA Method 25 preceded by 150°C (300°F) filter or an in-stack filter when the stack temperature was greater than 150°C, (300°F) and are reported as methane; (b) noncondensible organic compounds are defined as the results of EPA Method 25 preceded by a filter maintained at 88°C (190°F) and are reported as methane; (c) particulate and condensible organics are defined as the results of the ODEQ-7 front- and back-half catch, regardless of the front filter temperature; (d) the emission factors reported are based on maximum dryer production and have not been adjusted for re-dry; and (e) the emission factors have been adjusted for trim losses, and are reported as thousand square feet (MSF) on a 3/8-in thick plywood trimmed to 4 by 8 feet.

A. Total Organic Compounds in Uncontrolled Emissions

Emission of total organic emissions presented as lbs CH_4/MSF from individual tests on uncontrolled emissions are listed in Table 9 by wood species and dryer type. Total organic emissions from drying Douglas fir ranged between 1.0 and 2.1 lb/MSF and averaged 1.3 lb/MSF. An emission of 0.03 lbs/MSF was measured for processing of Douglas fir re-dry. Loblolly and shortleaf pine emissions averaged 3.25 lb/MSF, whereas lodgepole pine produced 2.0 lb/MSF of total organic compounds.

Direct wood-residue fired dryers produced an average of 3.1 lb/MSF total organic emissions when drying Douglas fir. Drying of hemlock in a similar dryer produced emissions between 0.4 and 1.1 lb/MSF and averaged 0.8 lb/MSF total organic compounds. This wide range for the hemlock results may be due to the drying of other white wood species with hemlock.

The data base for the comparison of emissions from direct and indirect heated dryers is limited. Comparison of the emissions from drying for Douglas fir indicated a potential for higher emission rates of total organic compounds from wood-residue direct heated than from steam heated (indirect) veneer dryers.

B. Noncondensible Organic Compound in Uncontrolled Emissions

Emissions of noncondensible organic compounds from veneer dryers not equipped with emission control devices are listed in Table 10 according to wood species and dryer type. The data is presented as lbs CH_4/MSF as measured by EPA Reference Method 25 preceded with a filter maintained at 88°C (908°F). The average noncondensible organic emission from drying Douglas fir in a steam heated dryer was 0.75 lb/MSF. This value is similar to the quantity of terpenes in Canadian or Coastal Douglas fir (10) as shown in Table 2 and found by WSU (6) as shown in Table 3. Noncondensible organic emissions for processing hemlock in a steam heated dryer averaged 0.69 lb/MSF. Drew (10) found no terpenes in hemlock woods whereas the WSU report (7) showed 0.31

NO APPENDIX DATA FOR MILLS L & M — T. VOC

TABLE 9 TOTAL ORGANIC COMPOUNDS IN UNCONTROLLED EMISSIONS

(All data were results from EPA-Method 25)

Type	Species	Mill	Exhaust Temperature °F	Exhaust Rate DSCF/MSF	Emission Rate lb/MSF
Steam					
	Douglas Fir Sap	A	360	71,700	2.1
	Douglas Fir Heart	A	350	36,000	1.1
		E	310	55,500	1.2
		E	310	57,200	1.1
	Douglas Fir Mixed	D	303	24,200	1.0
		D	314	25,100	1.2
		D	309	25,700	1.2
	(LODGEPOLE PINE)	F	315	45,200	1.0
		F	320	53,500	1.6
		F	322	57,500	1.7
	Douglas Fir & Hemlock	E	315	48,200	0.9
	Lodgepole Pine	A	352	55,000	2.0
	Loblolly & Shortleaf Pine	G	325	55,400	3.4 - AVG. RUN 1
		G	326	53,800	3.8 - AVG. RUN 2
	(DOUGLAS-FIR & WHITE FIR)	J	317	12,200	2.7
		J	319	15,600	3.1
	Douglas Fir Re-dry	A	342	31,800	0.03
Wood-Residue Direct-Fired					
	Douglas Fir Sap	M	325	139,000	3.9
	Douglas Fir Heart	M	325	83,000	2.4
	Douglas & White Fir	L	305	68,400	0.9
	Hemlock & White Fir	J	314	103,000	0.4
		J	314	103,000	0.7
		J	314	103,000	0.9
		J	314	89,500	1.1

NO DATA

DOUGLAS-FIR & WHITE FIR

lb/MSF noncondensible organics. Drying of lodgepole pine in a steam heated unit resulted in 2.14 lb/MSF noncondensible organic emissions. Drew (10) found 2.3 lb/MSF turpentine in lodgepole pine and WSU found 2.36 lb/MSF noncondensible emissions from drying lodgepole pine (7). Overall, the noncondensible organic emissions found agrees with other data on turpentine content of the wood species being dried and other noncondensible organic measurements reported in the literature.

NC-VOC

TABLE 10 NONCONDENSIBLE ORGANIC COMPOUND IN UNCONTROLLED EMISSIONS

(All data were results from EPA Method 25 preceded by an 88°C filter)

Dryer Type	Veneer Species	Mill	Emission Factor lb/MSF
Steam			
	Douglas Fir	D	0.7
		D	0.8
		D	0.8
	Hemlock	D	0.7
		D	0.7
	Lodgepole Pine	G	2.2 - Avg - Run A
		G	2.1 - Avg - Run B
Wood-Residue Direct-Fired			
	Douglas Fir	K	2.1
		M	1.7
		M	3.0
	Douglas & White Fir	L	0.7
		L	1.2
	Hemlock	J	0.9
	Hemlock & White Fir	J	0.5
		J	0.4
		J	0.6

NO DATA

DOUGLAS-FIR + WHITE FIR

These data indicated that the noncondensible organic materials in emissions from steam heated veneer dryers resulted largely from evaporation of turpentines from the wood. Nearly all the turpentines in the wood were removed during the drying process. The noncondensible organic emissions are therefore likely to be a function of the wood species and not be related to dryer operating parameters such as production rate, dryer temperature, and exhaust flow rate.

Noncondensible organic emissions from wood-residue fired direct heated veneer dryers for Douglas fir and hemlock averaged 2.3 and 0.9 lb/MSF, respectively. The noncondensible organic emissions from wood-residue direct fired dryers were greater than emissions found for the same wood species processed in steam heated dryers. A study conducted at dryer K (Appendix C) showed passage of veneer dryer emissions through the blend box resulted in partial conversion of condensible organics to noncondensible organics. A small contribution of noncondensible organics, approximately 0.2 lb/MSF, would be expected to result from the combustion of the wood-residue used for fuel. While the above findings should be verified by a similar study at a second site, they do offer a logical explanation for the greater quantity of total organic compounds emissions from wood-residue fired direct heated veneer dryer as compared to steam heated dryers.

C. Particulate and Condensible Organic in Uncontrolled Emissions

Particulate and condensible organic compounds in uncontrolled veneer dryer emissions are listed in Table 11 by wood species and dryer type. This data was collected from historical ODEQ-7 measurements as well as measurements using this method during this study. Particulate and condensible organic emissions from steam heated dryers ranged between 0.26 and 2.84 lb/MSF for Douglas fir, and between 0.07 and 0.23 for white fir. Emissions for gas fired direct heated dryers ranged between 0.33 and 4.3 for Douglas fir, 0.52 and 0.86 for white fir, and 1.6 and 4.2 for western pine species. Particulate and condensible organic emissions from wood-residue fired direct heated veneer dryers ranged between 0.46 and 1.5 lb/MSF for Douglas fir, and 0.9 and 1.6 for white fir. The particulate and condensible organic emissions from wood-residue fired direct heated veneer dryers contain ash particulate from wood combustion.

(1) Concentration Relationship to Emission Temperature - Concentrations of particulate and condensible organic emissions for steam and gas-fired direct heated dryers processing Douglas fir were plotted as a function of the stack temperature in Figure 8. When the three data points exhibiting low concentrations at high temperature were eliminated, the resulting data correlated with an r of 0.78. Higher stack temperatures correlated with higher concentrations in the emissions. Stack temperatures are indicative of the operating temperature in the dryer. Observed concentrations in proportion to dryer operating temperatures were judged to be associated with the increased volatilization of resin and fatty acids at the higher dryer operating temperatures.

TABLE 11 PARTICULATE AND CONDENSIBLE ORGANIC IN UNCONTROLLED EMISSIONS

(All data are results from ODEQ Method 7)

Dryer Type	Veneer Species	Air Discharge 10^3 DSCF/MSF	Temp. °F	Emissions lb/MSF	Data Source
Steam	Douglas Fir Sapwood	124	202	0.26	a
		33	300	0.43	a
		157	360	0.67	a
		486	375	2.84	a
	Douglas Fir Heartwood	29	277	0.38	b
	Douglas Fir Mixed	190	300	1.25	a
		81	350	2.02	a
		40	336	0.96	c
		50	336	1.20	c
		37	336	0.94	c
		21	303	0.64	d
		21	314	0.54	d
		22	309	0.39	d
		45	315	0.99	g
		54	320	1.31	g
		58	322	1.28	g
		35	--	0.59	h
		30	--	0.45	h
	White Fir	214	285	0.23	a
		105	294	0.07	a
		56	300	0.20	a
		26	311	0.20	a
		43	325	0.18	c
		42	332	0.17	c
		26	328	0.10	c
	Lodgepole Pine	53	315	0.79	e
	Douglas Fir Mixed & Small Amount of Pine	48	338	1.1	c
		58	334	1.4	c
	Redry	52	330	0.7	c
	Douglas Fir Mixed	111	--	1.5	b

(a) Data from BWR Associates (20).
(b) Data from ODEQ files.
(c) Data provided by mills.
(d) Data from EPA Contractor TRC (20,21).
(e) Data from NCASI studies (Appendix C).

TABLE 11 (Con't.)

Dryer Type	Veneer Species	Air Discharge 10^3 DSCF/MSF	Temp. °F	Emissions lb/MSF	Data Source
Direct Heated Gas Fired					
	Douglas Fir Heartwood	46	355	0.3	a
		318	--	4.3	b
		145	--	2.3	b
	Douglas Fir Mixed	145	320	2.1	a
		167	305	1.6	a
		38	362	0.9	a
		90	350	1.5	a
	White Fir	140	317	0.5	a
		159	320	0.7	a
		37	385	0.5	a
		88	360	0.9	a
	Pine	71	325	1.6	a
		166	317	4.1	a
		171	374	4.2	a
~~Direct-Fired Gas-Fired~~ DIRECT WOOD-FIRED (PER NCASI)					
	Douglas Fir Sapwood	57	760	1.5	a
	Douglas Fir Heartwood	52	325	1.2	a
	Douglas Fir Mixed	107	265	1.1	a
		135	250	0.5	a
		77	310	1.2	a
	White Fir	63	--	0.9	a
		63	--	1.4	b
		53	--	1.2	b
		79	327	1.5	e
		90	327	1.6	e
	Pine	186	420	1.3	a
	Spruce	208	420	1.3	a

(a) Data from BWR Associates (20).
(b) Data from ODEQ files.
(c) Data provided by mills.
(d) Data from EPA Contractor TRC (20,21).
(e) Data from NCASI studies (Appendix C).

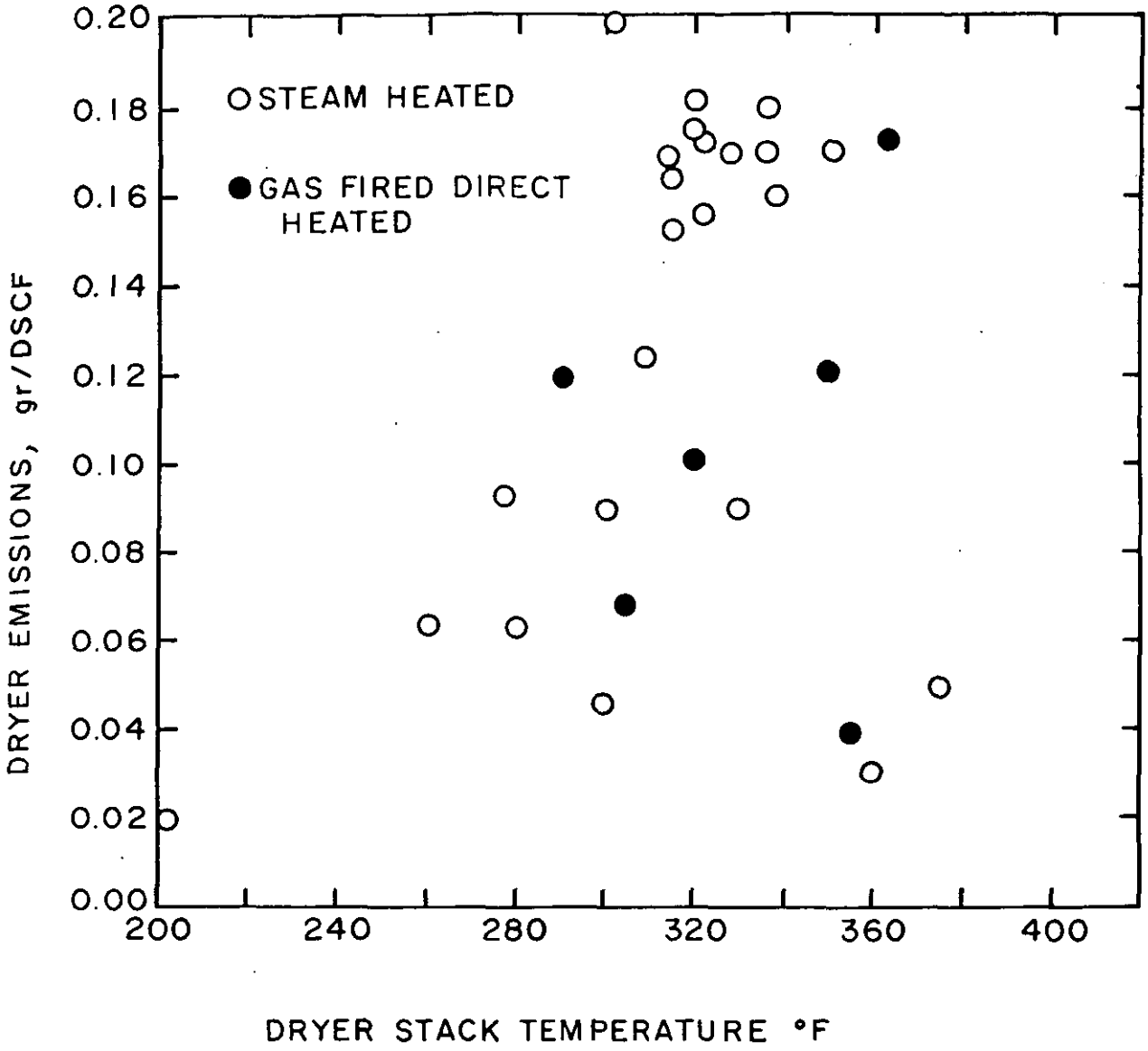

FIGURE 8

EFFECT OF DRYER TEMPERATURE
(AS INDICATED BY DRYER STACK TEMPERATURE)
ON PARTICULATE AND CONDENSIBLE ORGANIC EMISSION CONCENTRATION

(2) Emission Factors as a Function of Dryer Exhaust Rate - Most dryers are operated within a temperature range of 150°C (300°F) and 177°C (350°F), resulting in similar particulate and condensible organic concentrations. Emissions expressed as lbs/MSF, calculated by multiplication of the concentration and gas flow rate expressed as DSCF/MSF, should be a linear function of emission rate. Figure 9 shows this relationship for Douglas fir

particulate and condensible organic emissions. This figure shows a linear relationship at emission rates less than 80 x 10^3 DSCF/MSF. At flow rates above 80 x 10^3 DSCF/MSF, the emission of particulate and condensible organics is less than at the lower flow rates, and the data is more scattered. Figures 10 and 11 show similar plots for white fir and western pines. The similar slopes in Figure 9 and 11 indicate that particulate and condensible emissions from steam heated drying of Douglas fir and Lodge pole pine should be similar for like dryer operating conditions.

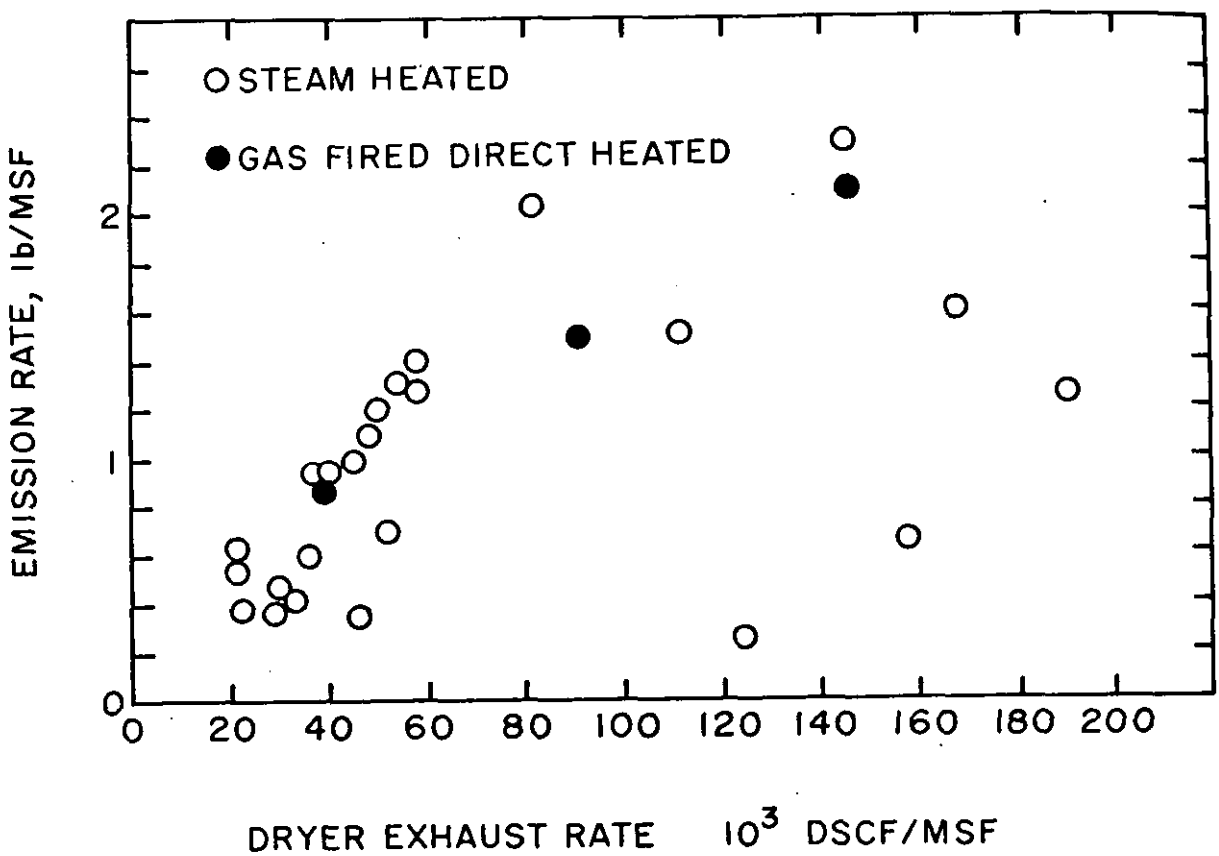

FIGURE 9

MASS EMISSION RATE OF PARTICULATE AND CONDENSIBLE ORGANIC EMISSIONS AS A FUNCTION OF DRYER EXHAUST RATE WHEN DOUGLAS FIR IS BEING DRIED

These data indicated an equilibrium is reached between the condensible materials measured by this test, probably resin and fatty acids in the wood, and the veneer dryer gases. This equilibrium can limit the vaporization of condensible organics

when the gas replacement rate on a production basis is small. Although the wood may contain more resin and fatty acids, they are not removed presumably because of a lack of driving force to the gas phase. The equilibrium concentration in the air is a function of the temperature and of levels of the resin acid in the wood. Wood species with higher resin and fatty acid contents such as pine may have higher resin and fatty acid vapor pressures. The vapor pressure of a material in a mixture is often proportional to its concentration in the mixture. White fir, being essentially devoid of pitch and rosin, produces little condensible organic material. At higher gas emission rates the air inside the dryer is replaced more rapidly, causing cold spots. Condensation of these organics leads to the formation of pitch inside the dryer which requires periodic cleaning. Equilibrium concentrations of organics in the fresh air entering the dryer is not achieved quickly, explaining the non-linearity of the data in Figure 9 for the high dryer exhaust rates.

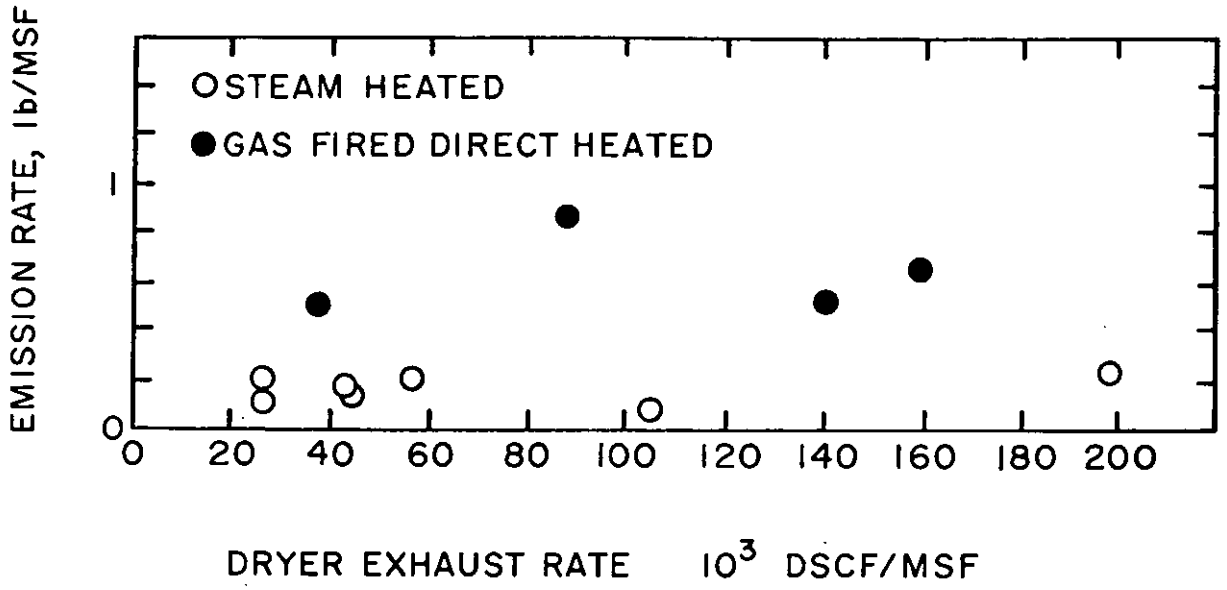

FIGURE 10

MASS EMISSION RATE OF PARTICULATE AND CONDENSIBLE ORGANIC EMISSIONS AS A FUNCTION OF DRYER EXHAUST RATE WHEN WHITE FIR IS BEING DRIED

Another factor that could lead to higher emission rates is operation of the dryer at too low a redry rate (23). At low redry rates wood stays in the dryer too long which results in scorching and evolution of smoke. Normal redry rates are between 10 to 15 percent of the veneer fed to the dryer.

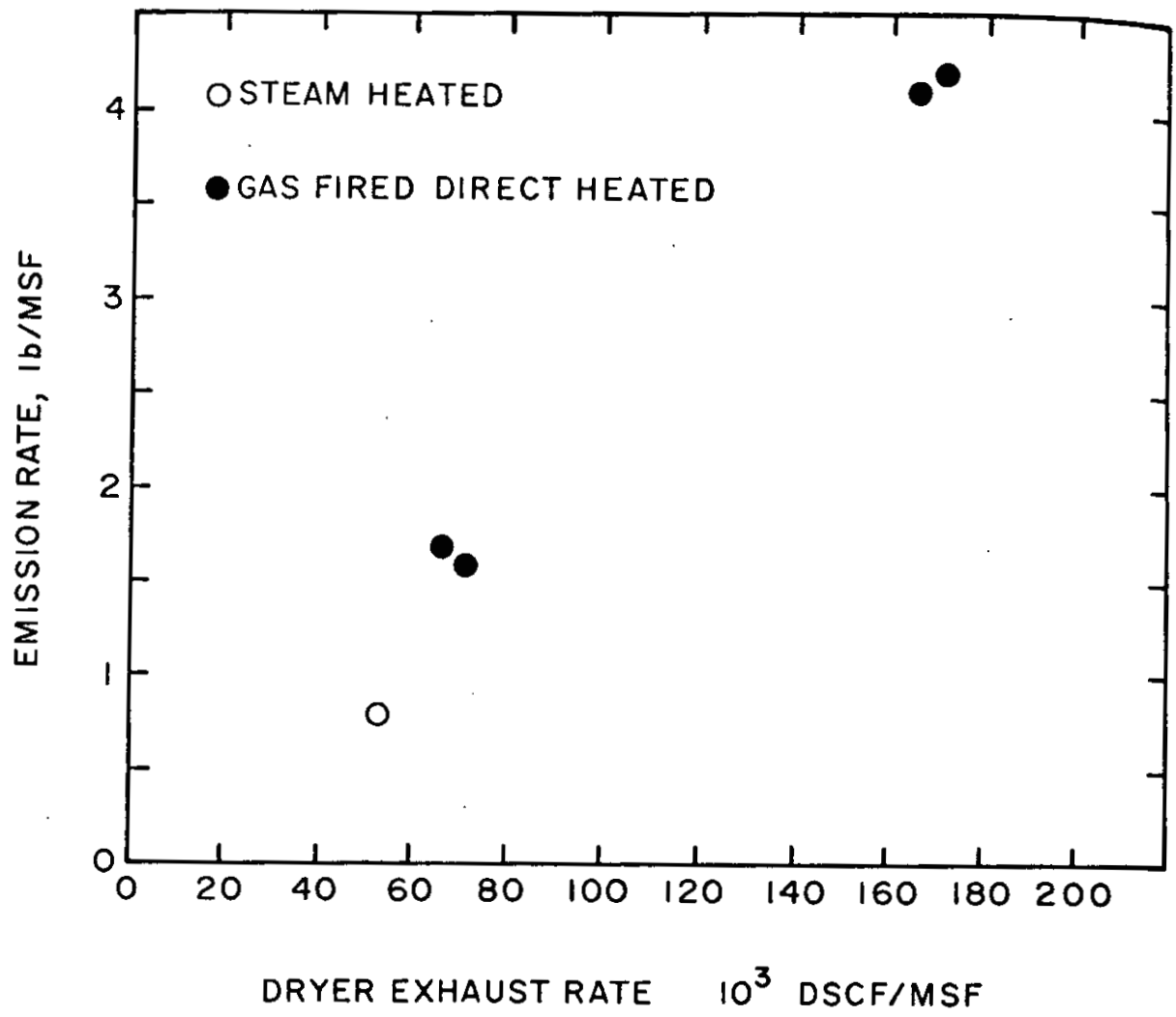

FIGURE 11

MASS EMISSION RATE OF PARTICULATE AND CONDENSIBLE ORGANIC EMISSIONS AS A FUNCTION OF DRYER EXHAUST RATE WHEN WESTERN PINE SPECIES ARE BEING DRIED

Energy conservation and environmental regulation requiring emission control has resulted in a decrease in air discharge per unit of production in recent years. Based on this study, most steam heated dryers can be expected to operate at exhaust rates less than 60 x 10^3 DSCF/MSF. Based on the data from this study the lower air exhaust rates, a range of particulate and condensible organic emission factors for new veneer dryers of from 0.33 to 2.0 lb/MSF for Douglas fir, 0.07 to 0.35 for white fir and 0.7 to 1.7 for western pine species would be projected. There is no data available for southern pine species.

D. Particulate and Condensible Emissions from Wood-Residue Fired Direct Heated Dryers

Particulate and condensible emissions from wood-residue fired direct heated dryers ranged from 0.46 and 1.5 lbs/MSF for Douglas fir and between 0.9 and 1.6 lbs/MSF for white fir. In several studies organic and non-organic particulate in the front-half catch of the ODEQ-7 procedure was differentiated by extraction with acetone. The extracted acetone portion was dried and weighed and its weight added to the ODEQ-7 back-half catch. In one study, Mill J, Appendix C, where a mixture of Douglas and white fir was being dried, an average of 15 percent of the total particulate was found to be organic material. In Study I, Appendix C, the organic content of the ash was found to be 27 percent when a combination of hemlock and white fir were dried. This is in contrast to the percent organic compounds found in the particulate and condensible organic emissions from steam heated dryers where emission rates of between 0.4 and 1.4 lb/MSF were better than 95 percent organic material (21,22). Results from study K, Appendix C, indicated that condensible organics were broken down into lower molecular weight compounds when dryer emission were recycled through the blend box to cool the temperature from the combustion process prior to the dryer.

E. Discussion

Uncontrolled veneer dryer emissions at stack gas temperatures above 300°F contain particulates and gaseous organics. The particulates material can be either wood fibers or ash in emissions from wood-residue fired direct heated dryers.

A portion of the gaseous organic compounds present in veneer dryer emissions condense to form aerosols upon entering the atmosphere, producing the characteristic blue haze. The condensible organics consist mostly of fatty and resin acids. Concentrations of these condensible organic compounds in the stack gas are related to the dryer temperature, with higher dryer operating temperatures resulting in higher concentrations in the emissions. Emission rates of condensible organics are related to production rates, wood species, dryer temperature, and dryer exhaust rate.

Noncondensible organic emissions from steam heated dryers are related only to compounds with low boiling points, principally the turpentine content of the green veneer and thus are directly related to the production and wood species being processed. Total organic compound emissions are the sum of the condensible and noncondensible organic emissions. Total organic emission rates from steam heated units will be a function of the wood species, dryer temperature, emission volume, and production rates.

Total organic emission rates from wood-residue fired direct heated dryers will be higher than emissions from steam heated dryers due to: (a) a small contribution of organic compounds

from the combustion in the fuel cell and (b) condensible organics passing through the blend box may be partially degraded to lower molecular weight noncondensible organic compounds. This reduces the vapor pressure of condensible organics in the dryer, unbalances the equilibrium, and allows further evaporation of condensible material. Total organic emissions and particulate and condensible organic emissions when expressed as lb/MSF should also be higher for gas-fired direct heated veneer dryers than for steam heated dryers. Gas-fired direct heated dryers require higher exhaust rates to maintain a sufficient oxygen level in the dryers to support combustion.

Particulate and condensible organic emissions, and hence total organic emissions, when expressed as lb/MSF hourly averages, are strongly affected by the green veneer moisture content. When relatively wet wood is being dried the dryer production rate is reduced by the limited capacity of the heat delivery system. Normally dampers that control air exhaust rates from the dryer are not re-adjusted when woods of different moisture contents are dried. The adjustment of these dampers is to minimize fugitive emissions. The reduced production rate when relatively wet veneer is dried, a constant exhaust rate, and a constant particulate and condensible organic emission grain loading leads to an increase in emissions expressed as lb/MSF, although the emissions expressed as lb/hr may remain constant for a particular wood species.

Emission factors reported in this bulletin are one-hour average values when the dryer was operating at full capacity on the species specified and are not adjusted for the percent redry. Normally about 10 to 15 percent of the veneer must be redried. Emission factors for redry are very low in comparison to green veneer. Daily average emission factors should be adjusted to compensate for the amount of redry, or be calculated using daily net production.

VI VENEER DRYER EMISSION CONTROL EQUIPMENT

Veneer dryer emissions have been controlled using two types of technologies, wet collection devices and incineration. These technologies were installed primarily to control blue haze resulting from the condensation of organics when the emissions were released to the atmosphere. Wet collectors are also used to control nonorganic emissions from wood-residue fired direct heated veneer dryers. No emission control devices have been designed or installed to specifically control total organic compound or noncondensible organic compound emissions. Effectiveness of these technologies for the capture of total organic compounds, particulate condensible organics, and noncondensible organics is discussed in the following sections.

A. Description of Wet Collectors Used for Control of Veneer Dryer Emissions

(1) Operation Principles of Wet Collectors - Scrubbers remove particulate material from gas streams by impingement. Organic material contained in hot veneer dryer emissions are in a gaseous form as they leave the dryer. The emissions are cooled either by the scrubbing solution or by water sprays provided specifically to cool the emissions and form aerosols which are to be removed by the scrubber.

The organic compound removal efficiency of a scrubber is governed by the degree of condensation achieved and the ability of the scrubber to remove the condensed organics. Condensation kinetics in the scrubber effect its performance. Fast quenching of veneer dryer emissions produce a high supersaturation of condensible organics and the formation of aerosols with expected particle diameters of less that 0.005 microns. These aerosols must grow to a sufficient size to be removed by the scrubber. Particle growth is initially fast under high supersaturated conditions; but slows once a saturation condition is established. Uncontrolled veneer dryer emissions vented to the atmosphere grow to a mass average diameter of 0.10 microns within 3 ft of the stack but do not grow further. Particle sizes 5 ft from the stack ranged between 0.02 and 0.6 microns diameter (8). Removal of particles in this size range from a gas stream does not occur by impaction, but by turbulent diffusion to the scrubbing fluid. In most scrubbers the main capture mechanism of particles with diameters less than 0.3 microns is diffusional collection.

The degree of condensation achieved depends on the organic composition, temperature to which the gas stream can be cooled, and the particle size distribution formed. The scrubbing solution is generally recycled and comes to an equilibrium temperature balanced by the heat input from the hot gases and the heat loss due to water evaporation. This temperature is close to the uncontrolled emission wet bulb temperature and is in the general range of 63 to 77°C (145 to 170°F). Oleic acid has a vapor pressure corresponding to 0.0006 gr/DSCF (2 ppm as CH_4) at these temperatures and should be in aerosol form. However, the vapor pressure of extremely small aerosols is higher than that for the same compound on a flat surface as shown in Figure 7 in Section III B. Sesquiterpenes have a vapor pressure corresponding to about 18 gr/DSCF at this temperature, a concentration that is greater than the amount of sesquiterpenes present. Sesquiterpene and terpenes would be expected to pass through scrubber on a veneer dryer in an uncondensed form.

(2) Wet Collector Scrubber Descriptions - Four wet collection devices were studied for effectiveness in controlling veneer dryer emissions. These were: (a) Georgia-Pacific scrubber, (b) Rader Sandair filter (c) Ceilcote ionizing wet filter, and (d) the Burley scrubber. The NCASI sampled emissions from these control devices for total organic compounds and noncondensible

organic emissions during these studies. Particulate and condensible organic emission data were generated by: (a) BWR Associates (b) TRW under contract to the EPA, and (c) NCASI staff.

Veneer dryer emissions enter the sand filter by flowing downward through a series of water sprays and under a baffle plate. Organic aerosols are formed by cooling the gases with the water spray. Some of the aerosols are removed by the baffle plate scrubber. Scrubber water is recirculated after the organics and wood particles have been partially removed by a decanter. The gases then flow to a series of filter cells containing a 1 to 3 foot depth of sand supported by a stainless steel mesh screen. Water is sprayed onto the sand and flows down through the sand with air. The small spaces between the sand particles provide maximum contact for particle agglomeration and collection. Gas is separated from the liquid beneath the cells and the gas flows to an entrainment separator before discharge.

The Georgia-Pacific scrubber is designed to precondense organic compounds by cooling the emissions with water sprayed into the duct prior to the scrubber. A set of cyclones separate the spray water from the emissions. The gases are then drawn through an induced draft fan and passed to a packed bed for collection of organic aerosols and entrained moisture. On some units a demister is located above the packed beds in the stack. Condensed organics are removed from the scrubbing solution by a decanter and the water is recycled to the scrubber.

The Ceilcote ionizing wet scrubber consists of a quench spray located in the duct work leading to the scrubber, a water spray prescrubber to remove large wood particulates, a high voltage ionizing section, and a cross-flow irrigated packed bed scubber. A second ionizing and scrubber section is sometimes added for additional efficiency. A corona discharge in the ionizing section produces gaseous ions to charge particulate in the gas stream to increase interception by the scrubbing solution or packed tower. The scrubber is packed with 2 in. Tellerette packing. A section of unirrigated packed bed serves as a mist eliminator. The scrubber solution is recirculated through the packing after being skimmed to remove condensed organics and wood particulates.

The Burley scrubber consists of 3 to 5 spray chambers in series. The five chamber model is equipped with a high speed centrifugal fan on the outlet to remove water droplets. Condensed organics are removed from the recirculated solution by decanters. Burley scrubber are normally located on top of the dryer.

B. Measured Emission Rates from Wet Collectors

Inlet and outlet concentrations as well as percent removal of total organic compounds, noncondensible organics, and particulate condensible organics for three of the wet collectors

studied are listed in Table 12. Total organic compound removals ranged between 20 and 64 percent for the Sandair filter. Non-condensible organic compounds ranged between a 40 percent removal to a 9 percent increase for the Georgia-Pacific and Ceilcote ionizing wet scrubber. Particulate and condensible organic removals ranged from 11 to 85 percent for all three devices. Condensible and particulate removals accounted for much of the total organic compound removal. For instance, the average total organic compounds removed by the Sandair filter was 306 ppm, whereas the average of particulate and condensible organics was 0.123 gr/DSCF, which corresponds to 250 ppm when a conversion factor of 2050 ppm CH_4/gr/DSCF is used.

Data collected during a study of the Burley scrubber at mill A illustrated the difficulty in establishing removal efficiency of wet collectors controlling veneer dryer emissions. The inlet and outlet of the Burley scrubber were sampled with EPA method 25 preceded by an in-stack filter at stack temperature while redry was being processed. The total organic compound emission in the scrubber inlet was 25 ppm whereas the noncondensible organic emission in the scrubber oulet was 150 ppm, an increase of greater than 125 ppm noncondensible organics across the scrubber. These data suggested that noncondensible organic compounds, such as terpenes, were being stripped from the scrubber solution. Terpenes are soluble in the condensible organics collected by the scrubber and reach an equilibrium in the scrubbing solution. This, along with the noncondensible removal data attained at other scrubbers, would indicate that some removal of noncondensible organic material by a scrubber occurs.

An ODEQ-7 sample of the Burley scrubber exit gas taken at the same time as the EPA-25 sample showed particulate and condensible emissions of 0.072 gr/DSCF, 76 percent of which were captured in the front-half of ODEQ-7 train. This data indicated entrainment of scrubber solution or revolatilization of organics. Because the scrubber can contribute to as well as collect organic compounds from the emissions, individual tests cannot be used to evaluate overall scrubber efficiencies. A detailed knowledge of immediate past operations with regard to materials being dried and the average of a large number of tests should be used to determine scrubber capabilities.

Although the Ceilcote scrubber showed good particulate and condensible organic removals, the plume had a high opacity. The opacity was believed to be associated with sodium chloride aerosol from the burning of hogged ply trim containing high salt content glues in the direct fired burner. Most of the particulate removed from the emissions by the Ceilcote scrubber was ash from the fuel cell.

C. Discussion of Observed Wet Collector Performance

The generally low particulate and condensible organic emission removal efficiencies by these scrubbers can be partially explained. Some wet collectors in use were designed to function

TABLE 12 WET COLLECTOR EFFICIENCIES IN REDUCING VENEER DRYER EMISSIONS

Scrubber	Emission Parameter		Emission Concentrations Inlet ppm	Outlet ppm	Percent Removal
Sand Filter	Total Organic Compounds	(1)	680	256	62
			525	270	49
			648	521	20
			480	243	49
			830	448	46
			646	231	64
			gr/DSCF	gr/DSCF	
	Particulate and Condensible Organics	(2)	0.17	0.03	79
			0.17	0.05	72
			0.18	0.03	83
			0.16	0.03	78
			0.17	0.03	85
			0.09	0.03	66
Georgia-Pacific	Total Organic Compounds		1210	1306[3]	-8
			1290	1221[3]	5
			1334	923	31
	Noncondensible Organic Compounds		694	495	28
			1020	643	40
			746	786	5
			gr/DSCF	gr/DSCF	
	Particulate and Condensible Organic Compounds	(4)	0.198	0.115	42
		(4)	0.169	0.107	37
		(4)	0.124	0.086	45
		(5)	0.117	0.048	59
		(5)	0.089	0.046	48
Ceilcote	Noncondensible Organic Compounds		226	297	31
			561	508	-9
			gr/DSCF	gr/DSCF	
	Particulate and Condensible Organic Compounds	(6)	0.164	0.035	79
			0.154	0.033	79
			0.146	0.044	70
			0.128	0.056	56
			gr/DSCF	gr/DCSF	
	Condensible Organic Compounds	(7)	0.021	0.0063	71
			0.028	0.0056	79
			0.016	0.0053	66
			0.025	0.022	11

(1) Outlet samples were sampled anisokinetically. The outlet TGNMO concentrations are a sum of organics caught on filter and in trap.
(2) This data was supplied from mill tests.
(3) Sample results are believed to be high due to contamination by acetone during sampling.
(4) Particulate and condensible data were collected by TRC during an EPA sponsored study.
(5) ODEQ-7 data from mill records.
(6) Particulate and Condensible data collected by BWR.
(7) Condensible organics were determined by acetone extraction of particulate and condensible organic compound samples.

as particulate collection devices. Wet scrubbers as particulate control devices generally operate best on particles with diameters greater than 0.5 micron. Aerosols formed by rapid condensation of organics in veneer dryer emissions are generally less than 0.1 micron in diameter. Removal of aerosols of less than 0.3 micron diameter in wet scrubbers occurs by diffusional mechanisms, similar to gas absorption. Two of the scrubbers studied utilized packed bed sections. Packed beds can be designed as effective gas absorbers. The third used a sand bed, which may be expected to behave similarly to a packed bed. These packed bed sections probably accounted for a major portion of the condensible organic compound removals observed at these locations.

Another reason for low wet collector efficiency for removal of condensible organic material is the residual vapor pressure of the organic aerosol, especially at higher scrubber solution temperatures. Extemely small aerosols exert a vapor pressure greater than the same compound contained in larger particles or on a flat surface. Aerosol size distributions 5 ft above an uncontrolled veneer dryer stack showed that most of the particles had diameters less than 0.01 um (8). Particles of this size would also likely be formed in the condensation section preceding the scrubbers.

Figure 12 shows the vapor pressure of small aerosols expressed as gr/DSCF. Also plotted in Figure 12 is ODEQ-7 total particulate and organic compound concentrations at several scrubber outlets. The outlet concentrations fall above the vapor pressure curves, indicating passage of noncondensed organic material as well as organic aerosols through the scrubbers. The data used in Figure 12 came from references 21, 22, and 24.

The vapor pressure lines represent the maximum condensible particulate removal performance that may be expected by the scrubber. Scrubbers with higher water temperatures would be expected to operate at limited condensible organic material removals. Scrubber water temperatures adjust themselves to approach the dryer uncontrolled emission wet bulb temperature. Dryers operating with minimum air flows will have high moisture contents in their exhaust, and therefore will have high exhaust gas wet bulb temperatures and high scrubber water temperature. A scrubber operating on a dryer emission with a wet bulb temperature of 82°C (180°F) may expect a maximum efficieny of 50 percent on condensible organic compounds.

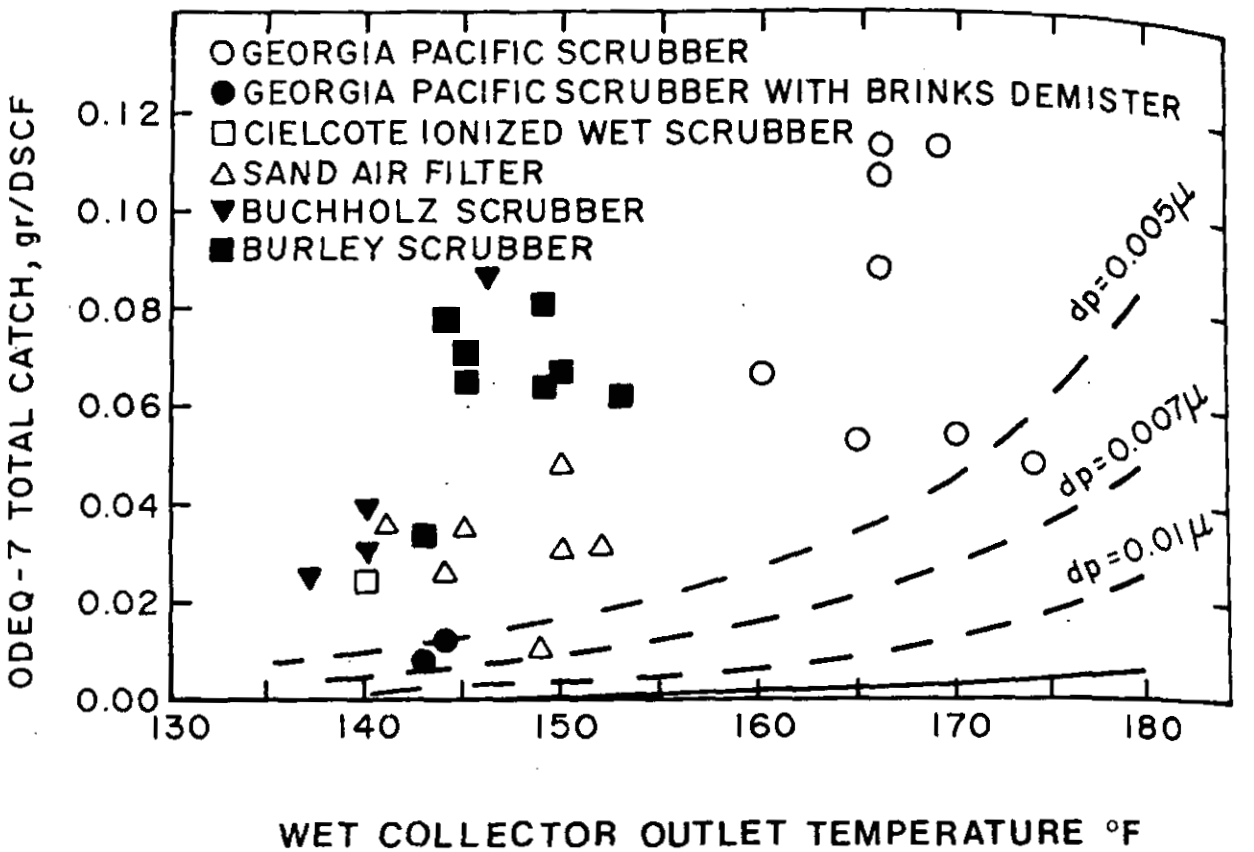

FIGURE 12

PARTICULATE AND CONDENSIBLE ORGANIC EMISSION CONCENTRATIONS IN WET COLLECTOR EXHAUSTS AND THEORETICAL VAPOR PRESSURES OF CONDENSIBLE ORGANIC EMISSIONS AT SEVERAL AEROSOL PARTICLE SIZE DIAMETERS AS A FUNCTION OF THE SCRUBBER SOLUTION TEMPERATURE

D. Experience and Efficiency of Power Boiler Incineration of Veneer Dryer Emissions

A number of mills in the Pacific Northwest have chosen to control veneer dryer emission by incineration in existing wood-residue fired power boilers. Emissions from the dryer were collected, ducted to the boiler, and admitted to the boiler as overfire and underfire air. One boiler incinerating veneer dryer emissions was fired on natural gas.

(1) Veneer Dryer Emission Incineration Studies - Measurement of total organic compounds in veneer dryer exhaust being used as combustion air and in the flue gas from two wood-residue fired Dutch oven boilers were made to determine effectiveness of the boiler in destroying these compounds. Total organic and condensible organic compound emissions were measured at one of the boilers when no veneer dryer emissions were being fired. Descriptions of the boilers and tests performed are contained in mill reports D and E in Appendix C.

At mill D, veneer dryer exhaust was used as combustion air in a Dutch oven boiler. The boiler inlet and outlet were sampled with EPA-25 preceded with an in stack filter. This test was to determine if a reduction in organic material across the boiler could be detected. No boiler measurements without veneer dryer emissions in the incoming air could be taken. Dutch oven boilers have had emissions measured as high as 0.5 lb/10^6 Btu heat input. Results of the tests are shown in Table 13. Total organic compounds in the exhaust fed to the boiler ranged between 12.8 and 16.4 lbs per hour. Organic emissions from the boiler ranged between 11.2 and 17.1 lb/hr or 0.13 to 0.32 lb/10^6 Btu. In light of the variable organic emission rates found and the unknown organic emission rates resulting from wood-residue combustion in this unit, these tests were inconclusive in determining the effectiveness of this wood-residue boiler in the control of veneer dryer emissions. Further testing of this boiler while no veneer dryer emissions being incinerated will be required to determine the effectiveness of this boiler in the destruction of organics in veneer dryer emission.

TABLE 13 TOTAL ORGANIC EMISSIONS TO AND FROM BOILER AT MILL E

Run No.	Total Organic Emissions To Boiler lb/hr	Total Organic Emissions From Boiler lb/hr	Percent Change in Organic Emission Through Boiler
1	12.8	17.1	+34
2	16.4	6.9	-58
3	13.6	11.2	-18

Results from the studies at mill E are summarized in Table 14. The total organic compounds in the veneer dryer emission at mill E used for combustion air ranged 16 to 23 lb/hr as CH_4 whereas the total organic emissions from the boiler ranged between 1.7 to 18.1 lb/hr, and averaged 9.5 lb/hr as CH_4 when veneer dryer emissions were being incinerated. When no veneer dryer emissions were being incinerated the boilers total organic emissions averaged 12 lb/hr. Likewise, condensible organic compounds in the veneer dryer emissions averaged 15.5 lb/hr to each boiler whereas the condensible organics emissions from boiler No. 2 averaged 3.4 lb/hr while incinerating veneer dryer emissions. When no veneer dryer emissions were being incinerated the boilers condensible organic emissions averaged 4.5 lb/hr.

Although there is insufficient data to statistically compare the boiler emissions when fired with and without veneer dryer emissions in the combustion air, the data indicated complete destruction of the organics in the veneer dryer emissions. Both the average total organic emissions and the condensible organic

TABLE 14 TOTAL ORGANIC EMISSIONS TO AND FROM BOILER AT MILL E

Run No.	Veneer Dryer Organic Emissions to Boiler		Boiler Organic Emissions		Organics Removal Efficiency	
	Total lb/hr	Condensible lb/hr	Total lb/hr	Condensible lb/hr	Total Percent	Condensible Percent
1	16.1	14.5	2.3	3.4	160	108
2	23.3	18.1	14.0	5.0	91	92
3	0	--	14.5	6.3	--	--
4	0	--	9.6	2.8	--	--
5	21.0	13.9	1.7	1.7	149	113
6	19.7	--	10.3	--	109	--
7	19.9	--	18.1	--	69	--
8	17.4	--	4.8	--	141	--

* Efficiencies were calculated from:

$$\text{Efficiencies} = \frac{\text{organics in inlet} - (\text{organics in outlet} - \text{background})}{\text{organics in inlet}}$$

emission from the boiler were lower when veneer dryer emissions were being incinerated. Organic material removal efficiencies presented in Table 14 were calculated using boiler data corrected for the boiler background organic emissions as determined by runs 3 and 4.

The Dutch oven boiler fuel conditions ranged from poor (wet and dirty) to good. Fuel conditions were good during test runs 1 through 5 and 8, and poor during tests 6 and 7. Boiler steam loads ranged between 40,000 and 70,000 lb/hr. Total organic compound emissions expressed as $lb/10^6$ Btu fired followed no trends related to boiler operating conditions. Heat inputs were calculated using a factor of 1840 SCF $CO_2/10^6$ Btu that is typical of hogged fuel (25).

Boiler steam production efficiencies were reduced when veneer dryer emissions were incinerated. They were poorest when veneer dryer emissions were being incinerated and wet fuel was being fired. Incineration of veneer dryer emissions resulted in an appropriate 10 percent increase in fuel usage at this boiler despite the efficiency benefit associated with a warmer combustion air.

The wood-residue fired boiler investigated in this study was capable of complete destruction of organic compounds in veneer dryer emission when introduced to the unit with unheated combustion air. Boiler total organic compound emission were generally lower when incinerating veneer dryer emissions in the combustion air. Both total organic compounds and condensible organic compounds were destroyed. Destruction of organic emissions was variable, ranging between 69 to 160 percent. The Dutch oven fuel quality or boiler load appeared to have no effect on the boiler organic destruction efficiency. Organic compound destruction efficiencies found at this boiler cannot be extrapolated to other boilers because of possible organic destruction in the boiler in the secondary combustion chamber where sander dust is suspension fired with additional fresh combustion air.

E. Design Considerations and Costs Associated with Incineration of Veneer Dryer Emissions in Wood-Residue Fired Boilers

Existing boilers that have been retrofit to accept veneer dryer emissions for incineration have generally been oversized, inefficiently operated boilers. Generally, these boilers do not have oxygen meters or other means for optimizing firing rates or combustion air usage and therefore tend to be operated with high excess air usage. New boilers being installed at existing or new mills will likely be instrumented for operation at optimum conditions. Incineration of veneer dryer emissions in new fully instrumented boilers will likely affect efficiency of the unit and intial size. Appendix D shows calculations for optimum boiler sizing for a unit dedicated to the production of steam for mills with dryers processing Douglas fir and southern pine derived veneer.

When veneer dryer emissions are used as combustion air in a dedicated boiler the effects of the moisture in the combustion air on boiler operation should be evaluated. The three basic factors of combustion, time, temperature, and turbulence, must be considered. For the residence time in the boiler to remain similar to that when no dryer exhaust gases are being incinerated, and the boiler tubes to be capable of extracting the energy from the flue gases, the combustion box and heat exchange section sizes must be increased to accommodate the volume of moisture introduced. Much of this additional gas volume results from the moisture content of the veneer dryer exhaust gases and an increase in excess air to compensate for reduced oxygen levels in the combustion chamber from dilution with the extra moisture. A greater volume of combustion air and moisture must be heated, thus resulting in a reduction in flame temperature and greater heat losses at the stack. An analysis of the factors affecting combustion, as shown in Appendix D, indicated that adibatic flame temperature is the limiting factor.

The calculations in Appendix D indicated that a mill processing Douglas fir derived veneer and using veneer dryer emissions as combustion air would require a new boiler about 40 percent larger than one where veneer deyer emissions were not incinerated in the unit. A mill processing southern pine derived veneer and using veneer dryer emissions as combustion air would be required to build a boiler about 45 percent larger than if veneer dryer emissions were not incinerated. The larger boiler required for southern pine is a result of the higher moisture content of the veneer dried. A small increase in fuel usage would be required to compensate for heat losses associated with the larger volume of boiler flue gas with an elevated moisture content. The efficiencies gained from recovering heat from the veneer dryer emissions were found to be insufficient to compensate for additional stack heat losses.

Incineration of veneer dryer emission in a wood-residue fired boiler places severe limitations on flexibility of operation of the boiler. The increased mass of gases to be heated reduces flame temperatures and may require burning auxiliary fuel. Continued combustion in a spreader stoker wood-residue fired boiler requires a minimum adibatic flame temperature of 1700°F (25). For inceneration of veneer dryer emissions from drying Douglas fir and southern pine in the example in Appendix D the adibatic flame temperature has been reduced to 1870°F and 1780°F respectively, as compared to 2570°F when veneer dryer emission are not being incinerated. When wood-residue fuel moisture exceeds 50 percent, supplemental fuel firing will be needed to maintain combustion. An example of supplemented fuel firing occurred at mill E when wet fuel was used.

VII SUMMARY

(1) Gaseous organic compounds in veneer dryer emissions can be categorized into two general classes of compounds, (a) terpenes and (b) resin and fatty acids. Terpenes are known to be photochemically reactive and lead to the formation of ozone in the atmosphere. Resin and fatty acids condense into aerosols in the atmosphere and are suspected to be non-photochemically reactive. The uncontrolled emission rates of these compounds from veneer dryers were quantitated using sampling techniques that attempted to separate the compounds into their general classes, as well as measure the total organic emissions.

(2) Particulate and condensible organic compound emissions were measured with a modification of EPA Method 5 known as Oregon Department of Environmental Quality Method 7. ODEQ-7 includes extraction and analysis of the impinger catch.

(3) Total organic compounds were measured with EPA Method 25 preceded by a filter maintained at a temperature greater than 150°C (300°F). The filter removed nonorganic particulate from the sample that interfere with the test. When organics in particulate or aerosol form were present in the stack gases the samples were isokinetically drawn from the stack by attachment of EPA-25 to an EPA Method 5 train with the probe and filter maintained at greater than 325°F.

(4) Noncondensible organic compound emissions were measured with an EPA Method 25 train preceded by a 86°C (190°F) filter. Samples were drawn isokinetically when organic aerosols were present by using an EPA-5 train drawning a sample immediately following the heated filter.

(5) Total organic compound in uncontrolled emissions from steam heated veneer dryers ranged between 0.9 and 3.9 lb as methane/MSF veneer dried on a 3/8 in finished product basis. Total organic compound emissions were less than the sum of condensible and noncondensible organics because of an overlap in the analytical procedures.

(6) Emissions of noncondensible organic compounds can be related to the turpentine content of the veneer being dried and to the dryer type. Typical noncondensible organic emissions from steam heated dryers were 0.8 lb/MSF for Douglas fir, 0.7 lb/MSF for hemlock, and 2.2 lb/MSF for lodgepole pine.

(7) Noncondensible organic compound emissions from wood-residue fired direct heated dryers were higher than found at steam heated dryers and ranged between 1.7 and 3.0 lb/MSF for Douglas fir. It was concluded that condensible organics were partially broken down into lower molecular weight noncondensible compounds when cycled through the blend box following the combustion chamber.

(8) Particulate and condensible organic emissions from steam heated dryers were found to be a function of the veneer species, dryer temperature, and the amount of air passed through the dryer. Particulate and condensible emissions from steam heated and direct gas fired dryers ranged between 0.26 and 4.3 lb/MSF for Douglas fir, 0.07 and 0.20 for white fir, and 0.79 and 4.2 for lodgepole pine.

(9) Wood-residue fired direct heated dryers were found to have particulate and condensible organic emissions ranging between 0.5 and 1.6 lb/MSF. These emissions appeared to be independent of wood species due to the greater influence of ash in the exhaust gas from the combustion of wood.

(10) Veneer dryer emission control devices studied were of two general types, wet collectors and incineration of emissions by use as combustion air in a power boiler. Removal of particulate and condensible organic emissions by wet collectors ranged between 37 and 85 percent. Good condensible organic compound removal by wet collectors appeared to be a function of the ability of the wet collector to capture aerosols, good mist elimination, and scrubber water temperature. Wet collectors were poor at removing noncondensible compounds from exhaust gases, and ranged between a 9 percent increase and 40 percent removal.

(11) Incineration of organic compounds by use of veneer dryer emissions as combustion air appeared to be effective. However, accommodation of the moisture in the dryer exhaust gases limits the boiler operation. Calculations show that a boiler supplying steam to a plywood mill would need to be increased in size by 45 percent to handle the increased gas volume resulting from moisture in the dryer exhaust gases. The additional moisture in the combustion air limits the amount of moisture allowed in the fuel to less than 50 percent on a wet basis, if supplemental fuel use to maintain combustion is to be avoided.

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APPENDIX A

ODEQ-7 PROCEDURES

STATE OF OREGON

DEPARTMENT OF ENVIRONMENTAL QUALITY

Source Sampling Method 7

Sampling Condensible Emissions From Stationary Sources

1. Principle and Applicability

   1.1 Principle: Particulate matter including condensible gases is withdrawn isokinetically from a flowing gas stream. The particulate matter is determined gravimetrically after extraction with organic solvents and evaporation.

   1.2 Applicability: This method is applicable to stationary sources whose primary emissions are condensible gases. It should be considered a modification of Source Sampling Method 5 and applied only when directed to do so by the Department.

2. Sampling Apparatus (Figure 7-1)

   2.1 The probe, sampling train, and metering system are the same as outlined in 3. Sampling Apparatus of Source Sampling Method 5 with the following exceptions:

      2.1.1 The heated filter and cyclone are optional, but should be used if significant quantities of solid particulate are present.

      2.1.2 An unheated glass fiber filter is placed between the third and fourth impingers.

3. Sample Recovery Apparatus

   3.1 The sample recovery apparatus is the same as outlined in 4. Sample Recovery Apparatus of Source Sampling Method 5.

4. Reagents

   4.1 The reagents are the same as outlined in 5. Reagents of Source Sampling Method 5.

5. Sampling Train Preparation

   5.1 The sampling train preparation is the same as outlined in 6. Sampling Train Preparation of Source Sampling Method 5 with the following exception:

      5.1.1 Insert numbered and weighed filters into each of the front (if used) and rear filter holders.

6. Pretest Preparations and Leak Check

6.1 The pretest preparations and leak check are the same as outlined in Sections 7 and 8 of Source Sampling Method 5.

7. Condensible Particulate Train Operations

7.1 The train operation is the same as outlined in Section 9 of Source Sampling Method 5. It is important to note that the gas temperature leaving the last impinger must not exceed 70°F as temperatures above this may cause loss of condensible material by revolatilization.

8. Condensible Particulate Train Cleanup

8.1 Cleanup should be performed in an area free of wind and airborne dust which may contaminate the sample or cause sample loss. If possible, the train should be cleaned in a laboratory.

8.2 After the probe and nozzle have cooled, remove the end seals and brush while rinsing with acetone into a suitable marked container.

Note: Exercise caution so that none of the rinse is lost and no extraneous material enters the rinse (such as from the pitot tubes or condensed material from the outside of the nozzle).

8.3 Should it be necessary to clean the train in the field, use the following procedure:

8.3.1 Thoroughly rinse all sample exposed surfaces prior to the front filter support, with acetone. Remove any adhering particles with the aid of a rubber policeman. Place the rinsings in the probe rinse bottle. If the front filter is not used, all sample exposed surfaces prior to the first impinger should be included in this rinse.

8.3.2 Remove the front (if used) and rear filters, place in a petri dish and seal. Since a heavy loading of condensible material on the rear filter may leave a residue in the filter container which would necessitate removal with solvent, glass petri dishes are preferred.

8.3.3 Measure and record the volume (or weight) increase of the first three impingers to the nearest 1 ml (or 1 g) and transfer their contents to a labeled container. Rinse the impingers and interconnects with distilled water and add to the container.

8.3.4 Rinse all sample exposed glassware between the front filter (if used) or the first impinger (if the front filter is not used) and the fourth impinger (including glass filter frits) with acetone and place in a suitable marked container. If the moisture condensate in Section 8.3.3 was determined by use of a graduated container, it should also be rinsed with acetone and the rinse added to the impinger rinse container.

8.3.5 Determine the weight gain of the silica gel in the fourth impinger and record. Alternately transfer the silica gel quantatively to an air tight container to be weighed in the laboratory.

8.3.6 Collected samples should be analyzed within one week of collection in order to prevent any possibility of biological or chemical degradation.

9. Analysis

9.1 Desiccate the filter(s) at 70°F or less in the field container for 24 hours and weigh .

Note: In some cases, desiccation may give rise to a slow vaporization of the condensible material. Therefore it is not recommended that an attempt to weigh to constant weight be made.

9.2 Transfer the acetone rinse (Section 8.3.1) into a tared beaker or evaporating dish. Rinse the container with acetone (police to remove particulate) and add the rinse to the beaker. Evaporate the solvent at 70°F or less and laboratory pressure, desiccate 24 hours and weigh . See note in Section 9.1.

9.3 Transfer the acetone rinse from the impingers (Section 8.3.4) to a tared beaker or evaporating dish and treat as in Section 9.2.

9.4 Transfer the water (Section 8.3.3) to a separatory funnel. Rinse the container with distilled water and add to the separatory funnel. Add 25 ml of chloroform to the separatory funnel, stopper and vigorously shake 1 minute, let separate and transfer the chloroform (lower layer) into a tared beaker or evaporating dish. Repeat twice more. Repeat the above extraction using three 25 ml portions of diethyl ether in place of the chloroform. Transfer the either (upper layer) to the same container as used to contain the chloroform.

Note: It is necessary to rinse the field container for water (if used) with solvent. This rinse may be made using the extracting reagents in which case it is added to the impinger extract container or with acetone in which case it is added to the container in Section 9.3.

9.5 Transfer the remaining water from the separatory funnel to a tared beaker or evaporating dish and evaporate at 105°C . Desiccate for 24 hours and weight.

9.6 Evaporate the combined impinger water extracts from Section 9.4 at 70°F or less and laboratory pressure, desiccate for 24 hours and weigh . See note in Section 9.1.

9.7 Evaporate portions of the solvents used in a manner similar to the sample evaporations to determine the solvent blanks.

9.8 Record all laboratory data in the Laboratory Data Reporting Sheet, Figure 5-9, Source Sampling Method 5.

10. Calculations

10.1 The calculations are the same as outlined in 14. Calculations of Source Sampling Method 5.

11. Minimum Acceptable Test Requirements

11.1 The minimum acceptable test requirements are the same as outlined in 15. Minimum Acceptable Test Requirements of Source Sampling Method 5.

12. Minimum Test Report Information

12.1 The test report should contain sufficient information about the source to accurately define its operation during the test. Also sufficient data and calculations shall be included to document the source test results.

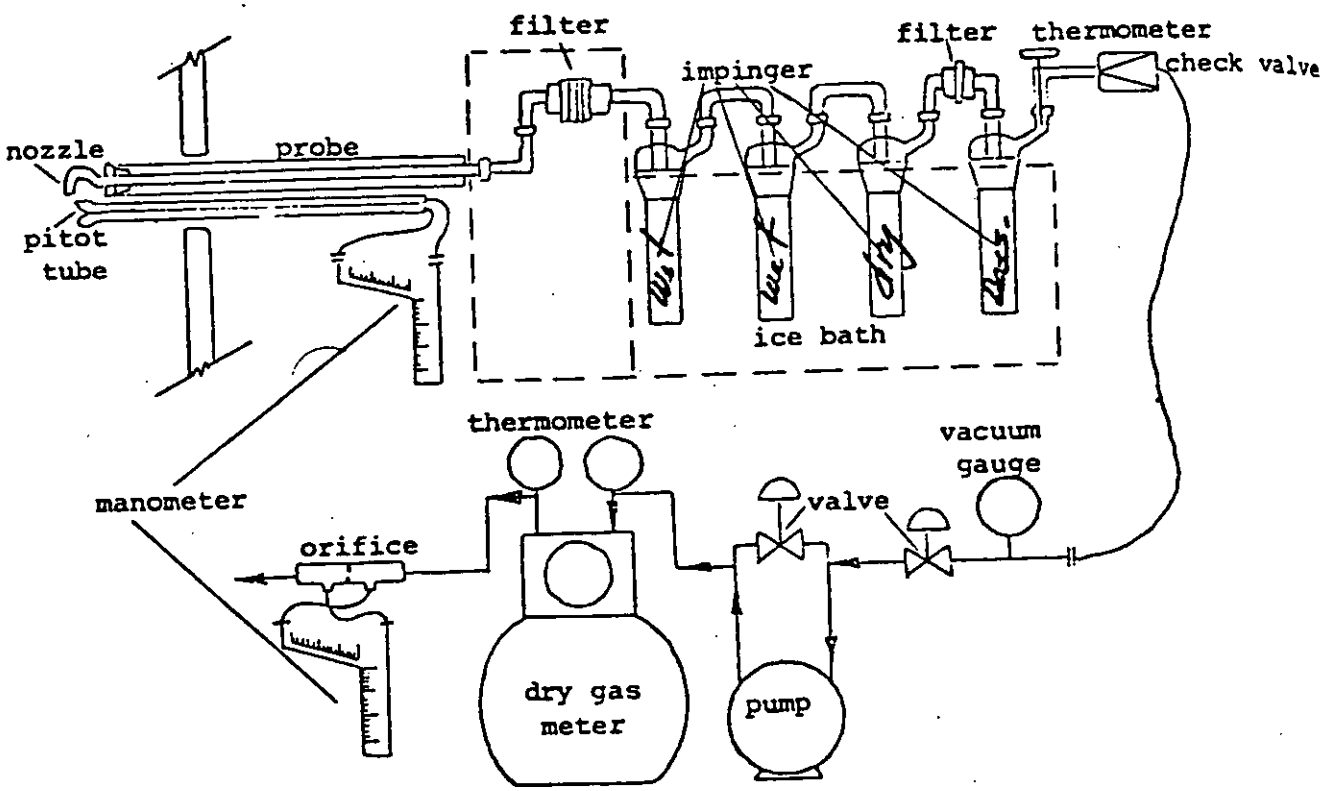
filter
filter
thermometer
check valve
impinger
nozzle
probe
pitot
tube
ice bath
thermometer
vacuum
gauge
manometer
valve
orifice
dry gas
meter
pump

Figure 7-1

STATE OF OREGON

DEPARTMENT OF ENVIRONMENTAL QUALITY

Source Sampling Method 5

Sampling Particulate Emissions From Stationary Sources

1. Principle and Applicability

   1.1 Principle. Particulate matter including condensible gases are withdrawn isokinetically from a flowing gas stream. The particulate matter is determined gravimetrically after removal of combined water.

   1.2 Applicability. This method is applicable to the determination of particulate emissions from stationary sources except those sources for which specified sampling methods have been devised and are on file with the Department.

2. Acceptability. Results of this method will be accepted as demonstration of compliance (or non-compliance) provided that the methods included or referenced in this procedure are strictly adhered to and a report containing at least the minimum amount of information regarding the source is included as described in Sections 15 & 16. Deviations from the procedures described herein will be permitted only if permission from the Department is obtained in writing in advance of the tests.

3. Sampling Apparatus (Figure 5-1)

   3.1 Probe - Pyrex® glass lined with heating system capable of maintaining sample gas temperature at 250° F at its exit end during sampling. Probes longer than six (6) feet which are to be used at temperatures of 600° F or less may have liners constructed of seamless 316 stainless steel or Incology 825[1]. Probes for temperatures in excess of 600° F may be constructed of Borosilicate glass (limit 900° F) or Quartz glass (limit 1650° F). Probes for temperatures in excess of 1650° F must be approved by the Department before use.

   3.2 Probe Nozzle - Constructed of stainless steel (316) with an external taper 30° or less to a sharp leading edge. The inside diameter of the nozzle shall be constant throughout the length of the nozzle. The wall thickness of the nozzle shall be less than or equal to 0.065 in. and a straight run of at least two times the internal diameter shall be provided between the leading edge and the first bend or point of disturbance. The nozzle shall be connected to the probe liner in such a way as to provide an airtight seal with no exposed threads or gaps to collect particulate matter. Calibration of nozzle is covered in Section 13.4.

3.3 Pitot tube - Type S or equivalent attached to the probe. The probe nozzle and face openings of the pitot tube shall be adjacent and parallel to each other (not necessarily in the same plane) and the free space between the nozzle and the pitot tube shall be at least 0.5 in. Calibration of the pitot tube is covered in Section 13.1.

3.4 Differential pressure gauges - Inclined or vertical fluid manometer capable of measuring the pressure differential to within 10% of the minimum measured value. Below 0.1 in. H_2O gauge, micromanometers with sufficient sensitivities shall be used. Other differential pressure measuring devices may be used provided they are calibrated against a fluid manometer and are adequately sensitive.

3.5 Cyclone (optional) - Miniature glass cyclone used when heavy concentrations of particulate are expected. The cyclone will extend the time a filter can be used before plugging.

3.6 Filter holder - Pyrex® glass with a glass frit filter support and silicone rubber gasket. The holder shall provide a positive seal against leakage from the outside or around the filter.

3.7 Filter heating system - Capable of maintaining a temperature of 250°F around the filter holder. A temperature gauge shall be provided to monitor this temperature.

3.8 Impingers - Greenburg-Smith design. The first, third and fourth may be modified by replacing the tip with a 1/2 inch ID glass tube extending to within 1/2 inch of the bottom of the flask. The second impinger shall have the standard tip installed.

Note: All connections between the probe and last impinger shall be made with glass ball joints.

3.9 Metering system - Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 5°F dry gas meter accurate to within ± 1% and flow measuring device (orifice or rotometer) enabling isokinetic sampling to be maintained.

3.10 Barometer - Mercury, aneroid or other type capable of measuring atmospheric pressure to within 0.1 in. Hg. If the barometric pressure is to be obtained from a nearby weather bureau station, the true station pressure (not corrected for elevation) must be obtained and an adjustment for elevations differences between the station and sampling site must be applied.

3.11 Temperature and pressure measurement equipment - As described in Source Sampling Method 2.

3.12 Gas analyzer - As described in Source Sampling Method 3.

3.13 Nomograph

3.14 Timer - Integrating type, accurate, readable to the nearest 5 seconds per hour.

4. Sample Recovery Apparatus

4.1 Probe brush and nozzle brush - nylon bristle or equivalent at least as long as the probe liner and the nozzle respectively.

4.2 Wash bottles - inert to the solvent used in them (usually acetone).

4.3 Sample storage containers - glass with glass or Teflon[1] lined cap or other material which is leak tight, resistant to chemical attack from acetone and allows complete recovery of particulate matter.

4.4 Petri dishes - for filter samples, glass or plastic. Alternately, individual paper envlopes with waxed paper liners may be used, but tare and final weights should not be included in the weight of the envelop or liner.

4.5 Graduated cyliner and/or balance - to measure condensed moisture to within 1 ml or 1 g. Graduate cylinders shall have subdivisions of 2 ml or less and balances shall be sensitive to 1 g.

4.6 Plastic storage containers - air tight containers to store silica gel unless it is weighed at the sampling site or transported to the laboratory in the impinger.

4.7 Rubber policeman - to aid in recovering sample from the train previous to the filter.

4.8 Dessicator - laboratory type using Drierite [1], indicating dessicant or equivalent.

4.9 Analytical balance - accurate and sensitive to $\pm$ 0.1 mg.

5. Reagents

5.0 Separating funnel - 500-1000 ml with Teflon [1] stopcock and plug.

5.1 Beakers - 250 & 400 Pyrex [1] or equivalent.

5.2 Filters - glass fiber filters, without organic binder, of near neutral pH, free of pinhole leaks, and exhibiting at least 99.95% efficiency on 0.3 micron DOP smoke particles. MSA-1160BH or equivalent, individually numbered for identification and pre-weighed as described in Section 6.1.

5.3 Silica gel - indicating type 6-16 mesh, dried at 175°C (350°F) for 2 hours if previously used.

5.4 Water - distilled, with a maximum total residue content of 0.001%. (0.01 mg/ml).

5.5 Acetone - reagents grade with a maximum total residue content of 0.001%. (0.01 mg/ml)

5.6 Crushed ice - any grade, crushed fine enough to provide efficient cooling for the impingers.

5.7 Stopcock grease - acetone resistant, heat stable, silicone grease.

5.8 Diethyl ether - reagent grade with a maximum total residue content of 0.001%. (0.01 mg/ml)

5.9 Chloroform - reagent grade with a maximum residue content of 0.001%. (0.01 mg/ml)

6. Sampling Train Preparation

6.1 Weigh numbered glass fiber filter paper to the nearest 0.1 mg on an analytical balance after dessication over Drierite for 24 hours or more.

6.2 Insert the filter into the filter holder and assemble taking care not to tear orbend the filter. Tighten the filter holder sufficiently to prevent leaks.

6.3 Add 100 $\pm$ 1 ml of distilled water to each of the first two impingers.

6.4 Add approximately 200 g of accurately weighed silica gel ($\pm$ 1 g) to the fourth impinger.

6.5 Alternately after charging each of the impingers with the appropriate material, weigh the impinger and contents on balance to the nearest 1 g.

6.6 Assemble the train as shown in Figure 1 and check for leaks as in Section 8.

6.7 Seal the train with aluminum foil, a blanked connector or some other means to prevent contamination.

7. Pretest Preparations

7.1 Select a sampling site and the minimum number of traverse points as described in Source Sampling Method 1.

7.2 Determine the approximate moisture content as described in Source Sampling Method 4.

7.3 Make a preliminary pitot traverse to determine the maximum, minimum, and average pitot reading, duct temperature, and static pressure as described in Source Sampling Method 2.

7.4 Choose a nozzle size based on the range of pitot readings as described in Section 12 such that it is not necessary to change the nozzle size in order to maintain the isokinetic sampling rates for all traverse points.

7.5 Clean the chosen nozzle and probe (the shortest available which will reach all the traverse points), assemble and seal each end with aluminum foil to prevent contamination.

7.6 Attach the probe to the sample case, attach the electrical and hose connections, and turn on the probe and filter heating system. Adjust the heater controls to maintain the appropriate temperatures.

8. Leak Check

8.1 Plug the inlet to the filter.

8.2 With the fine flow adjustment (bypass) completely open, open the coarse flow adjustment completely and adjust to a vacuum of 15 in. Hg by closing the fine flow adjustment.

8.3 After sufficient time has elapsed for stabilization, measure the leakage rate for 1 minute or more and record. A leakage rate of less than 0.02 cfm at 15 in. Hg is acceptable. Use acetone resistant stopcock grease on impingers and ball joints if necessary to seal against leaks.

8.4 Slowly remove the plug from the filter inlet and immediately close the coarse flow adjustment.

9. Particulate Train Operation

9.1 Each point should be sampled a minimum of 2 minutes and a complete set of data readings should be taken at every point. If each point is sampled more than 5 minutes, a complete set of data readings should be taken at equal intervals during the sampling of every point but not less frequent than every five minutes.

9.2 Pack crushed ice around the impingers, turn on the probe heater and adjust so that the gases leaving the probe are 250°F. Add ice occasionally during the test in order to keep the temperature of the gas leaving the train at 70°F or less.

9.3 Position the probe nozzle at the first traverse point (taking care not to allow the nozzle to touch the stack walls) and block off the openings around the probe. Record the initial gas meter reading, temperatures, static pressure and pitot reading on the Particulate Field Data Sheet (Figure 5-5).

> Note: The probe should never be left in the stack when not sampling as particulate will be collected in the nozzle.

9.4 Calculate (as described in Section 12) and record the desired orifice setting, open the coarse flow adjustment and immediately start the timer.

9.5 As rapidly as possible, adjust the orifice reading using the coarse and fine flow adjustments to the desired reading.

9.6 At the end of the first sampling point (or not more than 30 seconds before) reposition the probe nozzle at the next sampling point.

Note the gas meter reading exactly at the end of the first time interval.

9.7 After the pitot readings have stablized, note the pitot reading, calculate the desired orifice setting, and adjust with the fine and coarse flow adjustments to the new setting. This should be done as rapidly as possible to avoid anisokinetic sampling.

9.8 Continue the above steps until all traverse points have been sampled an equal interval of time (except adjusted traverse points as described in Source Sampling Method 1.)

9.9 At the conclusion of the run, close the coarse flow adjustment, note the final gas meter reading and temperatures and withdraw the probe completely.

9.10 Seal the nozzle with aluminum foil as soon as it cools sufficiently to do so, disconnect the probe from the sample case, seal all other openings and transport to the cleanup (or storage) area.

9.11 Throughout the sample run, collect an integrated gas sample for composite analysis as described in Source Sampling Method 3.

9.12 Under no circumstances disconnect or loosen any part of the airtight train until the probe has been completely removed from the stack.

10. Particulate Train Cleanup

10.1 Cleanup should be performed in an area free of wind and airborne dust which may contaminate the sample or cause sample loss. If possible, the train should be cleaned in a laboratory.

10.2 After the probe and nozzle have cooled, remove the end seals and brush while rinsing with acetone into a suitable container (labelled).

Note: Exercise caution so that none of the rinse is lost and no extraneous material enters the rinse (such as from the pitot tubes).

10.3 Should it be necessary to clean the train in the field, use the following procedure:

10.3.1 Rinse all sample exposed surfaces prior to the filter (including the front half of the filter holder) with acetone. Remove any adhering particles with the aid of a rubber policeman. Place the rinsings in the probe rinse bottle.

10.3.2 Remove the filter without disturbing the particulate cake, place in a petri dish and seal.

10.3.3 Measure and record the volume (or weight) increase of the first three impingers and transfer their contents into a labelled container. Rinse the impingers and innerconnects with distilled water and add to the container.

10.3.4 Rinse all sample exposed glassware between the filter (excluding the glass frit filter support) and the fourth impinger with acetone and store in a suitable marked container.

10.3.5 Determine the weight gain of the silica gel in the fourth impinger and record. Alternately transfer the silica gel quantitatively to an airtight container to be weighed in the laboratory.

10.3.6 Collected samples should be analyzed within one week of collection in order to prevent any possibility of biological or chemical degeneration.

11. Analysis

11.1 Dessicate the filter (in the field container) for 24 hours and weigh to constant weight.

11.2 Transfer the acetone rinse (Section 10.3.1) into a tared beaker or evaporating dish. Be sure all particulate is removed from the container. Evaporate the solvent at laboratory temperature and pressure, dessicate for 24 hours and weigh to constant weight.

11.3 Transfer the acetone rinse from the back-half (Section 10.3.4) to a tared beaker or weighing dish. Evaporate as in 11.2 and weigh to constant weight.

11.4 Transfer the water in the impingers to a separatory funnel (Teflon[1] stoppered). Rinse the container withdistilled water and add to the separatory funnel. Stopper and vigorously shake the separatory funnel 1 minute, let separate and transfer the chloroform (lower layer) into a tared beaker or evaporating dish. Repeat twice more. Repeat the above procedure using three 25 ml portions of diethyl ether in place of the chloroform.

11.5 Transfer the remaining water in the separatory funnel to a tared beaker or evaporating dish and evaporate at 105°C. Dessicate for 24 hours and weight to constant weight.

11.6 Evaporate the combined impinger water extracts from Section 11.4 at laboratory temperature and pressure, dessicate for 24 hours and weigh to constant weight.

11.7 Evaporate portions of the solvents used in a manner similar to the sample evaporation to determine the solvent blanks.

11.8 Record all laboratory data on the Laboratory Data Reporting Sheet, Figure 5-9.

12. Nomograph Operation

12.1 Correction factor

12.1.1 Determine ΔH@ for the orifice as described in the calibration

12.1.2 Estimate the probable meter temperature, Tm, often 20°F above ambient temperature, H_2O in stack gas, and Pa/Pm (ratio of absolute stack pressure to absolute meter pressure) as described in Section 7.

12.1.3 Determine the correction factor "C" using the correction factor nomograph, Figure 5-2a, as described on the nomograph.

12.2 Operating Nomograph

12.2.1 Adjust the sliding scale on the operating nomograph, Figure 5-2b, such that the "C" factor determined in Section 12.1.3 is opposite Reference Point A.

12.2.2 Using the preliminary pitot traverse data and duct temperature determined in Section 7, draw a line from T_s to the values of ΔP and select a suitable D (nozzle diameter) from the probe tip diameter scale.

12.2.3 Draw a line from T_s through D (actual diameter of nozzle to be used) and note where the line crosses the ΔP scale.

12.2.4 Draw a line from the ΔP obtained in 12.2.3 to Reference Point B on the ΔH scale and note where the line crosses the K factor scale. This point should be marked for future reference.

12.2.5 During sampling, align the pitot reading, ΔP, with the K factor setting, Section 12.2.4, to obtain the desired ΔH.

12.2.6 If T_s (absolute) changes by more than 50°F the K factor should be recalculated starting with 12.2.3.

13. Calibration

13.1 Orifice and dry gas meter

13.1.1 Connect the components as shown in Figure 5-3. The wet test meter is a 1 of per revolution with ± 1% accuracy and capable of operating at a rate comparable to the expected sampling rate.

13.1.2 Run the pump about 15 minutes at an orifice reading of about 0.5 in. H_2O to allow the dry gas meter and pump to warm up and to wet all interior surfaces of the wet test meter.

13.1.3 Gather the information as required in Figure 5-4.

13.1.4 Calculate γ and $\Delta H@$ as described in Figure 5-4. If an average γ of 1.00 $\pm$ 0.01 is not obtained, the dry gas meter must be adjusted. If an average $\Delta H@$ of 1.84 $\pm$ 0.25 is not obtained, the orifice opening should be enlarged or replaced. Additionally the $\Delta H@$ should not vary more than $\pm$ 0.15 over the range of operation of 0.5 to 8 inches of H_2O.

13.1.5 Calibrate the orifice and dry gas meter every month or after every 5 tests whichever occurs first.

13.2 Temperature gauges

13.2.1 Check temperature gauges against mercury-in glass thermometers of certified accuracy or against suitable temperature standards (boiling or freezing points) at least yearly.

13.3 Probe Nozzle

13.3.1 Measure the inside nozzle diameter on at least 10 different diameters - to the nearest 0.001 inch using a micrometer or caliper. The nozzle diameter is the average of these readings to the nearest 0.001 inches.

13.3.2 The largest deviation from the average should not exceed $\pm$ 1% of the average diameter.

13.3.3 Calibrate the nozzle at least after every test.

14. Calculations

14.1 Gas velocity

14.1.1 Calculate the average gas velocity, V_s, from the pitot tube readings and gas temperatures using equation 5-2

$$(V_s)avg = \frac{K_p C_p}{P_s M_s} \sqrt{(\Delta P_s T_s)avg} \qquad (5\text{-}2)$$

Where the symbols and units are the same for equation 2-2 in Source Sampling Method 2.

14.2 Gas volumetric flow rate

14.2.1 Calculate the volumetric flow rate of the gas from the duct area and the average gas velocity using equation 5-3

$$q_s = \frac{0.123 A_s (V_s)_{avg} (1-Bwo) P_s}{T_s} \qquad (5\text{-}3)$$

where the symbols and units are the same as equation (2-3) in Source Sampling Method 2.

14.3 Dry gas volume

14.3.1 Calculate the volume of gas sampled using equation 5-4

$$Q_d = \frac{17.650_m \left(P_o + \frac{\Delta H}{13.6}\right)}{T_m} \qquad (5\text{-}4)$$

where Q_d = volume of gas samples, SDCF

Q_m = volume of gas through meter (meter conditions), CF

P_o = barometric pressure, absolute, in. Hg.

ΔH = average pressure drop across the orifice, in. H_2O

T_m = average dry gas meter temperature, ^oR

14.3.2 In the event the gas passing through the dry gas meter was not dry, the above equation must be multiplied by $(1-B_{wm})$ where B_{wm} is the volume fraction of water in the metered gas (assume saturation at the temperature of the last impinger).

14.4 Moisture content of duct gas

14.4.1 Calculate the moisture content of the duct gas from the total volume of water vapor condensed using equations (5-5), (5-6), and (5-7).

$$Q_v = 0.0474\ V_v \qquad (5\text{-}5)$$

where Q_v = volume occupied by water vapor, SCF

V_v = volume of water condensed in impingers and on silica gel, g or ml.

$$mv = \frac{100\ Q_v}{Q_d + Q_v} \qquad (5\text{-}6)$$

where mv = volume percent of moisture in the sampled gas.

$$m_d = \frac{Q_d}{Q_d + Q_v} = 1 - \frac{mv}{100} \qquad (5\text{-}7)$$

where md = volume fraction of dry gas in the sampled gas

14.5 Calculate the molecular weight of the wet gas using the volume fraction of dry gas and the dry molecular weight using equation 5-8.

$$M_s = m_d M_d + 18\ (1-m_d) \qquad (5\text{-}8)$$

where M_s = molecular weight of the wet stack gas, lb/lb mole

Md = molecular weight of the dry stack gas as defined in Source Sampling Method 3, equation (3-2)

14.6 Calculate the total particulate grain loading and correct to 12% carbon dioxide (when necessary) from the volume of gas sampled, the total weight of particulate sample and the % CO_2 using equation 5-9, and 5-10.

$$C_g = \frac{0.0154\ W}{Q_d} \qquad (5\text{-}9)$$

where C_g = total particulate grain loading, gr, scf

W = weight of particulate sample, mg

$$C'_g = \frac{12\ C_g}{\%\ CO_2}$$

where C'_g = total particulate grain loading corrected to 12% CO_2, gr/sdcf @ 12 % CO_2 (5-10)

$\%CO_2$ = percent by volume carbon dioxide as determined in Source Sampling Method 3.

14.7 Calculate the total particulate emission rate from the total particulate grain loading and the volumetric flow rate using equation 5-11

$$C_t = 0.00857\ C_g q_s \qquad (5\text{-}11)$$

where C_t = total particulate emission rate, lbs/hr

q_s = Volumetric flow rate in duct, DSCFM as determined in Source Sampling Method 2.

14.8 Calculate the percent of isokinetic sampling rate from equation 5-12.

$$I = \frac{1039\ T_s Q_d}{V_s P_s m_d D_n^2 t} \qquad (5\text{-}12)$$

where I = Percent of isokinetic sampling rate

T_s = Average stack temperature, ^{o}R

P_s = Average stack absolute pressure, in. Hg

D_n = Average nozzle inside diameter, in.

t = Total sampling time, min.

Q_d = Volume of gas sampled, SDCF

V_s = Average gas velocity, FPM

m_d = Volume fraction of dry gas

15. Minimum Acceptable Test Requirements

15.1 In order for a source test by this method to be acceptable as sufficiently accurate, the following requirements must be met unless otherwise indicated by the Department in writing:

15.1.1 A minimum sample volume of 60 SDCF of gas per run must be sampled.

15.1.2 A minimum run time of 60 minutes on continuous operations or one complete cycle covering at least 60 minutes on cyclic operations. A minimum of two runs per test is required.

15.1.3 The Department is notified in advance of all source tests so that it may have an observer present if desired.

15.1.4 All equipment used in the test shall be as specified in Section 3,4, and 5.

15.1.5 All equipment used in the test shall be calibrated at the specified interval or more often and the calibration data and results included in the test report.

15.1.6 Accurate description of the sampling site.

15.1.7 Sufficient data to confirm that the sampling rate was within $\pm$ 10% of isokinetic.

16. Minimum Test Report Information - the following information concerning the source shall be included in the source test report.

16.1 Boilers

16.1.1 Name of manufacturer, nameplate capacity, and installation date of boiler and associated control equipment.

16.1.2 Control equipment on boiler (including cinder reinjection equipment).

16.1.3 Steam production rate, steam pressure and range of steam flow where possible. Use of a steam flow integrater is desirable.

16.1.4 Fuel composition (including estimated moisture content where applicable).

16.1.5 Opacity readings during or immediately after test by a certified reader.

16.2 Asphalt Plants (See Note 1)

16.2.1 Type, location and capacity of plant.

16.2.2 Control Equipment present.

16.2.3 Pressure drop across control equipment, water pressure on scrubber nozzles when present.

16.2.4 Production rate and type of mix during test.

16.2.5 Dryer fuel and firing rate.

16.2.6 Mix temperature (on drum mix plants)

16.2.7 Fines content of total aggregate feed.

16.2.8 Opacity readings during or immediately after test by a certified observer.

16.2.9 Photographs of plant in operation including plume after steam dissipation.

16.2.10 Special testing or production problems encountered.

fied

NOTE 1: The source test requirements for asphalt plants constructed or modified after June 11, 1973 differ from this method in that only the particulate collected in the front half of the train (from the probe to the filter inclusive) is used in the grain loading and emission rate calculations. The impinger section may be replaced with a suitable condenser system.

APPENDIX B

EPA METHOD 25 PROCEDURES

I EPA METHOD SAMPLING AND ANALYSIS METHOD

The procedure used for data collection was similar EPA Method 25 procedures. The principle of the procedure is to separate organic compounds at the time of collection into high and low molecular weight fractions using a cold trap (-78°C). The light components are captured in an evacuated tank. The trap containing condensed organics is burned to convert organics to CO_2 for analysis in the laboratory. The light organics captured in the evacuated tank are separated on a chromatographic column yielding concentrations for CO, CH_4, CO_2, C_2H_6 and C_2H_4. All other organics are eluted in one peak. Summation of the trap and tank organic results gives TGNMO stack concentrations. All results are reported as methane. Alterations to EPA Method 25 as stated in the Federal Register include taking a filtered sample, duplicate analysis, using oversize traps and tanks, a modified burnout system that prevents loss of sample from organic material condensation after being burned out of the trap, and various other minor changes to improve the accuracy of the method.

A. Sampling

Anisokinetic field samples were taken simultaneously in duplicate through separate 1/4 in. stainless steel probes when sampling stack gases that had temperatures higher than 150°C (300°F) and a total gaseous nonmethane organic analysis was desired. The stack end of the probes were filled with glass wool before each sample was drawn to prevent collection of particulates in the traps. Six feet of 1.8 in. stainless steel tubing ran from the probes to the traps which were submerged in granular dry ice. The connection between the probe and sampling line was kept inside the stack during sampling. Schematics of the trap construction and sampling assembly are presented in Figures B-1 and B-2 respectively. Condensible organics and water vapor were captured in the traps. From the traps the gas flowed through a rotometer, a flow control valve, and into a 17-liter evacuated stainless steel tank.

All screw connections in the sampling system were checked for leaks in the field before sampling by pressurizing with air at 30 psi and soaking the joints individually with soapy water. Leaks detected were eliminated prior to sampling.

Sampling flow rates were set at about 230 ml/min so that about 13 liters of sample were collected in the one hour sampling period. When a trap froze due to condensation of stack moisture, the trap inlet was heated momentarily with a propane torch to melt the ice. The sampling system was watched closely to maintain the proper flow rate. After sampling, the trap and 6-foot section of line to the probe were capped and transported to the laboratory packed in dry ice. Tank pressures were measured before and after sampling to determine sample size. Orsat analyses were made for CO_2 and O_2 during sampling.

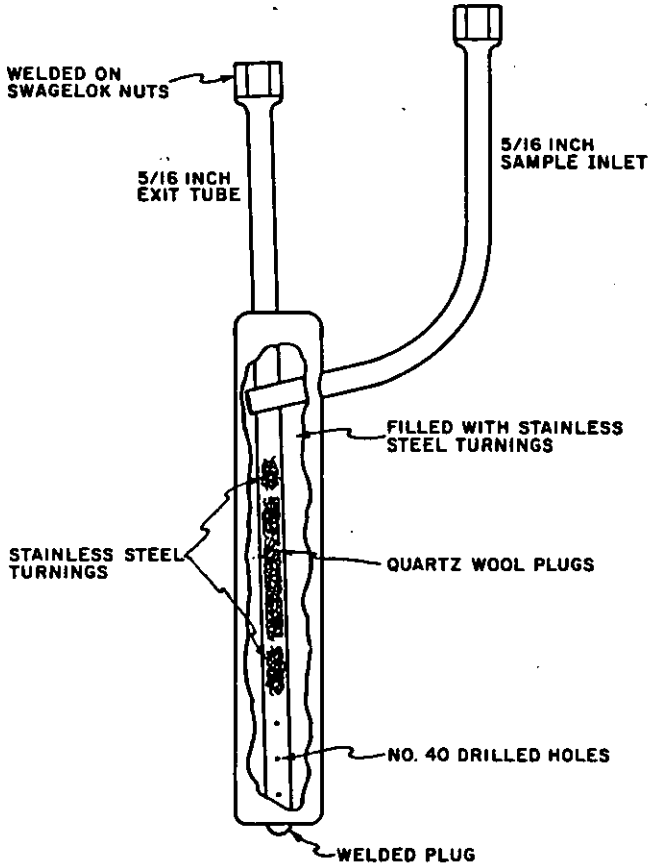

FIGURE B-1

CONDENSATE TRAP

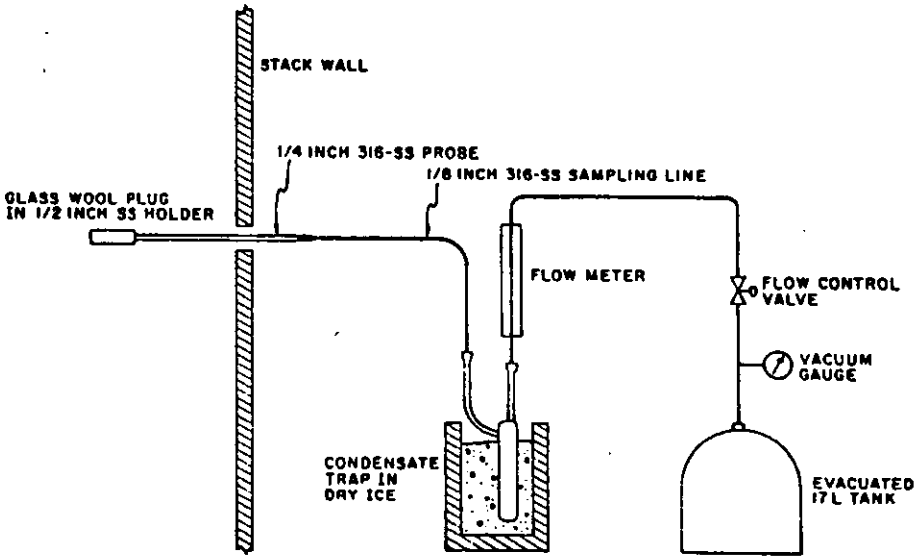

FIGURE B-2

TGNMO SAMPLING TRAIN

When anisokinetic samples that had been preceded by a 88°C (190°F) filter were desired to give results for noncondensible organic compounds. The samples were drawn through a sample conditioning device shown in Figure B-3. The sample is drawn into a 2-1/2 ft long, 3/8 in. diameter stainless steel insulated probe. The probe is equipped with a heater to maintain the temperature at 88°C (190°F) if needed. A 3/8 in Whatman 934 A-H glass filter supported by two stainless steel screens. The temperature of the gas leaving the filter was monitored with a thermometer. A heated tee was provided for connection of two EPA-25 sampling trains.

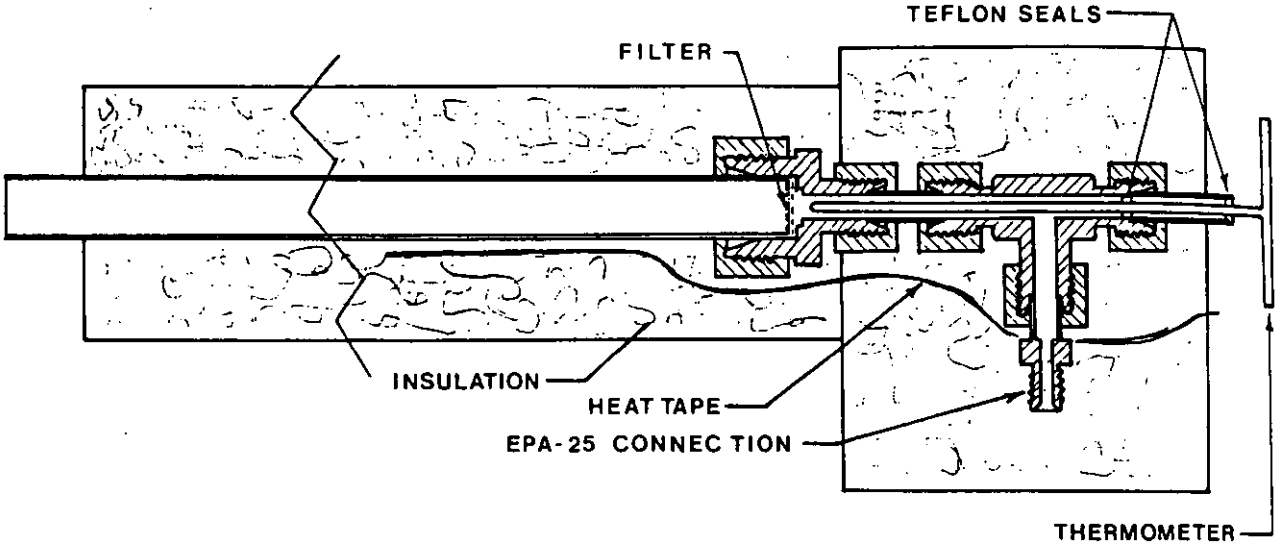

FIGURE B-3

SAMPLE CONDITIONING PROBE FOR
88°C (190°F) FILTER FOR EPA METHOD 25 SAMPLES

When filtered isokinetic samples were required, the EPA-25 samples were taken as a slip stream from an EPA-25 particulate sampling train just following the hot filter. The temperature of the gas leaving the filter was measured, and the probe and filter oven temperature controls set to produce the desired filter temperature.

B. Sample Preparation

When the samples were returned to the laboratory, each trap and sample tank combination used in the field was connected to the trap burning system in the sequence of trap, oxidation tube furnace, U-tube water trap packed in dry ice, and IR analyzer and sampling vessel as shown in Figure B-4. The stack gases remaining in the trap were flushed into the tank with carbon compound free air (hereafter referred to as zero air) at a rate of 100 cc/min. When all the CO_2 was flushed and into the tank as indicated by the IR detector response, the tank was pressurized with zero air via a trap bypass.

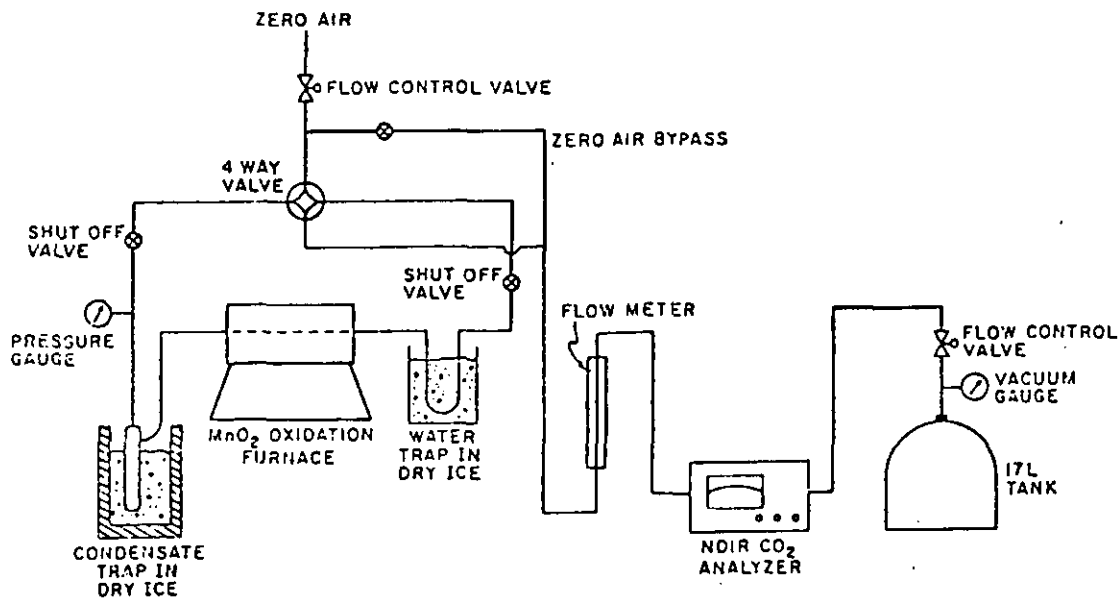

FIGURE B-4

TRAP BURNOUT SYSTEM, FLUSH MODE

Following sampling tank pressurization, a 4-liter stainless steel vessel evacuated to a minimum of 28 in. Hg was then attached in the tank's place. Zero air was passed through the sampling line and trap while they were heated to a dull red color with an acetylene torch. A metering valve in the zero air supply line controlled the pressure in the trap to 15 to 25 in. Hg while flow was controlled by a valve on the evacuated vessel. Pressure in the trap can increase rapidly due to boiling of condensed water. The trap was monitored to avoid excess pressures that may result in leaks.

Care was taken that the sampling line, trap, and lines to the oxidizer were heated sequentially so that incompletely oxidized organics that might recondense in the system would be revolatilized. Each trap was burned until the CO_2 in the carrier gas, as shown by the IR analyzer, had returned to baseline. The vessel was then pressurized to less than 5 in. Hg. The volume of water in the water trap was measured and recorded. Stack moisture content was calculated from this data.

Zero air was prepared by further purifying zero grade air from cylinders. Air from the cylinder was passed over air oxidation catalyst to oxidize organics to carbon dioxide removal. The nitrogen carrier has used for the chromatographic column was cleaned by passing through a molecular sieve and through a catalytic oxidation column. Trace quantities of carbon dioxide in the nitrogen carrier has do not interfere with the analysis.

C. Sample Analysis

The analysis system components consisted of an injection port with an inert septum, a silicon SF-96 on Chromosorb W/Porapak Q column operated at -78°C, -30°C, 25°C, and 100°C with back flush capability, a MnO_2 oxidation furnace operated at 600°C for oxidation of the CH_4, CO, and organics to CO_2, and hydrogen addition to the nitrogen carrier at a rhodium catalyst methanator operated at 400°C to convert CO_2 to CH_4. The column was made of 1/8 O.D. stainless steel tubing packed with 3 ft of 10 percent methyl silicone on Supelcoport 80/100 mesh followed by 1.5 ft Porapak Q 60/80 mesh. The CH_4 was analyzed by a flame ionization detector (FID). The FID output was integrated with an integrator. A second inert injection port was placed just prior to the oxidation furnace for system checks. A schematic in shown in Figure B-5.

Starting with the column submerged in a dry ice-isopropanol bath at -78°C, a 5 mL sample was drawn from the pressurized evacuated sampling tank and injected into the carrier gas to the column. Carbon monoxide and methane were separated. The column was then operated at room temperature for carbon dioxide elution. After the elution, the column was placed in boiling water bath and the carrier gas flow through the column reversed. The volatile organics were released from the column. Each evacuated sampling tank was analyzed in triplicate. On the first injection of each duplicate pair, the column was placed in a $CaCl_2$ -ice bath at -30°C to separate ethylene, ethane, and propane. If these compounds were not detected the samples were analyzed as above, but if present, the samples were analyzed with the -30°C column temperature step.

Analysis of the sampling tank for carbon dioxide required separate injections from that used for the organic analyses. The amount of carbon dioxide in a 5 mL injection was shown to overload the reduction catalyst causing a low carbon dioxide value to be reported. Carbon dioxide concentrations in the tanks were

determined in triplicate using 1.2 mL injections directly to the oxidizer. Carbon monoxide and TGNMO concentrations were subtracted from the CO_2 value thus attained.

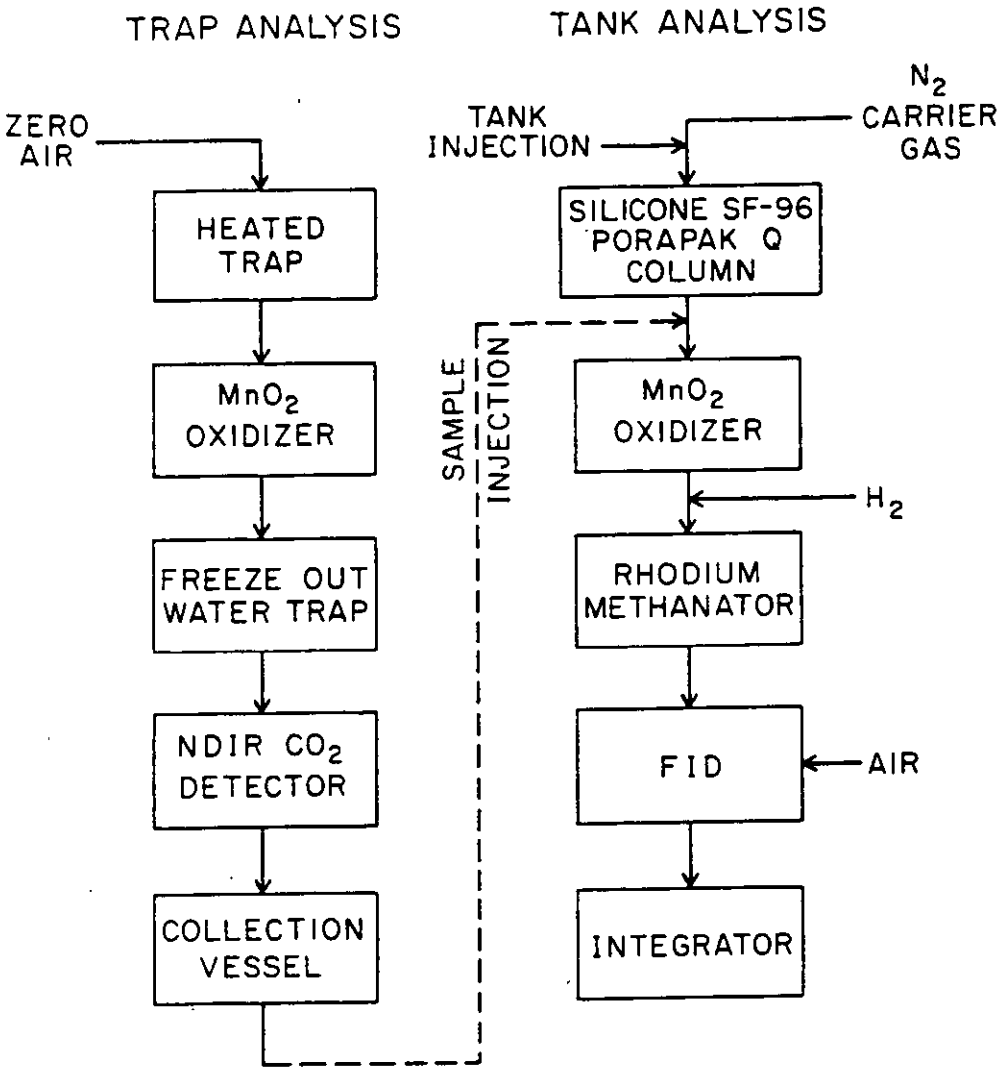

FIGURE B-5

TGNMO ANALYTICAL SCHEME

D. Calculations

Laboratory results were in terms of ppm TGNMO as methane as found in the sampling tank or vessel. These were corrected to standard conditions in the stack. To obtain results corrected to stack concentrations, the tank and vessel volumes corrected to

standard condition were divided by the sample colume corrected to standard conditions and multiplied by the tank or vessel TGNMO concentrations respectively. Summation of tank and vessel concentrations were presented as stack TGNMO concentration at standard conditions.

The sample volume at standard conditions was calculated by:

$$\text{Sample Vol.} = (9.124)\ (V_T)\ \left(\frac{P_2}{T_2} - \frac{P_1}{T_1}\right)$$

where: V_T = tank volume in liters

P_1 = absolute pressure in the tank prior to sampling, in. Hg

T_1 = absolute temperature in the tank at time of measurement of P_1, °K

P_2 = absolute pressure in the tank after sampling, in. Hg

T_2 = absolute temperature of the tank at time of P_2 measurement, °K

The volume of the tank or vessel at the time of analysis was calculated by:

$$\text{Pressurized Container Volume} = \frac{(Vc)\ \ (Pc)\ \ (9.124)}{Tc}$$

where: Vc = container volume, liters

Pc = pressure of container when filling is completed, in. Hg

Tc = absolute temperature of container at time of measurement of Pc, °K.

The TGNMO's in those containers were calculated by:

$$\text{Stack Concentration} = \left(\text{Container Concentration} - \text{Container Blank}\right) \cdot \left(\text{Pressurized Container Volume}\right) / \left(\text{Sample Volume}\right)$$

The container blanks are a column blank and the zero air total carbon concentration for the tank and vessel respectively. Both blanks were kept below 5 ppm.

II QUALITY CONTROL

The TGNMO analysis system was checked for proper operation at frequent intervals. Daily checks were made for FID sensitivity, zero air purity, column carrier gas purity and system leaks.

Weekly checks were made on all catalysts efficiencies. Bi-weekly checks were made for evacuated sampling tank leaks and tank contamination.

A. Catalyst Efficiency Checks

All catalyst efficiencies were checked at the beginning of each week.

(1) Oxidation Catalyst Efficiency Check - To check the oxidation catalyst, the reduction catalyst was bypassed while operating the TGNMO analyzer in an otherwise normal fashion. Triplicate injections of 5 mL each of standard methane gas were made. If the catalyst was operating properly, the only gas reaching the FID was carbon dioxide and no response was indicated. Any response was reported and the catalyst efficiency recorded. When the catalyst efficiency was found to be less than 95 percent, it was replaced.

(2) Reduction Catalyst Efficiency Check - With the TGNMO analysis system in its normal operating mode triplicate injections of a CO_2 standard were made directly to the reduction catalyst and the FID response recorded. Triplicate injections of a standard methane gas were made directly to the reduction catalyst to calibrate the FID. The usual calibration curve could not be used because reduction catalyst inefficiencies were included in it. When the catalyst efficiency was less than 95 percent it was replaced.

(3) Cryogenic Freeze-Out Trap Oxidation Catalyst Efficiency Check - The cryogenic trap oxidation catalyst was checked by connecting the methane calibration has cyclinder to the trap oxidation catalyst and venting to atmosphere a flow of 160 mL/min. Triplicate samples of the flow taken from an injection/withdrawl port following the catalyst were injected into the TGNMO analysis system while the carrier gas bypassed both the oxidizer and the methanator. A response from the FID detector indicated a faulty oxidizer catalyst in the cryogenic trap burnout system. At a catalyst efficiency of less than 95 percent it was replaced.

B. Carrier Gas Contaminate Check

The purity of the chromatographic column nitrogen carrier gas and the zero air used for cryogenic trap burning as well as for tank and vessel pressurization were checked daily. Impurities in either gas results in a positive bias in the results.

(1) Zero Air Check - Zero air was checked for its total carbon content by withdrawing a sample from a port in the zero air supply line when the trap burnout system was receiving a flow of 160 mL/min, and injecting it into the TGNMO analysis system prior to the oxidizer. A zero air total carbon content greater than 5 ppm indicated that replacement of the ascarite CO_2 filter molecular sieve, or zero air oxidation catalyst was required.

(2) Nitrogen Carrier Gas Contaminant Check - The nitrogen carrier gas was checked for contaminants daily as follows. The column was flushed of all carbon by placing it in boiling water while in the back flush mode. The column was then passed through the temperature sequence as if a sample had been injected starting with the dry ice-isoproponal bath in the forward mode. If the organic peak calculated was more than 5 ppm, the carrier gas cleanup system was regenerated with a new molecular sieve and oxidation catalyst. Organic peaks of less than 5 ppm were subtracted from that day's tank analyses.

C. Leak Checks

Leaks in the TGNMO analysis and sampling system are not readily apparent and the system must be diligently checked to assure integrity of the samples. Each section of the sampling and analysis system was checked for leaks daily prior to use.

(1) Tank Leaks - The evacuated sampling tanks were checked for leaks once every two weeks by evacuating them to more than 25 in. Hg measuring the vacuum with a mercury manometer, and remeasuring the vacuum 24 hours or more later. If the vacuum decreased, the tank was assumed to have leaked. The leak was located by pressurizing the tank to 30 in. Hg submerging it in water. Once the leak was located and fixed, the tank was retested and returned to service.

(2) Sampling Assembly Leaks - The gauge assembly, connections between the gauge assembly, rotometer, traps, and sampling lines were checked daily at the sampling site for leaks. The sampling line was capped and a tank pressurized to 30 in Hg was attached to the gauge assembly. All connections in the system were squirted with soapy water and inspected for bubbles. If a leak was found it was corrected before sampling.

(3) Trap Burnoff Assembly Leaks - This assembly was checked for leaks daily by plugging the trap burnoff system where the trap was connected and a vacuum of 20 in. Hg drawn on the system. Both the flow meter and the IR analyzer were monitored. A flow through the flow meter or a CO_2 response on the IR analyzer indicated a leak which was repaired prior to use of the system. The leak location can be found by tracing the system with dry ice wrapped in a towel. When the IR analyzer gives a response, the leak has been located. All trap connections to the burnout system were checked for leaks by squirting the joints with soapy water while the system was under pressure.

D. Flame Ionization Detector Calibration

Daily calibration checks of the flame ionization detector (FID) were required to detect changes in gas flow and leaks which can decrease sensitivity. Two calibrations are needed, one through the decrease sensitivity. Two calibrations are needed, one through the catalyst and FID, and one through the column, catalyst, and FID.

Several criteria had to be satisfied by the calibration check namely: (a) calibration curve linearity, and (b) calibration curve drift from pre-set limits over the duration of the project.

(1) Linearity - Linearity of the detector was checked at the beginning of the project by multiple injections of standard methane gas. Different size injections were used to simulate six different concentrations of methane, between 20 ppm to 1035 ppm. A regression analysis yielded r^2 values of 1.000 and 0.995 for injections directly to the oxidizer and injections through the column, respectively, indicating good linearity.

Linearity was checked once a week. Three simulated concentrations of methane were injected both through the column and bypassing the column. An r^2 was calculated to determine if linearity was maintained.

(2) FID Sensitivity Check - The day-to-day calibration curve will exhibit random variations due to differences in gas flows and other detector operating conditions. It is also possible for the calibration line (FID sensitivity) to drift from its average position. Such a drift would indicate gradual changes in gas flows, leaks in the analysis system, or catalyst inactivation. Any calibration line drift was detected from the normal random variations found.

Random variations at any point on the calibration line will give a normal distribution. The characteristics of that distribution was quantified at the beginning of the study. Once those distributions were quantified, any daily average calibration point falling outside 90 percent of the distribution indicated a possible problem with the system. When this occurred, septum conditions, connection leaks, and gas flow deviations were checked and the reason for the deviation identified and corrected.

A fixed portion of a population distribution can be found by $\bar{x} \pm K^{*}s$, where K is a value found in a statistical table (26), and depends upon the number of samples taken, the confidence interval, and the percentage of the population to be included, $\bar{x}$ and s are the mean standard deviation of the population, respectively. For this work, 90 percent of the normal day-to-day variation will be accepted with 95 percent confidence.

(3) Calibration Accuracy - Establishment of a daily calibration line was made using 4 injections of 5 mL standard 1033 ppm methane gas in air. A calibration line was drawn between the 1033 ppm concentration and zero. Percent calibration accuracies at the 95 percent confidence level were calculated from the mean and standard deviation of the integrator counts by the equation:

$$\pm \text{ \% accuracy} = \frac{s}{\bar{x}\sqrt{n}} t_{\nu/2:n-1} \times 100$$

If accuracy was better than ± 3 percent, the calibration points were accepted, if not, the system was checked for problems and more calibration injections were made until the ± 3 percent accuracy was achieved.

E. Data Rejection

Non-duplicated results from paired samples were an indication of errors either during the sampling or sample preparation portions of the procedure. Data was rejected when the analytical results from the duplicate samples did not agree with each other. A paired result was accepted when the absolute difference between the pair was not greater than two times the standard deviation of all the test data taken from a source.

APPENDIX C

MILL STUDY REPORTS

I MILL STUDY REPORTS

A. Mill A: Comparison of ODEQ-7 and EPA-25 Results

(1) Objective - The ODEQ Method 7 was designed to measure total particulate and condensible organic compounds and EPA Method 25 to measure total gaseous nonmethane organic (TGNMO) compounds. The intent of this study was to compare the results of ODEQ-7 to EPA-25 when sampling veneer dryer emissions controlled by a wet scrubber. Other objectives were to determine the total organic emissions from a veneer dryer both prior to and following a Burley scrubber and to determine particulate and condensible organic emissions following a Burley scrubber when a variety of veneer species were being dried.

(2) Methods - ODEQ Method 7 sampling was performed by BWR Associates during a planned evaluation of a Burley scrubber on veneer dryer emissions. For additional information, all ODEQ Method 7 front filters were washed with acetone and reweighed following initial analysis. The purpose of the acetone wash was to estimate the front-half catch of organics condensed at 120°C (250°F).

EPA Method 25 sampling was performed by NCASI staff. An in-stack filter maintained at stack temperature was included in the sampling probe. Duplicate samples were not taken due to equipment limitations. Method EPA-25 data was taken before and after the scrubber to determine scrubber efficiency and emission factors. In addition, EPA-25 samples were taken from the ODEQ-7 sampling train following the second filter just prior to the silica gel impinger. This EPA-25 sample was used to determine the amount of organics passing through the ODEQ-7 sampling train.

Data from ODEQ Method 7 is normally presented in terms of gr/DSCF whereas data from EPA Method 25 is presented in terms of ppm as methane. A factor to convert one set of units to the other (3374 ppm/gr/DSCF), was calculated assuming veneer dryer condensible organic emissions to be abietic acid.

(3) Process Description - The source tested was a steam heated 4 deck, 18 section, 2 zone Coe veneer dryer equipped with a Burley 5 section wet scrubber. The discharge of the scrubber was modified for testing by installation of a 34 in. diameter stack 8 ft in height. A tubular flow straightener was installed in the base of the stack directly above the axial exhaust fan. All the veneer dried at this mill was peeled at other locations.

(4) Results - Results from the comparative testing at the first sampling site are listed in Table C-1. The EPA-25 data shown is for samples drawn in parallel with ODEQ-7 and samples taken after

the back-half filter of ODEQ-7. The ODEQ-7 data shows: (a) the acetone soluble portion of the front filter, (b) the acetone insoluble portion, (c) the back-half catch, and (d) the total catch. The results showed that the EPA-25 samples taken at the scrubber outlet did not compare with the ODEQ-7 results. The post ODEQ-7 samples showed that a considerable amount of organics passed through the ODEQ-7 train.

TABLE C-1 RESULTS FROM COMPARATIVE SAMPLING WITH METHODS ODEQ-7 AND EPA-25

Veneer Species	Concurrent With ODEQ-7 gr/DSCF* (ppm)	Following ODEQ-7 gr/DSCF* (ppm)	Acetone Sol. Portion of Filter Catch gr/DSCF (ppm)	Acetone Insol. Portion of Filter Catch gr/DSCF (ppm)	Back-Half Catch gr/DSCF (ppm)	Total gr/DSCF (ppm)
Douglas fir Sapwood	0.030 (100)	0.023 (78)	0.038 (128)	0.001 (3)	0.025 (84)	0.064 (216)
White fir Sapwood	0.089 (300)	0.086 (289)	0.007 (24)	0.003 (10)	0.016 (54)	0.026 (88)
Douglas fir Redry	0.079 (268)	0.066 (223)	0.045 (152)	0.012 (40)	0.023 (78)	0.080 (270)
White fir Sapwood	0.029 (97)	0.031 (105)	0.008 (27)	0.012 (7)	0.014 (47)	0.024 (81)
Pine	0.222 (749)	0.122 (412)	0.049 (165)	0.009 (30)	0.023 (78)	0.081 (273)

* Converted from ppm methane to gr/DSCF assuming the catch was abietic acid
( ) ppm TGNMO as methane

A material balance using results of both sampling techniques was performed. Differences between the EPA-25 stack sample and the EPA-25 sample following the ODEQ-7 back-half filter did not compare with the ODEQ-7 results. The ODEQ-7 samples consistently showed more organic material collected than the difference of the EPA-25 samples taken with an in-stack filter and following the ODEQ-7 back-half filter. These results also indicate that more organics passed the ODEQ-7 front filter than the EPA-25 probe filter. This conclusion is reasonable when considering the ODEQ-7 front filter was maintained at 120°C (250°F), whereas the stack temperature was 68°C (154°F). The higher ODEQ-7 filter and probe temperature apparently resulted in revaporization of condensed organics. Organic particulate present in the stack at 68°C (154°F) was filtered and not included in the EPA-25 samples.

Emission factors for total organic compounds prior to the scrubber are listed in Table C-2. Drying of green veneer produced between 1.1 to 2.1 lb/MSF total organic compounds.

M-25 UNCONTROLLED

TABLE C-2 TOTAL ORGANIC COMPOUNDS FROM VENEER DRYER

Veneer Species	Production MSF/hr	Air Flow DSCF/MSF	TGNMO ppm	TVOC TGNMO lb/MSF
Douglas Fir Sapwood	4.66	71,600	693	2.1
Douglas fir Heartwood	10.11	36,100	747	1.1
Redry	12.02	31,800	25	0.03
Lodgepole Pine	6.20	55,000	890	2.1

TABLE 9 P. 30

TABLE C-3 EMISSIONS FOLLOWING A BURLEY SCRUBBER

PARTICULATE & CONDENSIBLE ORGANIC COMPOUNDS

Veneer Species	Production MSF/hr	Air Flow DSCF/MSF	TVOC EPA-25 Result ppm	EPA-25 Result lb/MSF	PM + COND ODEQ-7 Result gr/DSCF	ODEQ-7 Result lb/MSF
Douglas fir	4.66	71,700	105	0.31	0.062	0.64
Sapwood	4.49	75,500	100	0.31	0.064	0.55
	6.66	50,300	--	--	0.065	0.46
Douglas fir	10.16	35,100	--	--	0.078	0.39
Heartwood	10.11	36,100	352	0.52	0.071	0.36
White fir	5.22	67,300	--	--	0.031	0.30
	5.27	65,200	300	0.81	0.026	0.25
	4.85	73,700	97	0.30	0.024	0.25
Redry	10.81	35,300	268	0.39	0.08	0.40
	12.02	31,800	151	0.20	0.072	0.33
	6.62	58,200	--	--	0.051	0.42
Lodgepole	4.52	75,500	749	2.3	0.081	0.87
Pine	6.20	62,300	--	--	0.067	0.59
	4.61	81,700	--	--	0.033	0.38

Emission factors for particulate and condensible organic compounds measured by ODEQ-7 and for EPA-25 samples with an in-stack filter taken at the scrubber outlet are shown in Table C-3. Non-organic compounds as determined by the acetone wash of the front filter, were less than 15 percent for all the samples. The EPA-25 results ranged between 0.20 and 2.3 lb/MSF as methane and the ODEQ-7 results ranged between 0.30 and 0.87 lb/MSF as dry weight.

The organic emissions following the scrubber were greater than the organic emissions entering the scrubber when redry was being processed. This indicated that some organics dissolved in the scrubber solution were stripped when the scrubber was lightly loaded. High grain loadings shown by the ODEQ-7 results when redry was being processed also indicated that condensed organics were being carried out of the scrubber. These condensed organics were likely contained in a mist. This smoothing effect from stripping organics from the scrubber solution made it difficult to measure scrubber efficiencies. Rough calculations showed that more than 4 hours of steady operation were required for the scrubber to reach equilibrium.

(5) Conclusions - This study showed no comparison between ODEQ-7 results and EPA-25 results. The results of the two sampling methods differed because of: (a) gaseous organic compounds passed through the ODEQ-7 train and (b) because of the exclusion of condensed organics from the EPA-25 train by the in-stack filter held at a temperature of 68°C (154°F).

Emission factors for uncontrolled emissions from this veneer dryer were measured for several wood species. The efficiency of the scrubber in removing organic compounds could not be established because of the slow response of organic compounds in the scrubber outlet following a process change.

B. Mill B: Exploratory Studies With EPA Method 25

(1) Purpose - This study was conducted to determine: (a) the need for isokinetic sampling and (b) the proportion of organic material caught on an in-stack filter when sampling with EPA Method 25.

(2) Methods - A veneer dryer was sampled both before and after a sand filter control device with EPA Method 25. Sampling was performed with probes designed to quantify material collected on them using the EPA-25 analysis system. The probe was made of a Swagelok 1/8 in. male connector to 1/4 in. female connector with the 1/4 in. end packed with quartz wool. The probe was tightly capped on both ends during transportation to and from the laboratory. The probes and filters were connected to the burnout system and heated to 200°C (390°F) in an oven to vaporize condensed organics. Wood particulates that may have collected on the filter were not burned. The vaporized organics passed

through the oxidation catalyst, the NDIR CO_2 monitor, and into an evacuated vessel for subsequent measurement by EPA-25 analysis procedure.

Duplicate samples were collected simultaneously before and after the sand filter. One probe of the duplicate was directed into the gas flow and the other was held perpendicular to the gas flow. Consistently different analytical results would indicate a need for isokinetic sampling.

(2) Results - The results are presented in Table C-4. The samples drawn perpendicular to the stack gas flow after the sand filter contained significantly less TGNMO than those drawn parallel to the gas flow. Samples drawn before the sand filter showed no significant difference in analytical results between probe orientation in most cases. These results indicated that isokinetic sampling may be required following wet collection devices on veneer dryers.

M-25

TABLE C-4 RESULT FROM SAMPLING FILTER CONFIGURATIONS

Sample Number	Probe Direction	Before Sand Filter VOC TGNMO ppm	Before Sand Filter Filter Catch ppm	After Sand Filter VOC TGNMO ppm	After Sand Filter Filter Catch ppm	% TGNMO Reduction Across Sand Filter
A	perpendicular	(682)	(14)	(130)	(16)	81
USE →	parallel	(678)	(0)	(339)	(27)	50
B	perpendicular	(544)	(21)	(176)	(12)	68
	parallel	(507)	(0)	(336)	(15)	34
C	perpendicular	(669)	(7)	(493)	(11)	26
	parallel	(627)	(11)	(512)	(26)	22
D	perpendicular	(299)	(7)	(206)	(7)	31
	parallel	(660)	(1)	(260)	(14)	61
E	perpendicular	(811)	(18)	(318)	(4)	61
	parallel	(850)	(13)	(563)	(11)	34
F	perpendicular	(430)	(1)	(436)	(40)	-1
	parallel	(862)	(0)	(446)	(2)	48

Particle size distributions for uncontrolled dryers indicated a predominance of particles in size range that behaves like a gas. The above results agree with particle size measurement previously determined. However, stack gases following wet control devices contained entrained water droplets of sufficient size to require isokinetic sampling to obtain a representative sample. These water droplets may contain condensed and dissolved volatile organics.

The amount of volatile organic matter caught on the filters prior to the Method 25 cryogenic trap was small compared to the total catch. The sample train filter catch for the control device inlet ranged between 0 and 4 percent of the total TGNMO. For samples taken after the control device the filter catch ranged between 1 and 13 percent of the total TGNMO. The particulates caught on the probe filter for the sample taken after the control device tended to be higher than for the sample taken at the inlet. The orientation of the filter to the gas flow did not affect the amount of particulate caught. This indicated that particulate matter impinging on the probe at this sampling site bled through the filter. It was concluded that isokinetic sampling of veneer dryer emissions appears necessary when particulate matter is present.

C. Mill C: Control of Steam-Fired Veneer Dryer Emissions with A Georgia-Pacific Corp. Scrubber

(1) Introduction - A wet scrubber designed for removal of condensible organic emissions from a steam heated veneer dryer was sampled to determine removal efficiencies for: (a) total nonmethane organics, (b) particulate and condensible organics, and (c) noncondensible nonmethane organics. Sampling was conducted by NCASI and TRC Environmental Consultants Inc., an EPA contractor.

(2) Source Description - The plywood mill studied operated four steam heated veneer dryers. Dryers 1, 2, and 3, were 5 deck, 2 zone, longitudinal dryers with 22, 15, and 18 sections, respectively. Dryer number 4 was a 22 section jet dryer. Dryer exhausts were collected by a common insulated manifold and delivered to the scrubber.

The scrubber consisted of two parts: (a) a gas cooling section to encourage condensation of organics, and (b) a section for removal of condensed organics, particulate and water droplets. Gas cooling was accomplished by spraying high pressure water through nozzles into the duct leading to the scrubber. Water droplets and entrained organics were removed by four cyclones operating in parallel followed by a packed tower.

(3) Sampling Procedures - Sampling of the scrubber inlet and outlet was carried out on five different days. On the first three

sequential days TRC and NCASI participated in a cooperative sampling study. On the next two days the NCASI sampled the source alone.

During the TRC and NCASI cooperative effort the scrubber inlet and outlet were sampled with a combination of EPA Method 25, the reference method for total gaseous nonmethane organics (TGNMO), and a modification of EPA Method 5, the reference method for particulate matter. The EPA-25 samples were drawn as a slip stream from the EPA-5 train following the heated filter. The filter was maintained at 177°C (350°F) as monitored by a thermocouple in the gas stream. A second filter was placed between the third and fourth impingers as in ODEQ method 7. This sampling procedure gave analyses for: (a) particulate matter that is nonvolatile at 177°C (350°F), (b) organic compounds which are volatile at 177°C (350°F), and (c) organic compounds which are volatile at 177°C (350°F) but condense at 21°C (70°F). The results for these three analyses are expressed as: (a) gr/DSCF by weight measured, (b) ppm CH_4, and (c) gr/DSCF by weight measured, respectively.

Six EPA-25 sample collection trains were connected to a common manifold at each location. Four of the trains were designed and operated by TRC and two were designed and operated by NCASI. The trains operated by TRC consisted of two cryogenic traps in a series, one in an ice bath to condense moisture and the other in dry ice to condense organics from the sampled gas. The NCASI train used one trap in dry ice. The TRC samples were drawn into 4-liter stainless steel tanks whereas the NCASI samples were drawn into 17-liter tanks.

Simultaneous samples were taken from the scrubber inlet and outlet on three successive days. Three laboratories analyzed a pair of samples from the inlet and outlet. The laboratories were NCASI, Pollution Control Science, and TRC Environmental Consultants.

The tests by NCASI on the latter 2 days of sampling were conducted primarily to determine the quantities of noncondensible organics present in the inlet and outlet to the scrubber. An ODEQ-7 sampling train was used on the outlet side of the scrubber with the front filter maintained at 88°C (190°F). The probe was maintained at a temperature of 93-99°C (200-210°F). A pair of EPA-25 samples were taken from a point following the 88°C (190°F) filter. This sampling arrangement provided results for total condensible organic and particulate material, and noncondensible nonmethane organics. These results were expressed as gr/DSCF by weight measured and ppm as methane, respectively.

Scrubber inlet samples were taken with EPA-25 trains preceded by a filter held at 80°C (190°F). A 3/8 in. diameter Whatman 934-AH glass filter was placed between two screens at the end of a 3/8 in. O.D., 3 ft long stainless steel probe. The temperature of the gas leaving the filter was monitored with a

thermometer. A tee was provided for connection of 2 EPA-25 sampling trains. The two and one-half feet of probe, the filter holder, and splitting tee were heat traced, wrapped in insulation, and protected with a metal covering. Sampling was aniso-kinetic. Condensed organics were recovered from the probe filter by washing the assembly with acetone and filtering the acetone wash. The wash was dried at room temperature and weighed.

(4) Analytical Results - EPA Method 25 analytical results from each of the three laboratories analyzing samples from the three days of cooperative sampling are shown in Table C-5. The laboratories are: (a) NCASI, (b) Pollution Control Science, and (c) TRC.

A three factor of analyses variance (ANOVA) was used to evaluate the data. Results of the ANOVA are shown in Table C-6. In the ANOVA, variations in results due to sampling location, sample date, and laboratory analyzing the samples are compared to the variation found in the paired samples.

TABLE C-5 RESULTS OF EPA-25 ANALYSIS IN ppm C

M-25 Total Org Compds

Source	Laboratory	Test Day 1	2	3
Inlet	A	1292	1594	1304
		1128	995	1365
	B	803	1324	1206
		906	1460	996
	C	1186	1452	2116
		1246	1309	2159
Outlet	A	1292	1294	1018
		1321	1148	829
	B	1909	1033	712
		1168	851	1094
	C	1664	1484	686
		1886	1887	1028

Sources of variation in the analytical results were interpreted from the ANOVA results as follows:

- Changes in emission levels from day to day as measured by all laboratories for both inlet and outlet were detected with only 66 percent confidence.

TABLE C-6 RESULTS OF ANOVA

	Source of Variation	Sum of Squares SS	Degrees of Freedom DF	Mean-Square MS (SS/DF)	Mean-Square Ratio MSR (MS/MS_r)	Confidence 75% $F_{0.5:1:2}$	90% $F_{0.1:1:2}$	95% $F_{0.05:1:2}$	97.5% $F_{0.025:1:2}$
Main Factors	(1) Each Test Day	87,926	c-1 = 2	43,978	1.0	1.50	2.62	3.55	4.56
	(2) Inlet or Outlet	67,912	r-1 = 1	67,912	1.55	1.41	3.01	4.41	5.98
	(3) Laboratory	991,703	g-1 = 2	495,851	11.30	1.50	2.62	3.55	4.56
Interacting Factors	(4) Test Day - Inlet/Outlet	87,866	(c-1)(r-1) = 2	43,933	1.0	1.50	2.62	3.55	4.56
	(5) Test Day - Laboratory	40,952	(c-1)(g-1) = 4	10,238	0.32	1.48	2.29	2.93	3.61
	(6) Inlet/Outlet - Laboratory	28,426	(r-1)(g-1) = 2	14,213	0.32	1.50	2.62	3.55	4.56
	(7) Test Day - Inlet/Outlet - Laboratory	2,766,327	(c-1)(g-1)(r-1) = 4	691,581	15.75	1.48	2.29	2.93	3.61
Error	Error Residual	790,193	18	43,899					

- A change in TGNMO emission concentration across the scrubber as measured by all laboratories for all three days was detected with 76 percent confidence.

- There were significant differences in results from each analytical group at better than 99 percent confidence. Results of laboratory B were the lowest and laboratory C the highest.

- There was no day on which a change in TGNMO emissions across the scrubber was detected with better than 70 percent confidence.

- There was no laboratory that consistently found any significant changes from day to day in emission levels. This portion of the ANOVA lumps together the scrubber inlet and outlet analysis results thereby hiding changes that might have occurred in either. Laboratory C results showed daily trends in TGNMO emissions both on the scrubber inlet and outlet. These trends were in opposite directions, and thus cancelled each other out in the ANOVA.

- No laboratory found any consistent differences in either the scrubber inlet and outlet.

- Individual laboratories found significant differences in either the scrubber inlet or outlet on different days. These findings were not shared by the other laboratories.

Differences in the analytical results from each laboratory appear to be the main source of variation. Since this variation is much greater than the variation of the paired samples, the differences are likely due to the analytical procedures. Review of the data collected by TRC and PCS show large differences in results for the tank analysis, whereas the trap analysis were about the same.

Some of the variation in the data was not detected by the three factor ANOVA because of opposing trends in the inlet and outlet of the scrubber. Treatment of the inlet and outlet data as isolated events by the ANOVA procedure summarized in Tables C-7 and C-8. These tables show that there was significant variation in both the scrubber inlet and outlet if the data is analyzed on a day to day basis. Also, the difference in laboratory results was significant with less than 89 percent confidence on the scrubber outlet.

An estimate of the variance of the EPA-25 test method for each of the laboratories can be obtained from a 2x6 ANOVA on the paired samples. The estimate of the square of the standard deviation is given by the mean square of the residual. The standard deviations calculated in this manner were 188, 258, and 172 ppm, resulting in relative standard deviations of 0.156,

TABLE C-7 ANOVA ANALYSIS OF SCRUBBER INLET DATA

Source of Variation	Sum of Squares SS	Degrees of Freedom DF	Mean Square MS (SS/DF)	Mean-Square Ratio MS/MS_r	Confidence 95% $F_{0.05,\ 1,\ 2}$
Test Day	602,063	2	301,031	11.6	4.26
Laboratory	668,962	2	334,481	12.9	4.26
Interaction	687,111	4	171,778	6.6	3.63
Residual	232,861	9	25,873		

TABLE C-8 ANOVA ANALYSIS OF SCRUBBER OUTLET DATA

Source of Variation	Sum of Squares SS	Degrees of Freedom DF	Mean Square MS (SS/DF)	Mean-Square Ratio MS/MS_r	Confidence 95% $F_{0.05,\ 1,\ 2}$
Test Day	1,267,215	2	633,607	10.2	4.26
Laboratory	361,718	2	180,859	2.9	4.26
Interaction	426,682	4	106,670	1.7	3.63
Residual	557,332	9	61,925		

0.221, and 0.114 for laboratories A, B, and C, respectively. Confidence intervals about a data pair can be established by the student t test. The average of each laboratory's paired data is within $\pm(s)(t_{\alpha/2,\nu})/\sqrt{n}$ where ν is 5 degrees of freedom, and n is 2 for these samples. At the 95 percent confidence level, the average of a data pair is within ±342, 469 and 313 ppm of the true value for laboratories A, B, and C, respectively.

The particulate and condensible organic material samples collected by TRC with the modified EPA-5 particulate train were analyzed by CH2M Hill in Corvallis, Oregon. The results are listed in Table C-9. The particulate matter was the material collected in the probe and on the heated filter while the condensible organics were the material collected in the glassware following the heated filter and up to and including the filter between the third and fourth impinger in the EPA-5 sampling train.

TABLE C-9 PARTICULATE AND CONDENSIBLE ORGANICS

All values expressed as grains per dry standard cubic foot

Sample	Location	Particulate	Condensible Organics	Total
1	inlet	0.025	0.173	0.194
	outlet	0.020	0.092	0.112
2	inlet	0.016	0.152	0.163
	outlet	0.018	0.089	0.107
3	inlet	0.007	0.116	0.124
	outlet	0.027	0.060	0.087

Results from the NCASI collected samples for total, condensible and noncondensible organics are shown in Table C-10. Condensible organics, listed in the column labeled "before 88°C (190°F) filter", are reported in terms of gr/DSCF and ppm as CH_4. The samples on the inlet side were not drawn isokinetically and should not be considered equivalent to ODEQ-7 particulate results. The ppm as CH_4 number for the inlet side was obtained from analysis of the dried extract from the probe and filter in an EPA-25 organic trap. The dried extract was desolved in ether, placed in an EPA-25 trap, purged with air to evaporate the ether, then burned out as per the normal EPA-25 procedure. The ppm as CH_4 values from the outlet before 88°C (190°F) filter samples were derived from multiplication of the result expressed as gr/DSCF by factors derived during the sampling evaluation work reported in Section IV of this report. Listed in the "After 88°C, (190°F) Filter" column are the results from the duplicate EPA-25 filtered

samples and their average. The total organic column is the sum of the previous two columns expressed as ppm CH_4. The particulate and condensible organic columns in the total ODEQ-7 results are expressed as gr/DSCF. Hemlock was being dried on one dryer when sample 6 was being taken. Douglas fir was the only species being dried during all other trails. To determine the effect this change in wood species may have on the results from sample 6, several samples were collected from a dryer processing hemlock. The results are listed in Table C-11.

TABLE C-10 ANALYSIS RESULTS FROM NCASI COLLECTED SAMPLES

M-25 ?

Sample	Location	Before 88°C Filter	After 88°F Filter ppm	Total Organic ppm	Particulate and Condensible Organics gr/DSCF
4	inlet	0.17 gr/DSCF	604		
		496 ppm	783		
			Avg 694	1189	----
	outlet	0.028 gr/DSCF	539		
		46 ppm	460		
			Avg 495	541	0.053
5	inlet	0.27 gr/DSCF	1065		
		849 ppm	978		
			Avg 1022	1871	----
	outlet	0.053 gr/DSCF	587		
		106 ppm	699		
			Avg 643	749	0.113
6	inlet	0.25 gr/DSCF	599		
		497 ppm	892		
			Avg 746	1143	----
	outlet	0.031 gr/DSCF	795		
		91 ppm	777		
			Avg 786	877	0.067
7	inlet	0.13 gr/DSCF	733		
		444 ppm			
			Avg 797	1242	----
	outlet	No data due to equipment failure			
8	inlet	0.12 gr/DSCF	484 ppm		
		305 ppm	436 ppm		
			Avg 460 ppm		765 ppm

TABLE C-11 ANALYSIS RESULTS FROM DRYING HEMLOCK

Sample	Location	Before 88°C Filter	After 88°C Filter	Total
9	inlet	0.14 gr/DSCF	394 ppm	
		267 ppm	588 ppm	
			Avg 491 ppm	758 ppm

Some comments concerning the validity of the data are in order. The EPA-25 samples from tests 1 and 2 may have been contaminated with acetone. The acetone used to wash the EPA-5 samplings train was not completely dried before use. The sampling trains were allowed to dry overnight prior to sampling on the remaining tests taken by TRC. Vacuum grease was used on the 177°C (350°F) front filter during runs 1 through 3. It was applied more liberally on the scrubber outlet sampling train.

Particulate and condensible organic emission measurements on the scrubber inlet samples 4 through 9 were drawn anisokinetically. The weight reported represents only the condensible organic material in the emissions since the extracted samples were filtered prior to weighing. The values obtained for tests 5 and 6 appear to be high.

Total organic emissions from test 7 were obtained using an in-stack filter. Burning the extract from the 88°C (190°F) filter and probe in the EPA-25 analysis system yielded 348 ppm whereas the difference between the total organics and the organics passing the 88°C (190°F) filter measured 444 ppm. Considering the poor duplication (1426 ppm and 1060 ppm) of the total organic analysis by EPA-25 on this sample, the differences between the condensed organic material measurements by the two procedures appears reasonable.

(5) Engineering Results - Production data and emission gas flow measurements were collected by TRC, NCASI, and the mill. This data is listed in Table C-12.

Both TRC and NCASI made flow measurements at the scrubber outlet. The sampling ports at the scrubber outlet were within 1 diameter of the stack outlet. With a 9 ft diameter stack and the low stack gas velocities, any wind movement across the top of the stack could have affected the readings. For this reason, only scrubber inlet flows were used for calculation purposes.

TABLE C-12 PRODUCTION DATA AND AIR FLOW

Production Test	Veneer Species	Production MSF/hr. 3/8 in. Bases	Scrubber Inlet Air Flow DSCFM	DSCF/SF
1	Douglas fir	35.7	12,400	24.2
2	Douglas fir	34.4	12,100	25.1
3	Douglas fir	34.1	12,600	25.7
4	Douglas fir	27.5	12,600	27.5
5	Douglas fir	35.2	13,000	22.2
6	Douglas fir/ Hemlock	30.3	14,400	28.4
7	Douglas fir	32.2	12,600	23.5
8	Hemlock	7.1	4,403	37.0
9	Hemlock	7.1	3,859	32.4

The analytical results, production data, and flow measurements were used to calculate emission factors for the scrubber inlet and outlet. Tables C-13, C-14, and C-15 present the calculated emission factors and scrubber removal efficiencies for total nonmethane organics, particulate and condensible material, and noncondensible nonmethane organics respectively. The values reported in Tables C-13 and C-15 are lb/MSF expressed as methane whereas the values reported in Table C-14 are lb/MSF expressed as the weighed material.

The particulate organic uncontrolled emissions measured in tests 1, 2, and 3 taken by TRC are considered the only valid measurements for this parameter. The remainder of the inlet samples were obtained by a non-standard method. However, all the emission factors obtained by both methods were within the range of emission factors for Douglas fir measured for other dryers. The uncontrolled emissions for particulate and condensible organics measured in tests 1, 2, and 3 averaged 0.50 lb/MSF.

Each sampling team had different results for scrubber outlet particulate and condensible organic emission factors. TRC, in samples 1 through 3, showed average scrubber emissions of 0.32 lb/MSF. The NCASI, in samples 4 through 6, showed average scrubber emissions of 0.28 lb/MSF. Scrubber efficiencies indicated for removal of particulate and condensible

T-VOC

TABLE C-13 TOTAL ORGANIC EMISSIONS (lbs CH_4)

Test #	Uncontrolled Emissions lb/MSF	Controlled Emissions lb/MSF	Scrubber Efficiency Percent
1	1.00	1.13	-13
2	1.16	1.10	5
3	1.23	0.85	31
4	1.36	0.63	54
5	1.72	0.65	62
6	1.34	0.97	28
7	1.21		
8	1.17		
9	1.02		

PM & CPM

TABLE C-14 PARTICULATE AND CONDENSIBLE ORGANIC EMISSIONS

Test #	Uncontrolled Emissions lb/MSF	Controlled Emissions lb/MSF	Scrubber Efficiency Percent
1	0.58	0.34	42
2	0.53	0.33	38
3	0.40	0.28	30
4	0.67	0.21	69
5	0.86	0.35	59
6	1.01	0.27	73
7	0.44		
8	0.63		
9	0.65		

NC-VOC

TABLE C-15 NONCONDENSIBLE ORGANIC EMISSIONS (lbs CH_4)

Test #	Uncontrolled Emissions lb/MSF	Controlled Emissions lb/MSF	Scrubber Efficiency Percent
4	0.66	0.48	29
5	0.81	0.51	37
6	0.76	0.80	-6
7	0.78		
8	0.71		
9	0.66		

organic emissions were 37 percent and 67 percent for TRC and NCASI respectively. The NCASI scrubber efficiency may be high due to a non-standard testing method used to obtain inlet samples.

The results from sample 6 did not appear to be affected by the hemlock being dried in one dryer. Total organic emissions, Table C-13 for hemlock (tests 8 and 9) were 20 percent lower than those for Douglas fir. Noncondensible organic emission from drying hemlock were no different from drying Douglas fir. Hemlock comprised 15 percent of the production during sample 6. The emission factor for Douglas fir would be depressed by a calculated 3 percent due to the hemlock dried during test 6.

Noncondensible organic emissions from the dryers as measured by EPA-25 following a filter held at 88°C (190°F) in test runs 4 through 6 averaged 0.74 lb/MSF as CH_4. When hemlock was being dried during test runs 8 and 9 the noncondensible organic emission measured 0.68 lb/MSF as CH_4. Noncondensible organic emissions following the scrubber in tests 4 through 6 showed an average decrease of 0.18 lb/MSF as CH_4, which corresponded to a 20 percent removal.

The total nonmethane organic (TNMO) emissions going to the scrubber during tests 1 through 3 averaged 1.13 lb/MSF as CH_4 and for tests 4 through 7 averaged 1.41 lb/MSF as CH_4. The TNMO emissions after the scrubber for tests 1 through 3 averaged 1.03 lb/MSF as CH_4 and from tests 4 through 6 averaged 0.75 lb/MSF, to give an overall average of 0.91 lb/MSF. Average scrubber removal efficiencies for TNMO were 9 percent for tests 1 through 3 and 46 percent for tests 4 through 6. Possible contamination of the EPA-25 samples with vacuum grease or acetone may have caused the low scrubber efficiency reported for tests 1 through 3.

(6) Summary - A wet scrubber designed by Georgia-Pacific Corporation operated on emissions from four steam heated veneer dryers drying Douglas fir was sampled at the inlet and outlet for total nonmethane organic (TNMO) emissions, and particulate and condensible organic emissions by TRC, an EPA contractor, and NCASI. NCASI also sampled for noncondensible nonmethane organic emissions. The sampling procedures used were: (a) ODEQ Method 7 with a 177°C (350°F) front filter to measure particulate and condensible organics, (b) EPA Method 25 preceded by a 177°C (350°F) filter to measure TNMO, and (c) EPA Method 25 preceded by a 88°C (190°F) filter to measure noncondensible nonmethane organics. Analysis of EPA Method 25 samples collected to determine TNMO were performed by three independent laboratories. Analytical results from the laboratories did not show good agreement. Results from the sampling effort yielded emission factors for the uncontrolled emissions of: (a) 0.58 lb/MSF as dried weight for particulate and condensible organics, (b) 1.36 lb/MSF as CH_4 for total nonmethane organics, and (c) 0.74 lb/MSF as CH_4 for noncondensible organics for the

drying of Douglas fir. TNMO emissions were found to be 1.10 lb/MSF as CH_4 for hemlock. Emissions factors for the scrubber outlet were: (a) 0.32 lb/MSF as dried weight for particulate and condensible organics, (b) 0.60 lb/MSF as CH_4 for noncondensible nonmethane organics, and (c) 0.97 lb/MSF as CH_4 for TNMO for Douglas fir. Scrubber efficiencies were found to be 37 percent for particulate and condensible organics, 20 percent for noncondensible nonmethane organics, and 46 percent for TNMO.

D. Mill D; Study of Veneer Dryer Exhaust Gas Incineration In a Dutch Oven Boiler

(1) Objective - Incineration of veneer dryer emissions in power boilers is practiced by several Northwest mills. This study was undertaken to investigate the organic compound destruction efficiency of a wood-residue fired Dutch oven boiler using veneer dryer emissions as combustion air. Emission factor data for uncontrolled veneer dryer emissions was also collected.

(2) Methods - The boiler combustion air (veneer dryer emissions) and boiler exit gas were sampled with EPA Method 25 preceded with an in-stack filter. Gas flow rates were determined with pitot tube traverses. No background measurements were taken when the boiler was not incinerating veneer dryer emissions. The EPA-25 data was corrected for a CO_2 interference using procedures outlined in NCASI Atmospheric Quality Improvement Technical Bulletin No. 109 (18).

(3) Dryer and Boiler Description - Emissions from two 4-deck, single zone dryers were ducted to wood-residue fired Dutch oven boilers to be used as combustion air. The dryer emissions were introduced to two boilers under the grate above the wood-residue pile in the primary combustion chamber, and to the secondary combustion chamber. The boilers were old and did not have nameplates. The boilers produced about 41,000 lb/hr steam. The steam flow gauges had not been calibrated for a number of years. The sole use of this steam was for operation of the veneer mill. Both the boilers exhausted to a single stack.

(4) Results - Results of the tests are listed in Table C-16. Dutch oven boilers using ambient combustion air have had emissions measured as high as 0.5 lb/10^6 Btu heat input. Emission rates measured at this site ranged between 0.13 to 0.32 lb/10^6 Btu heat input. In light of the variable organic emission rates found and the unknown organic emission rates resulting solely from wood-residue combustion in this unit, these tests were inconclusive in determining the effectiveness of this wood-residue fired boiler in the control of veneer dryer emissions. Further testing of this boiler while no veneer dryer emissions are being incinerated will be required to determine its effectiveness in controlling veneer dryer emissions.

steam dryers

TABLE C-16 DATA SUMMARY OF EPA-25 RESULTS FOLLOWING INSTACK FILTER

VOC

Run #	Sample Location	Veneer Species	Production* MSF/hr	Stack Flow Rate DSCFM	TGNMO Emissions ppm	lb/hr	lb/MSF	lb/10^6 Btu	Percent Change
1	Boiler Inlet	Hemlock Douglas fir & Redry	14.4	13,000	398	12.8	0.90		
	Boiler Outlet		14.4	37,000	185	17.1	1.19	0.32	+34
2	Boiler Inlet	Douglas fir	13.3	12,300	535	16.4	1.23		
	Boiler Outlet		13.3	31,400	88	6.9	0.52	0.13	-58
3	Boiler Inlet	Douglas fir	13.0	12,400	440	13.6	1.05		
	Boiler Outlet		13.0	35,100	125	11.2	0.86	0.23	-18

* Production is on the basis of 3/8 in trimmed veneer being fed to the dryer A trim factor of 15 percent was used.

E. Mill E: Study of Incineration of Veneer Dryer Exhaust Gas In a Dutch Oven Wood-Residue Fired Boiler

(1) Objectives - Several Northwest mills practice veneer dryer emission incineration in power boilers to control the opacity associated with veneer dryer emissions. Incineration of dryer emissions in existing wood-residue fired boilers resulted in the reduction of opacity. However, no data exists on the capability of those boilers to combust the organic compounds in veneer dryer emissions. This study was designed to determine destruction efficiency for veneer dryer emissions by a retrofit boiler.

The U.S. EPA hired a contractor, TRC, to sample organic emissions from a Dutch oven wood-residue fired boiler. The NCASI was invited to sample the emissions simultaneously with the contractor. In addition, the NCASI also sampled the unit at a later date.

(2) Methods - Total organic compounds in the veneer dryer emissions and the boiler exhaust were determined with EPA Reference Method 25 with filters held at 177°C (350°F) when TRC was sampling or at stack temperatures when NCASI was sampling individually. The veneer dryer emission temperature was 162°C (320°F) and the boiler outlet temperatures were 127°C (260°F) and 193°C (380°F) for boilers 1 and 2 respectively. Particulate and condensible organic compounds were sampled with a modification to EPA Method 5 better known as ODEQ Method 7. Particulate matter is defined as those compounds captured in the heated probe or on a filter held at 177°C (350°F). Condensible matter is defined as material that passes through the filter and is captured in the condenser section of EPA Method 5 train and by the second filter, and retained through analysis.

The tests were conducted in two series. During the first series the boiler was operated at full capacity with a high quality wood-residue fuel. During the second series the boiler was operated at reduced capacity and with poor to medium quality wood-residue fuel. Fuel quality was judged on its moisture content and ability to burn in the boiler.

Sampling for particulate, condensible organics, and total organic compounds was carried out by TRC during the first 5 runs. The NCASI took simultaneous EPA-25 samples for total organic compounds along with TRC. Later, this same boiler was sampled with EPA Method 25 for runs 6 through 8 when the boiler was fired on fuel of medium to poor quality.

(3) Process Description - Veneer dryer emissions from six dryers were split and introduced to two boilers as underfire and overfire air. The boilers supplied steam to the veneer dryers, lay up presses, a hardboard mill, and steam turbines

for electricity production. In addition, the exhaust gas from boiler No. 1 was passed through a heat exchanger to heat air used to dry fiber for the dry process hardboard mill. Sawdust was injected at a tertiary combustion chamber following the boiler tubes and ahead of the heat exchangers.

The Dutch oven Combustion Engineering boilers were installed in the late 1940's. The boilers burned hogged wood, bark, dry trim, veneer clippings, hardboard dry wastes, and sander dust as fuel. Hogged fuel was burned in piles in the Dutch oven boiler. Sander dust was injected into the boiler secondary combustion chamber and just prior to the air heat exchanger and contributed 10 to 12 percent of the total Btu input at typical steam production.

Each boiler was capable of producing 77,000 lb/hr steam at 200 psi, but normally produced 60,000 lb/hr. About 10 MW was produced by steam turbines. The total steam production during testing averaged 110,000 lb/hr, of which about 50,000 lb/hr was used for drying veneer.

Veneer dryer emissions at about 163°C (325°F) provided approximately 30 percent of the total combustion air. Veneer dryer emissions were split about 40 percent undergrate and 60 percent overgrate in the Dutch ovens. Combustion air preheating was not practiced. Other combustion air entered the boiler through the fuel feed chutes, sander dust injection systems, and leaks. The boiler was operated with about 300 percent excess air as measured at the stack.

The exhaust from boiler No. 1 passed through multiple cyclones before being ducted to the stack. The exhaust from boiler No. 2 passed through a wet induced draft fan before being ducted to the stacks.

Exhausts from six steam-heated dryers were ducted to the boiler. Four of the dryers were 15 section, 5 deck, 3 zone cross-flow dryers. One dryer was a 16 section, 5 deck, 2 zone cross-flow dryer and one was a single zone, 6 deck longitudinal dryer. Douglas fir green veneer was dried during all tests.

(4) Results - The results, listed in Table C-17, were analyzed statistically for significance of variation due to different levels of organics contained in the source as opposed to variation in the results due to lack of analytical precision. Results of an analysis of variance (ANOVA) showed the variation in the data to be primarily due to variations in organic content in the gases sampled except for the boiler inlet data taken by TRC. The NCASI boiler outlet data for run No. 1 was below the detection threshold of EPA Method 25. The NCASI data has also been corrected for a CO_2 interference by procedures described in NCASI Atmospheric Quality Improvement Technical Bulletin No. 109 (18).

A considerable discrepancy existed between the boiler outlet total organic compound emission results obtained by NCASI and TRC that cannot be explained. The NCASI values expressed as lb methane/10^6 Btu fired are consistent with measurements taken at other Dutch oven boilers, whereas the TRC values were much higher. It may be that TRC was experiencing significant CO_2 interference in the analysis of the boiler outlet samples.

TABLE C-17 SAMPLE ANALYSIS AND ANOVA RESULTS

Run	Boiler No. 1 Inlet ppm NCASI	Boiler No. 1 Inlet ppm TRC	Boiler No. 2 Outlet ppm NCASI	Boiler No. 2 Outlet ppm TRC
1	569	2567	12	786
	517	587	6	695
2	701	448	137	1081
	756	1020	120	1269
3	--	--	196	871
	--	--	116	616
4	--	--	88	1503
	--	--	113	1347
5	799	866	13	607
	651	427	96	902
6	627	--	34	--
	603	--	83	--
7	617	--	181	--
	--	--	79	--
8	571	--	30	--
	595	--	41	--
	n=5	n=3	n=8	n=5
	F_r=4.9	F_r=0.06	F_r=3.2	F_r=9.1
	$F_{.1,4,5}$=3.5	$F_{.1,1,2}$=49	$F_{.1,7,8}$=2.8	$F_{.1,4,5}$=4.1

-- No sample

Total organic and condensible organic emissions from the veneer dryers and the boiler for eight different runs are listed in Table C-18. The total organic compounds in the veneer dryer emissions used for combustion air, derived by assuming that the veneer dryer emissions were equally split between the boilers, ranged between 16 to 23 lb/hr as CH_4. The total organic emisions in the boiler output ranged between 1.7 and 18.1 lb/hr, averaging

TABLE C-18 ORGANIC EMISSIONS TO AND FROM BOILER NO. 2

Run #	Veneer Dryer Organic Emissions to Boiler			Boiler Organic Emissions			Organics Removal Efficiency	
	Total lb/hr		Condensible lb/hr	Total lb/hr		Condensible lb/hr	Total[a] Percent	Condensible Percent
	NCASI	TRC	TRC	NCASI	TRC	TRC		
1	16.1	17.4	14.5	2.3	73.3	3.4	160	108
2	23.3	23.4	18.1	14.0	112.8	5.0	91	92
3	+	+	+	14.5	62.7	6.3	--	--
4	+	+	+	9.6	115.1	2.8	--	--
5	21.0	18.7	13.9	1.7	75.3	1.7	149	113
6	19.7	--	--	10.3	--	--	109	--
7	19.9	--	--	18.1	--	--	69	--
8	17.4	--	--	4.8	--	--	141	--

* Value based on results from one of pair of samples.
-- No sample taken
\+ No veneer dryer emissions were being ducted to the boiler
a Removal efficiency calculated using NCASI data.

(1) Assumed Veneer Dryer Emissions were split between boilers on an 1 to 1 basis.
(2) Efficiencies were calculated from:

$$\text{eff} = \frac{\text{organics in inlet} - (\text{organics in outlet} - \text{background})}{\text{organics in inlet}}$$

9.5 lb/hr as CH_4 when veneer dryer emissions were being incinerated. When no veneer dryer emissions were being incinerated, runs 3 and 4, the boilers total organic emissions averaged 12 lb/hr. Likewise, condensible organic compounds in the veneer dryer emissions averaged 15.5 lb/hr to each boiler, whereas the condensible organic emissions from boiler No. 2 averaged 3.4 lb/hr while incinerating veneer dryer emissions. When no veneer dryer emissions were being incinerated the boilers condensible organic emissions averaged 4.5 lb/hr.

Although there is insufficient data to statistically compare the boiler emissions when fired with and without veneer dryer emissions in the combustion air, the data available indicated complete destruction of the organics in the veneer dryer emissions. Both the average total organic emissions and the condensible organic emissions from the boiler were lower when veneer dryer emissions were being incinerated. Organic material removal efficiencies presented in Table C-18 were calculated using boiler data corrected for the boiler background organic emissions as determined by runs 3 and 4.

The range of boiler operating conditions during testing are shown in Table C-19. The Dutch oven fuel conditions ranged from poor (wet and dirty) to good. Fuel conditions were good during test runs 1 through 5 and 8, and poor during tests 6 and 7. Boiler steam loads ranged between 40×10^3 and 70×10^3 lb/hr. Total organic compound emissions expressed as lb/10^6 Btu fired followed no trends related to the boiler operating conditions. Heat inputs were calculated using a factor of 1840 SCF $CO_2/10^6$ Btu that is typical of hogged fuel (24).

TABLE C-19 BOILER OPERATING CONDITIONS

Run No.	Steam Production 10^3 lb/hr	Fuel Heat in put 10^6 Btu/hr	Fuel Moisture g H_2O/g Wood	Boiler Steam Production Efficiency Percent	Total Organic Compound Emissions lb/10^6 Btu
1	56	97	--	64	0.024
2	55	90	--	67	0.155
3*	50	82	--	71	0.173
4*	67	98	--	80	0.097
5	52	93	--	63	0.076
6	40	98	1.31	45	0.105
7	40	86	0.76	51	0.211
8	40	62	0.44	70	0.076

* Veneer dryer emission not incinerated

Boiler steam production efficiencies were reduced when veneer dryer emissions were incinerated. They were poorest when veneer dryer emissions were being incinerated and wet fuel was being fired. Incineration of veneer dryer emissions resulted in about a 10 percent increase in fuel usage at this boiler despite the efficiency benefit associated with a warmer combustion air.

Total organic compound emissions and particulate and condensible organic compound emissions from the veneer dryer are listed in Table C-20 as a function of veneer produced for runs 1, 2 and 5. During runs 6, 7, and 8, several veneer dryers were venting emissions to the atmosphere making emission and production measurements useless. The average emission rate from the dryer was 1.6 lb as CH_4/MSF total organic emissions (NCASI data) and 1.2 lb/MSF particulate and condensible organic emissions as measured by ODEQ Method 7. These two measurements cannot be compared since one is expressed as methane and the other as a dry weight of material.

TABLE C-20 ORGANIC EMISSIONS FROM THE VENEER DRYER

Test No.	Veneer to Dryer[a] 1000 ft²/hr	Total Organic[b] Emissions lb/hr		Total Organic[b] Emissions lb/MSF		Condensible and Particulate Emissions lb/hr	Condensible and Particulate Emissions lb/MSF
		TRC	NCASI	TRC	NCASI		
1	31.7	93.7	32.6	2.96	1.02	31.4	0.99
2	28.8	47.1	46.7	1.64	1.62	37.8	1.31
5	24.3	37.6	42.1	1.89	2.10	31.1	1.28

a Production is reported as raw veneer going to the dryers multiplied by a shrinkage and trim factor of 0.85, expressed on a 3/8 in. basis.

b Total organics are reported as methane.

(5) Conclusions - The wood-residue fired boiler investigated in this study was capable of complete destruction of organic compounds in veneer dryer emissions when introduced to the unit with unheated combustion air. Total organic compound emissions from the boiler were generally lower when incinerating veneer dryer emissions in the combustion air. Both total organic compounds and condensible organic compounds were destroyed. Destruction of organic emissions was variable, ranging between 69 to 160 percent. The Dutch oven fuel quality or boiler load appeared to have no effect on the boiler organic destruction efficiency. Organic compound destruction efficiencies found at this boiler cannot be extrapolated to other boilers because of possible

organic destruction in this boiler by the secondary combustion chamber where sander dust is suspension fired with additional fresh combustion air.

Incineration of veneer dryer emissions in this boiler resulted in a decrease in steam production efficiency. Incineration of veneer dryer emissions required about a 10 percent increase in wood-residue fuel fired.

Emissions of total organic carbon from the veneer dryers averaged 1.6 lb as CH_4/MSF 3/8 in. basis, and ODEQ-7 measured particulate averaged 1.2 lb/MSF.

F. Mill E: A Study of Organic Emissions Resulting From Drying of Lodgepole Pine

(1) Objective - This study was undertaken to determine quantities of particulate and condensible organic compounds, and noncondensible organic compounds in uncontrolled veneer dryer emissions when lodgepole pine was being dried.

(2) Methods - The dryer was tested at each of two outlet stacks. An ODEQ-7 train modified to operate with a 88°C (190°F) front filter temperature was used to gather information on particulate and condensible organics. The wet end stack was sampled first and the dry end stack sampled an hour later. To determine noncondensible organic concentrations, a pair of EPA-25 trains were connected to the ODEQ-7 train following the 88°C (190°F) filter. A second pair of EPA-25 trains with filters held at 88°C (190°F) were used to simultaneously take samples at the stack not being sampled by ODEQ-7 train. This second set of EPA-25 trains did not employ isokinetic sampling and were drawn from a single point in the stack.

(3) Dryer Description - The dryer sampled was a 2 zone, 6 deck, 16 section, steam heated dryer. One-eighth inch thick veneer was dried during the tests. The green end temperature was maintained at 174°C (345°F) and the dry end temperature at 190°C (375°F).

(4) Results - Results of test are shown in Table C-21 and Table C-22. The results indicated, for the dryer operating conditions during the test, that lodgepole pine has an emission factor of 0.79 lb/MSF as dry weight for total particulate and condensible organics and 2.1 lb/MSF as CH_4 for noncondensible organics.

G. Mill G: A Study of Measurement of Volatile Organic Compound Emissions from a Veneer Dryer Fed Loblolly and Shortleaf Pine

(1) Objective - The primary goal of this study was to determine a total nonmethane organic compound emission factor using EPA Method 25. In conjunction with this work, particulate samples were taken using an ODEQ-7 train which allowed for the drawing of

(2 STACKS)
WET END + DRY END = TOTAL

MILL F

TABLE C-21 EPA-25 RESULTS FOLLOWING A 88°C (190°F) FILTER REPORTED AS CH_4 WHILE DRYING LODGEPOLE PINE

Run No.	Sample No.	Production* MSF/hr	Wet End Noncondensible Organic Emissions Flow DSCFM	ppm	lb/MSF	Dry End Noncondensible Organic Emissions Flow DSCFM	ppm	lb/MSF	Total Noncondensible Organic Emissions lb/MSF
A	9021/3	9.2	2520	1980	1.36	4990	752	1.02	
	9022/4		1545	1.05		634	0.87		
				Avg	1.20	Avg	0.95	2.15	
B	9025/7	8.4	2220	2006	1.38	5170	439	0.67	
	9026/8			1998	1.31		645	0.99	
				Avg	1.35	Avg	0.83	2.14	

Table 10

1.6

2.26

C - 27

TABLE C-22 ODEQ-7 TRAIN RESULTS REPORTED AS DRY WEIGHT WHILE DRYING LODGEPOLE PINE

MILL F

ONE RUN
WET + DRY = TOTAL

Run No.	Sample Train Catch	Production* MSF/hr	Wet End Condensible Organic Emissions Flow DSCFM	gr/DSCF	lb/MSF	Dry End Condensible Organic Emissions Flow DSCF	gr/DSCF	lb/MSF	Total Condensible Organic Emissions lb/MSF
A	Front-half — FILT. PM	9.2	2520	0.0476	0.12	4990	--	--	
	Back-half — ORG. COND.			0.0583	0.14		--	--	
	Total			0.1059	0.25		--	--	
B	Front-half	8.4	2220	--	--	5170	0.0685	0.37	0.48
	Back-half			--	--		0.0335	0.18	0.32
	Total			--	--		0.1020	0.54	0.79

FILT. PM

ORG COND.

*Production is on the basis of 3/8 in. trimmed veneer being fed to the dryer. A trim factor of 15% was used.

Method 25 samples after the front filter via a slipstream. The front filter temperature was varied in order to determine the effect this parameter had on the amount of organics measured as "particulate material" (front-half Method 5 catch) and the amount measured as volatile organic compounds.

(2) Description of Sampling Site - The forest products facility represented a typical modern plywood mill in the South. It contained a total of three 4 deck, steam heated, Coe jet-dryers. Dryer No. 1 was a 24 section, 3 zone unit; No. 2 was a 20 section, 3 zone unit; and No. 3 was a 12 section, 2 zone unit. Dryers No. 1 and 2 were approximately 3 years old, and dryer No. 3 was about 15years old. All dryers were normally operated at 193°C (380°F) using steam produced by wood-residue boilers on-site.

The mill's feedstock came from loblolly pine (Pinus taeda L.) and shortleaf pine (Pinus echinate Mill.) logs that were held in wet storage in a nearby woodyard. The logs were soaked in a caustic bath and then peeled into strips, normally 1/6 in. to 1/10 in. thick. The strips were cut into sections and stacked. The stacks were then moved to the dryers with forklifts and loaded automatically into the green end. One operator stood by at the loading point to remove rejects and to assure a steady flow of veneer to the dryer.

The veneer traveled through the dryer in about 8.9 minutes and was dried to about 7 percent moisture. A sensor at the exit marked pieces that were 7 to 10 percent moisture for use as outer plies. Pieces that contained greater than 10 percent moisture were marked as redry. The average redry rate was 12 percent.

Dried veneer was glued, pressed, and trimmed into finished plywood. Redry was held until enough was accumulated to run through a dryer a second time at a faster rate and/or lower temperature.

Each dryer had a separate 24 in. diameter stack for the green end zone. Dampers on these stacks were adjusted to obtain optimum drying conditions. At this mill, the No. 1 damper was kept about 70 percent open, and the No. 2 and 3 dampers were kept about 30 percent open. The stacks rose approximately 18 ft above the dryer and dampers to the roof, then another 8 ft above the roof. Each stack was fitted with a rain cap.

At the dry end of each dryer there were three 48 in. diameter cooling stacks that drew ambient air from above the roof, blew it across the hot veneer, and exhausted it through three similar stacks on the opposite side of the dryer. These stacks rose to the same level as the green end stacks and were also fitted with rain caps.

There were no emission control devices on the dryers. There were few fugitive emissions at this mill because of the integrity of the new dryers.

During the tests the average dryer temperature was 193°C (380°F) in all green end zones. Veneer that had been cut and stacked up to 24 hours before drying was run during the first test with an average drying time of 8.9 minutes, and an hourly rate of 867 pieces measuring 53.75 in. and 101.5 in. x 1/6 in. thick. During the second test veneer was taken directly from the peeler to the dryer. The drying time was fixed at 9.0 minutes and the production rate was 880 pieces/hr at the above dimensions.

The No. 1 stack was chosen for sampling with the ODEQ-7 train because approximately one-half of the total dryer green end emissions were exhausted at this point. The No. 1 dryer had been down for routine maintenance twelve days before testing. Only one door showed a visible leak around a seal and was termed insignificant.

(3) Results - An average emission rate of 3.7 lb total organic compounds/MSF was found when loblolly pine and shortleaf pine mixed stock were dried in a steam heated dryer. Individual test results are shown in Table C-23.

TABLE C-23 VOC EMISSION FACTOR DATA (METHOD 25)

Sample	VOC Concentration ppm	Stack Flow Rate dscfm	Production Rate (MSF/hr. 3/8 in. basis)	Emission Rate lb/MSF as CH_4
Run-1				
Stack #1	1990	5270	--	1.78
Stack #2	3400	2130	--	1.23
Stack #3	1040	2300	--	0.41
Stack #5	--	5170	--	--
Total		14,900	14.6	3.42
Run-2				
Stack #1	3360	4170		2.35
Stack #2	3130	2030		1.07
Stack #3	914	1830		0.28
Stack #5	100	5070		0.08
Total		13,600	14.8	3.78

**uncorrected for 12 percent redry

A general trend of decreasing total nonmethane organic compound concentration from the feed to the discharge end of the dryer was evident. Results from the first run showed concentrations of 1120, 1670, and 500 ppm as CH_4 for stacks No. 1, 2, and 3, respectively. Results from the second run showed concentrations of 1630, 1530, 430, and 26 ppm as CH_4 for stacks No. 1, 2, 3, and 5 (cooling stack), respectively. The only difference in production parameters between the two tests was the use of veneer that had been peeled up to 24 hours before being dried for the first test, and the use of freshly peeled veneer for the second test. Total organic compound emission rates expressed as lbs/MSF were somewhat higher when freshly peeled veneer was being dried. The freshly peeled veneer was dried with less air flow through the dryer causing the higher organic concentrations in the stack.

The first ODEQ-7 test had an average front filter temperature of 89°C (193°F), a sample volume of 25.6 DSCF, drawn over 60 minutes at an isokinetic sampling rate of 152 percent. The total front-half catch was 0.0179 gr/DCSF the total back-half catch was 0.0275 grains/DSCF. The second ODEQ-7 test had an average front filter temperature of 125°C (257°F), a sample volume of 37.1 DSCF, drawn over 60 minutes at an isokinetic sampling rate of 280 percent. The total front-half catch was 0.00545 gr/DSCF and the total back-half catch was 0.0439 gr/DSCF.

ODEQ-7

5270 dscfm 7.3 MSF/hr

4170 dscfm 7.4 MSF/hr

The filter temperature difference had a significant effect on the portion of material caught on the front filter versus the portion caught in the back half of the train. The front-half catch with a 88°C (190°F) filter was 39.4 percent of the total, while the front-half catch at 121°C (250°F) was only 11.2 percent of the total.

There was no significant difference between EPA Method 25 samples drawn from behind the ODEQ-7 front filters and those drawn simultaneously using in-stack filters. For the test with the 88°C (190°F) filter, 2460 ppm total organics was measured in the wet end stack as compared to 1990 ppm measured with an in-stack filter at 163°C (325°F). The test with the 121°C (250°F) filter gave a result of 3250 ppm as compared to 3360 ppm measured with a simultaneous sample taken with an in-stack filter. The differences in concentration found with the in-stack and out-of-stack filter were within the error of the EPA-25 Method.

H. Mill H: Measurement of Volatile Organic Compound Emissions from a Veneer Dryer Utilizing Loblolly and Shortleaf Pine

(1) Objective - The objective of this study was to determine typical total gaseous nonmethane organic compound emissions from the drying of southern wood species using EPA Method 25.

(2) Description of Sampling Site - The forest products facility studied represented a typical modern plywood mill in the South. It contained a total of three 4 deck, steam heated, Coe jet-dryers. Dryer No. 1 was a 26 section, 3 zone unit; No. 2 was a

20 section, 3 zone unit; and No. 3 was a 14 section, 2 zone unit. All dryers were approximately one year old at the time of testing, and were normally operated at 193°C (380°F) using steam produced by wood-residue boilers on-site.

The mill's feedstock came from loblolly pine (Pinus teada L.) and shortleaf pine (Pinus echinate Mill.) logs that were held in wet storage in a nearby woodyard. The logs were soaked in a caustic bath and then peeled into strips, normally 1/6 in. or 1/8 in. thick. The strips were cut into sections and stacked. The stacks were then moved to the dryers with forklifts and loaded automatically into the green end. One operator stood by at the loading point to remove rejects and to assure a steady flow of veneer to the dryer.

The veneer traveled through the dryer in about 8 minutes and was dried to a target of less than 7 percent moisture. A sensor at the exit marked pieces that contained 7 to 10 percent moisture for use as outer plies. Pieces that were greater than 10 percent moisture were marked as "redry". The average redry rate was 12 percent.

From this point the dried veneer was glued, pressed, and trimmed into finished plywood. Redry was held until enough was accumulated to run through a dryer a second time at a faster rate and/or lower temperature.

Each dryer had a separate 24 in. diameter stack for each green end zone. Dampers on these stacks were adjusted to obtain optimum drying conditions. At this mill, the No. 1 damper was kept 25 percent open, the No. 2 damper was kept closed (bleed off only) and the No. 3 damper was kept 25 percent open. The stacks rose approximately 18 ft. above the roof. Each stack was fitted with a rain cap.

At the dry end of each dryer there were three 48 in. diameter stacks that drew in ambient air from above the roof, blew it across the hot veneer, and exhausted it through three similar stacks on the opposite side of the dryer. These stacks rose to the same level as the green end stacks and were also fitted with rain caps. Previous studies have shown emissions from these stacks to be insignificant.

There were no emission control devices on these dryers. There were no major seal leaks on any of the dryers. Fugitive emissions were concentrated at the inlet end of the dryers and were probably caused by the damper settings. Since these emissions did not visibly constitute a major fraction of the total dryer emissions, and since there was no way to adequately sample them, they were not considered in subsequent emission level calculations. This point should be kept in mind when comparing results from these tests with results from similar tests at other facilities.

The No. 2 dryer was chosen for sampling since it had the lowest level of fugitive emissions. This dryer's feed was 1/8 in. veneer. Average zone temperatures during testing were 182°C (359°F), 194°C (382°F), and 198°C (389°F) respectively for zones 1, 2, and 3.

(3) Summary of Results - Results from two successful tests on the No. 2 dryer are listed in Table C-24 and showed total green end total organic component VOC emissions to be 37.8 lb/hr amd 37.4 lb/hr as methane. Results from a third test were discarded due to analytical difficulties. Production rates during the two tests were 13.89 x MSF/hr and 12.17 x MSF /hr, 3/8 in. basis, respectively, with an average redry rate of 12 percent and 13 percent respectively. This yielded mass emission rates of 2.7 and 3.1 lb/MSF, 3/8 in. basis. The lower production rate during the second run was due to some minor feeder problems that were corrected within a few minutes.

TABLE C-24 VOC EMISSIONS RESULTS

Run	Production MSF/hr. (3/8" Basis)	Percent Redry	Stack	Flowrate dcsfm	Percent H_2O	Total Gaseous Organics ppm as CH_4	Total Gaseous Organics lb/hr. as CH_4	Total Gaseous Organics Percent RSD	lb/MSF 3/8" Basis
1	13.89	12	1	830	74.6	10220	21.2	1.11	
			2	700	60.7	4810	8.3	14.1	
			3	1300	32.8	2560	8.3	•	
Total			2830				37.8		2.7
2	12.17	13	1	860	69.6	9357	20.0	8.58	
			2	800	54.1	5092	10.1	2.14	
			3	1510	22.2	1955	7.3	2.50	
Total				3160			37.4		3.1
								Avg =	2.9

• only one sample

I. Mill I: Emissions from a Wood-Residue Fired Veneer Dryer

(1) Objective - The objective of this study was to determine the amount of organic compounds and particulate matter in emissions from a wood-residue fired direct heated veneer dryer while drying white fir and hemlock. Analytical results are reported for: (a) total organics, (b) inorganic and wood particulate, (c) condensible organics, and (d) noncondensible organic emissions.

(2) Sampling Procedure - Total organic compound emissions were measured with EPA Method 25 preceded with an in-stack filter. Stack temperatures were above 163°C (325°F). Condensible organic compounds were measured with an ODEQ-7 sampling train. Organic material captured in the probe and front filter were dissolved with ether from the dried samples and filtered to remove inorganic particulate. The ether was evaporated, and the weight remaining added to the ODEQ-7 train back-half catch. The residue left on the filter after ether extraction was dried, weighed and considered to be inorganic and wood particulate.

The noncondensible organic emissions were measured with EPA Method 25 preceded by a 88°C (190°F) filter. On two samples the filter in the ODEQ-7 train was used, and the other two samples were taken with 88°C (190°F) filters designed for the EPA-25 train.

(3) Dryer Description - The dryer sampled was a 6 deck, 17 zone, 2 section longitudinal dryer with an additional 2 cooling sections. It is direct heated with a fuel cell fired with wood residue. The fuel cell was manufactured by Advanced Combustion Systems. Exhaust from the fuel cell immediately entered a cylindrical blend box where it is mixed with recycled dryer gases. The fuel cell exhaust gases are cooled by this blend box to about 650°C (1200°F) before being fed to the dryer. Gases were extracted from the veneer dryer by a fan and conveyed to either a blend box or the stack. Recycle to the blend box was controlled to maintain the blend box exit temperature at its set point. The unit is used to dry hemlock and white fir only. The green end temperature was between 157 to 171°C (315 to 340°F) during these tests. Hemlock, or a mixture of hemlock and white fir were dried during these tests.

Samples were drawn from a port in the duct ahead of the fan. Exit flow measurement for the first three tests were taken from an earlier sampling report by Mogul Corp. Flow measurements for the remainder of the tests used one measurement taken at the stack exit. The stack configuration had been changed between the first three tests and the remaining tests.

(4) Results - Production and flow data are shown in Table C-25. Results for the tests are shown in Table C-26. Total organic compound emissions for hemlock averaged 0.78 and ranged between 0.42 and 1.12 lb/MSF. This wide range of total organic compound emissions could not be explained. Noncondensible organics, as measrued by one test, was 1.04 lb/MSF for when hemlock was being dried. Noncondensible organics for mixed hemlock and white fir were lower, averaging 0.56 lb/MSF. Total particulate and condensible organic compounds averaged 1.8 lb/MSF and was of 78 percent particulate.

TABLE C-25 PRODUCTION DATA

Date	Run No.	Wood Species Hemlock %	Wood Species White Fir %	Production MSF/hr	Air Discharge DSCFM	Air Discharge to Production DSCF/SF
5/27	1	100	0	8.9	13,000	87.6
5/27	2	100	0	8.9	13,000	87.6
5/27	3	100	0	8.9	13,000	87.6
7/28	4	57	43	6.9	9,000	79.0
7/28	5	21	79	8.2	9,000	66.4
7/28	6	50	50	6.0	9,000	89.7
7/28	7	100	0	7.1	9,000	75.8
7/28	8	100	0	7.1	9,000	75.8

TABLE C-26 EMISSION DATA

No.	Pollutant	Results ODEQ-7 gr/DSCF	EPA-25 Following 190°F Filter ppm as CH_4	EPA-25 Following In-Stack 325°F Filter ppm as CH_4	lb/MSF
1	Total organics	--	--	103	0.42 as CH_4
2	Total organics	--	--	157	0.65 as CH_4
3	Total organics	--	--	221	0.92 as CH_4
4	Inorganic particulate	0.103	--	--	1.33
	Condensible organics	0.030	--	--	0.38 = 1.71
	Noncondensible organics	--	157	--	0.58 as CH_4
5	Noncondensible organics	--	139	--	0.43 as CH_4
6	Inorganic particulate	0.100	--	--	1.47
	Condensible organics	0.026	--	--	0.39 = 1.86
	Noncondensible organics	--	155	--	0.65 as CH_4
7	Noncondensible organics	--	289	--	1.06 as CH_4
8	Total organics	--	--	308	1.11 as CH_4

J. Mill J: Control Efficiency of a Wet Ionizing Scrubber for A Wood-Residue Fired Direct Heated Veneer Dryer

(1) Objective - A wood-redisue fired direct heated veneer dryer with emissions controlled by an ionizing wet scrubber was sampled to determine its efficiency of organic compound and particulate matter removal. A second objective was to determine if the opacity of the stack gases resulted from organic aerosols or from salt aerosols formed from combustion of plywood trim containing high salt level glue. Additional information on total organic compound, condensible organic, and total particulate and condensible organic emission factors from uncontrolled wood-residue fired direct heated dryers was also collected.

(2) Methods - ODEQ-7 samples were taken by BWR Associates at the inlet and outlet of a Ceilcote wet ionizing scrubber. In addition to the usual ODEQ-7 sample work-up the probe and front filter catch were extracted with acetone and the extract dried and weighed to determine the ratio of condensible organics to particulate matter. Samples were taken with EPA Method 25 preceded by a filter maintained at 88°C (190°F) at the inlet and oulet of the scrubber. The samples were drawn anisokinetically. One sample was taken with EPA Method 25 with an in-stack filter at the scrubber inlet.

(3) Source Description - This plywood mill had three dryers. Dryer 1 was a 6 deck, 11 section, single zone Prentice dryer. Dryer 2 was a 6 deck, 14 section single zone Moor dryer. Dryer 3 was a 6 deck, 12 section, single zone Moor dryer with a sealing section on the feed end. Heat to the three dryers was supplied by a central fuel cell. The exhausts from the dryers was returned to a central blend box and the excess vented to the scrubber. The hot gas supplied to dryers 1 and 2 passed through an additional blend box. Gas flows and temperatures in the system are shown in Table C-27.

TABLE C-27 GAS FLOWS TO THE DRYERS

Dryer No.	1 Supply	2 Supply	3 Supply
Temp °C (°F)	493 (920)	493 (920)	532 (990)
ACFM	33,400	35,000	45,700
DSCFM	11,000	11,600	11,600
Percent CO_2	5.0	5.0	7.5

Dryers 1 and 2 processed Douglas fir veneer during all the tests. Dryer 3 processed white fir for the first three tests and Douglas fir for the fourth test.

(4) Results - The ODEQ-7 test are shown in Table C-28. The ionizing wet scrubber attained total particulate and condensible oragnic matter removals ranging between 61 and 81 percent. The lower removal efficiencies were caused by a reduction in condensible organic compound removal. Particulate removal efficiencies ranged between 71 and 82 percent whereas condensible organic compound removal efficiencies ranged between 18 and 81 percent. Condensible organic compound removal was lowest when only Douglas fir was being dried although the condensible organic compound grain loading was not different from when a combination of Douglas fir and white fir were being dried.

Test results for noncondensible organic compounds are shown in Table C-29. The results showed an average increase of 12 percent in noncondensible organics across the scrubber.

K. Mill K: Investigation of the Fate of Veneer Dryer Organic Compounds Cycled Through a Blend Box at a Wood-Residue Direct-Fired Veneer Dryer

(1) Objective - A wood-residue direct-fired veneer dryer was sampled with EPA Method 25 for organic compounds to determine: (a) emission factors for drying Douglas fir veneer in this type of equipment and (b) the fate of organic compounds in the dryer emissions when passed through the blend box where hot combustion gases are cooled.

(2) Methods - Total organic compounds in veneer dryer emissions were determined with EPA Reference Method 25 preceded with a filter at stack temperature located at the dryer exit and at the duct following the blend box. Stack temperatures were 163°C (325°F) and 388°C (730°F) respectively. Noncondensible organic compounds were determined with EPA Method 25 preceded with a filter held at 88°C (190°F). Duplicate simultaneous samples were collected for total organic compounds and a single sample collected for the noncondensible organic compounds. Gas flow rates were determined by pitot tube traverse at the system outlet, dryer outlet, and the duct from the blend box to the dryer. Flows recycled to the blend box were calculated by material balance. Carbon dioxide and oxygen measurements were made by an Orsat meter and analysis of the EPA Method 25 sample tanks. Moisture levels in the ducts were determined by recovery of moisture from the EPA-25 burnout traps.

(3) Process Description - An 18 section, two zone, six deck logitudinal dryer processed veneer brought to the mill site by truck. There was no on-site log peeling operation at this mill. A wood-residue fired fuel cell manufactured by Advanced Combustion Systems supplied heat directly to the dryer. The wood-residue fuel was derived from sander dust and hogged plywood trim. A small boiler attached to the fuel cell supplied steam to other plant processes.

21.8 MSF/hr (PM+COM) 19.5 MSF/hr 21.2 MSF/hr ODEQ-7 25.6 MSF/hr DOUG FIR ONLY

TABLE C-28 PARTICULATE AND CONDENSIBLE ORGANIC COMPOUND MEASUREMENTS

DOUG FIR / WHITE FIR

Run No.	1		2		3		4	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Flow DSCFM	24,300	23,100	23,600	23,400	25,100	24,400	28,800	26,200
Temp. °C	147	66	154	63	152	64	152	62
(°F)	(296)	(150)	(310)	(146)	(305)	(148)	(305)	(143)
gr/DSCF	0.164	0.035	0.154	0.033	0.146	0.044	0.128	0.056
Emissions lbs/~~MSF~~hr	34.2	6.9	31.1	6.5	31.4	9.1	30.8	12.6
Percent organic	13.1	18.0	17.4	16.9	10.7	12.1	19.6	39.7
Emissions lb/MSF	1.56	0.32	1.46	0.37	1.48	0.43	1.21	0.49
Scrubber Efficiency	21.9 MSF/hr	21.6 MSF/hr	21.3 MSF/hr	17.6 MSF/hr	21.2 MSF/hr	21.2 MSF/hr	25.5 MSF/hr	25.7 MSF/hr
Particulate		82.2		80.5		72.2		71.0
Organic		74.0		81.1		68.9		18.3
Over-all		81.1		80.6		72.3		60.7

M-25?

TABLE C-29 NONCONDENSIBLE ORGANIC COMPOUND AND CO MEASUREMENTS

Run No.	1		2		3		4	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Total Organics ppm	--	222	226	297	--	--	561	508
lb/MSF	--	0.53	0.68	0.80	--	--	1.20	1.29
CO ppm	--	2680	1960	1900	--	--	1650	1530
CO_2 Percent	--	3.9	3.8	3.7	--	--	3.5	3.0
Scrubber Efficiency	--	12.3%	10.3% -17.6	9.9%	--		8.8% -7.5	6.8%

Hot combustion gases from the fuel cell were blended with return air from the dryer in an attached chamber (blend box) to reduce the burner exhaust temperature to about 388°C (730°F) to prevent melt down of the duct work. Approximately 45 percent of the dryer exhaust was recycled to the blend box. The hot air entered the dryer in the plenum above each section.

(4) Results - Data from two sampling runs are reported in Table C-30. Data from run No. 1 are not reported due to leaks in the sampling system and the results judged not representative. Douglas fir heartwood and Douglas fir sapwood were dried during runs 2 and 3 respectively. Total organic emissions from the dryer system to the atmosphere were 2.4 lb/MSF for Douglas fir heartwood and 3.9 lb/MSF for Douglas fir sapwood. The noncondensible organic emissions were 1.7 lb/MSF for Douglas fir heartwood and 3.0 lb/MSF for Douglas fir sapwood. Carbon monoxide emissions from the dryer to the atmosphere averaged about 120 lb/hr or 8.8 lb/10^6 Btu heat input as determined by analysis of the EPA Method 25 evacuated tanks.

TABLE C-30 ANALYTICAL RESULTS

Run No.	Sample Location	Filter Temperature °C (°F)	Stack Flow DSCFM	Production MSF/hr	Non-Methane Organics ppm	Non-Methane Organics lb/hr	Non-Methane Organics lb/MSF	CO ppm	CO lb/hr
2	Fuel Cell Outlet	388 (730)	22,800	11.5	342	19.4	1.7	4330	
					488	27.6	2.4	4200	
				Avg.	415	23.5	2.1	4260	240
		88 (190)			445	25.2	2.2	4200	
	Dryer Outlet	163 (325)	27,600	11.5	712	48.9	4.3	2630	
					691	47.4	4.1	2640	
				Avg.	702	48.2	4.2	2640	181
		88 (190)			509	34.9	3.1	2320	
	Duct to Scrubber	163 (325)	15,900	11.5	702	27.8	2.4	2640	104
		88 (190)			509	20.1	1.7	2320	
3	Fuel Cell Outlet	388 (703)	23,460	7.17	367	21.4	3.0	4470	
					426	24.5	3.4	4520	
				Avg.	396	22.9	3.2	4500	260
		88 (190)			253	14.7	2.1	4550	
	Dryer Outlet	163 (325)	29,600	7.17	675	49.7	6.9	3190	
					693	51.0	7.1	3100	
				Avg.	684	50.4	7.0	3140	232
		88 (190)			517	37.6	5.2	3060	
	Duct to Scrubber	163 (325)	16,600	7.17	684	28.2	3.9	3140	130
		88 (190)			517	21.4	3.0	3060	

Total organic emissions being returned to the fuel cell blend box averaged 21.3 lb/hr whereas the blend box exit gases contained averaged 23.2 lb/hr. These results indicated there was a small increase in total organics throught the blend box. The burner produced 13.7×10^6 Btu/hr as calculated from a factor of 1840 SCF $CO_2/10^6$ Btu that is typical of burning wood-residue (24). The increase in total organics through the blend box corresponds to an organic compound contribution from the fuel cell of 0.14 lbs organic compounds/10^6 Btu. For comparison, a spreader stoker wood-residue fired boiler produces from 0.04 to 0.1 lbs organic compounds/10^6 Btu.

An average of 15.6 lb/hr noncondensible organic emissions were returned to the blend box whereas an average of 19.9 lb/hr noncondensible organics were discharged from the blend box. By difference, the condensible organics going to and from the blend box are 5.7 lb/hr and 3.3 lb/hr respectively. These calculations are presented in detail in Table C-31. A reduction in condensible organic compounds through the blend box with a corresponding increase in the total organic compounds indicated a partial break down of the higher molecular weight condensible compounds lower molecular weight noncondensible compounds.

(5) Conclusions - This study indicated that organic compounds in veneer dryer emissions were not converted to CO_2 and water when passed through a blend box at a wood-residue direct-fired veneer dryer. Higher molecular weight, condensible compounds are suspected to be partially broken down to lower molecular weight noncondensible organic compounds. Further studies would be needed to verify the above.

TABLE C-31 BALANCE OF CONDENSIBLE AND NONCONDENSIBLE EPA-25 MEASURED ORGANICS AT BLEND BOX OF WOOD-RESIDUE DIRECT-FIRED VENEER DRYER

		Total Organics lb/hr	Noncondensible Organics lb/hr	Condensible Organics lb/hr
a	Blend Box Outlet	23.2	19.9	3.3
b	Dryer Outlet	49.3	36.3	13.0
c	Duct to Scrubber	28.0	20.7	7.3
d	Return to Blend Box (btc)	21.3	15.6	5.7
e	Contribution from Burner (a-d)	1.9	4.3	-2.4
f	Conversion from Condensibles to Noncondensibles (e-1.9)	0	2.4	--

APPENDIX D

CALCULATIONS TO DETERMINE BOILER SIZE NEEDED TO ACCEPT VENEER DRYER EXHAUST GASES AS COMBUSTION AIR

CALCULATIONS TO DETERMINE BOILER SIZE NEEDED TO ACCEPT VENEER DRYER EXHAUST GASES AS COMBUSTION AIR

Control of veneer dryer emissions by incineration of dryer exhaust gases in a boiler producing steam for operations at a newly constructed plywood mil will require proper sizing of the boiler to accommodate the dryer exhaust gases. The calculations that follow find: (a) the size of a well operated boiler needed to provide steam to a plywood mill that has three veneer dryers, and a plywood press, (b) the size of a boiler at an identical mill that uses the boiler to incinerate the veneer dryer exhaust gases, and (c) boiler efficiencies and flame temperatures for both cases above. These calculations were reviewed by Rosemary Mattick of Weyerhaeuser Co., Corporate Energy, Development Section.

A. Example 1: Wood-Residue Fired Boiler Size Calculations for Plywood Mill with Veneer Dryer Emission Not Being Incinerated

(1) Basis - A plywood mill with a capacity of 570 MSF/day (170,000 MSF/year at 300 operating days/year) with three steam heated veneer dryers. To account for redry and down time, each dryer can accept 10 MSF/hr on a trimmed panel size, 3/8 in. thick basis. Boiler size requirements will be calculated for a mill processing Douglas fir and for a mill processing Southern pine. For energy conservation purposes, air flow through the dryers will average 30×10^3 DSCF/MSF. A diagram of the assumed boiler/mill configuration is shown in Figure D-1.

Fuel for the boiler will be derived from plywood trim, sander dust, peeling wastes, and bark. Dry plywood trim is estimated to be 4500 lb/hr. Plywood trimmings stored outside will increase in moisture due to rainfall, and may contain more than 35 percent moisture on a dry weight basis. For this example, the plywood trim is assumed to have 20 percent moisture on a dry basis. The remainder of the fuel is assumed to be at 100 percent moisture on a dry basis and is assumed to be approximately 6,500 lb/hr. The mixed fuel will have approximately 74 percent moisture on a dry basis.

(2) Solution - The energy required for the veneer dryers, from Figure 3, Section II A2, and allowing for some extra capacity, is 1.2×10^6 Btu/MSF for Douglas fir and 1.5×10^6 Btu/MSF for southern pines. Assuming 824 Btu delivered to the dryers per pound of steam, and 10,000 lb/hr steam to operate presses and log conditioning, a mill processing Douglas fir requires 54,000 lbs of steam/hr (2.0×10^6 Btu/MSF) and a mill processing southern pine requires 65,000 lb of steam/hr (2.4×10^6 Btu/MSF). A boiler with 60,000 lb/hr steam production capacity would be required for the mill processing Douglas fir and 70,000 lb/hr steam production capacity for the mill processing southern pine.

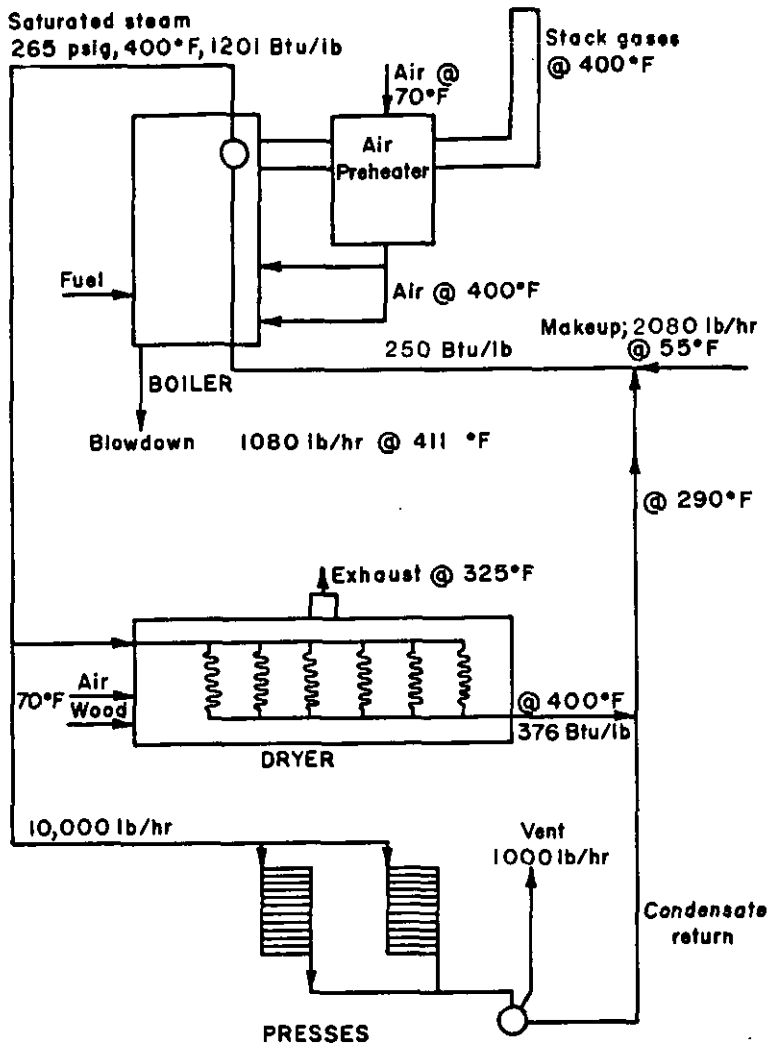

FIGURE D-1

BOILER AND STEAM SYSTEM FOR PLYWOOD MILL

To estimate the cost differences between the cases where the boiler is or is not used to incinerate veneer dryer emissions, the costs of the portions of the boiler that may be affected by the incineration are used for comparison purposes. Thus, the cost estimates that follow do not include costs for the mill steam handling system, feed water return and conditioning system, or fuel storage and unloading facilities. The boiler produces low pressure steam and therefore does not have a super heater. This boiler includes a scrubber. These boilers would cost about $1,500,000 and $1,610,000 respectively, based on a 2/3 scaling from a 1982 bid for a 80,000 lb/hr boiler at $1,760,000, installed, turn key. Other sources indicate that these cost estimates are low.

(3) Boiler Efficiency Calculations - The boiler efficiency is calculated as follows:

Wood residue has a composition of 50 percent carbon, 6 percent hydrogen, and 44 percent oxygen by weight. The amount of air required to combust 100 lb of wood is shown below.

$$\frac{(0.5 \text{ lb C/lb wood})\ (100 \text{ lb wood})\ (1 \text{ mole } O_2/\text{mole carbon})}{(12 \text{ lb C/mole C})} =$$

4.17 mole O_2 required/100 lb wood =

4.17 mole CO_2 produced/100 lb wood

$$\frac{(0.06 \text{ lb H/lb wood})\ (100 \text{ lb wood})\ (\tfrac{1}{2} \text{ mole } O_2/\text{mole O})}{(1 \text{ lb H/mole H})\qquad(2 \text{ mole H/mole O})} =$$

1.5 mole O_2 required/100 lb wood =

3.0 mole H_2O produced/100 lb wood

$$\frac{(0.44 \text{ lb O/lb wood})\ (100 \text{ lb wood})\ (\tfrac{1}{2} \text{ mole } O_2/\text{ mole O})}{16 \text{ lb O/mole O}} =$$

1.37 mole O_2 in wood/100 lb wood

Total oxygen required = 4.30 mole/100 lb wood

Wood has a heating value of 8700 Btu/lb

Stoichiometric oxygen required =

(4.3 mole/100 lb wood)(8700 Btu/lb wood) =

4.94 mole/10^6 Btu

At 45 percent excess air, the total oxygen required is 7.17 mole/10^6 Btu

At 21 percent oxygen in the combustion air, nitrogen fed to the boiler is 26.96 mole/10^6 Btu

From these molar flows the dry flue gas has a composition of 6.8 percent O_2, 14.1 percent CO_2 and 79.4 percent N_2.

Heat losses up the stack for dry gases are calculated as follows.

Assume a stack temperature of 400°F, and an ambient temperature of 70°F

O_2: (2.23 mole/10^6 Btu)(330°F)(7.3 Btu/mole °F) =
0.0054 Btu/Btu fired

CO_2: (4.79 mole/10^6 Btu)(330°F)(10.1 Btu/mole °F) =
0.0160 Btu/Btu fired

N_2: (26.96 mole/10^6 Btu)(330°F)(7.0 Btu/mole °F) =
0.0623 Btu/Btu fired

H_2O from
combustion: (3.45 mole/10^6 Btu)(330°F)(8.3 Btu/mole °F) =
0.0094 Btu/Btu fired

H_2O from air: (0.72 mole/10^6 Btu)(330°F)(8.3 Btu/mole °F) =
0.0019 Btu/Btu fired

H_2O from
combustion,
latent heat: (3.45 mole/10^6 Btu)(1053 Btu/lb)(18 lb/mole) =
0.065 Btu/Btu fired combustion, latent heat

Radiant heat loss = 0.018 Btu/Btu fired

Total Heat loss for combustion of dry wood = 0.178 Btu/Btu fired

Assuming 65 percent moisture (dry basis) wood residue fuel, the latent and sensible heat losses due to wood moisture are:

H_2O, latent:

(0.74 H_2O/lb wood)(1053 Btu/lb)/(8700 Btu/lb) =
0.0895 Btu/Btu fired

H_2O, sensible:

(0.74 H_2O/lb wood)(330°F)(8.3 Btu/mole °F)/(8700 Btu/lb)
(18 lb/mole) = 0.0129 Btu/Btu fired

Heat loss from wood moisture is 0.089 + 0.012 = 0.103 Btu/Btu fired.

Boiler Efficiency = 100 (1-0.178 - 0.103)

Boiler Efficiency = 72 percent

(4) Fuel Requirements - An energy balance on the water input and steam output from the boiler shows that 952 Btu/lb steam needs to be added to steam condensate returned to the boiler. The heat input is 8700 Btu/lb fuel. The boiler for the mill processing Douglas fir will burn 4.05 ton/hr wood residue and the boiler for the mill processing southern pine will burn 4.87 ton/hr wood residue on a dry basis.

(5) Boiler Air Requirements - Air requirements for the boiler at 45 percent excess air is 34.13 moles/10^6 Btu fired. For Douglas fir (DF) and southern pine (SP) the air requirements are:

DF: (54,000 lb steam/hr)(952 Btu/lb)(34.13 mole/10^6 Btu)
(385.2 ft^3/mole)/(0.73)(60) = 15,400 DSCFM

SP: (65,000 lb steam/hr)(952 Btu/lb)(34.13 mole/10^6 Btu)
(385.2 ft^3/mole)/(0.73)(60) = 18,600 DSCFM

Since the flue gas will have 8.3 moles $H_2O/10^6$ Btu fired, the flue gas will contain 19.6 percent water, and wet gas flow rates will be 18,400 SCFM and 22,200 SCFM respectively.

B. Example 2: Wood-Residue Fired Boiler Size Calculations for a Plywood Mill with Veneer Dryer Emissions Being Incinerated in the Boiler

(1) Basis - The plywood mill is the same as in example 1. Veneer dryer emissions are used as combustion air and are at about 300°F. The need for an air preheater is eliminated. The air preheater can be replaced with an economizer section on the boiler at approximately equivalent cost. The economizer will not reduce the stack gas temperature to the same level as the air preheater because the condensate return is already at a high temperature. The air flow through the dryer should be adjusted to satisfy the boiler air requirements. The boiler efficiency should be recalculated to account for the heat recovered from the veneer dryer exhaust. Figure D-2 depicts the mill/boiler configuration and heat flows or incineration of veneer dryer emissions.

(2) Solution - The boiler efficiency and flue gas volumes when veneer dryer emissions are incinerated were calculated in order to size the boiler.

Optimum excess air usage in a boiler will correspond to a minimum oxygen concentration in the exit gas that results in good combustion. Lower oxygen concentration will result in incomplete combustion and energy losss due to unburned material leaving the stack. High oxygen concentrations will result in heat losses to the stack due to the heating of excess air. Optimum combustion has been found to occur at about 45 percent excess air for wood-residue fired boilers. From example 1, the oxygen left following combustion is 2.23 mole/10^6 Btu fired. The total gas volume, including wood moisture is 42.45 mole/10^6 Btu fired, the O_2 concentration in the flue gas is 5.2 percent on a wet basis.

When veneer dryer emissions are incinerated in wood-residue fired boilers the oxygen in the combustion chamber is further diluted with moisture from the veneer dryer emissions. Assuming a 65 percent boiler efficiency, 54,000 lb/hr steam and 65,000 lbs steam respectively for DF and SP, and moisture inputs of 600 lb/MSF DF and 970 lb/MSF pine, moisture loads to the boiler are estimated to be 14.6 mole/10^6 Btu fired for Douglas fir and 19.1 mole/10^6 Btu fired for southern pine. Oxygen concentrations in the exit gas will decrease to 3.9 percent and 3.6 percent on a wet basis for processing Douglas fir and southern pine respectively. To prevent poor combustion resulting from oxygen

starvation the air provided to the boiler should be increased by 37 to 57 percent for Douglas fir and southern pine respectively to maintain 5.2 percent oxygen in the flue gas on a wet gas basis.

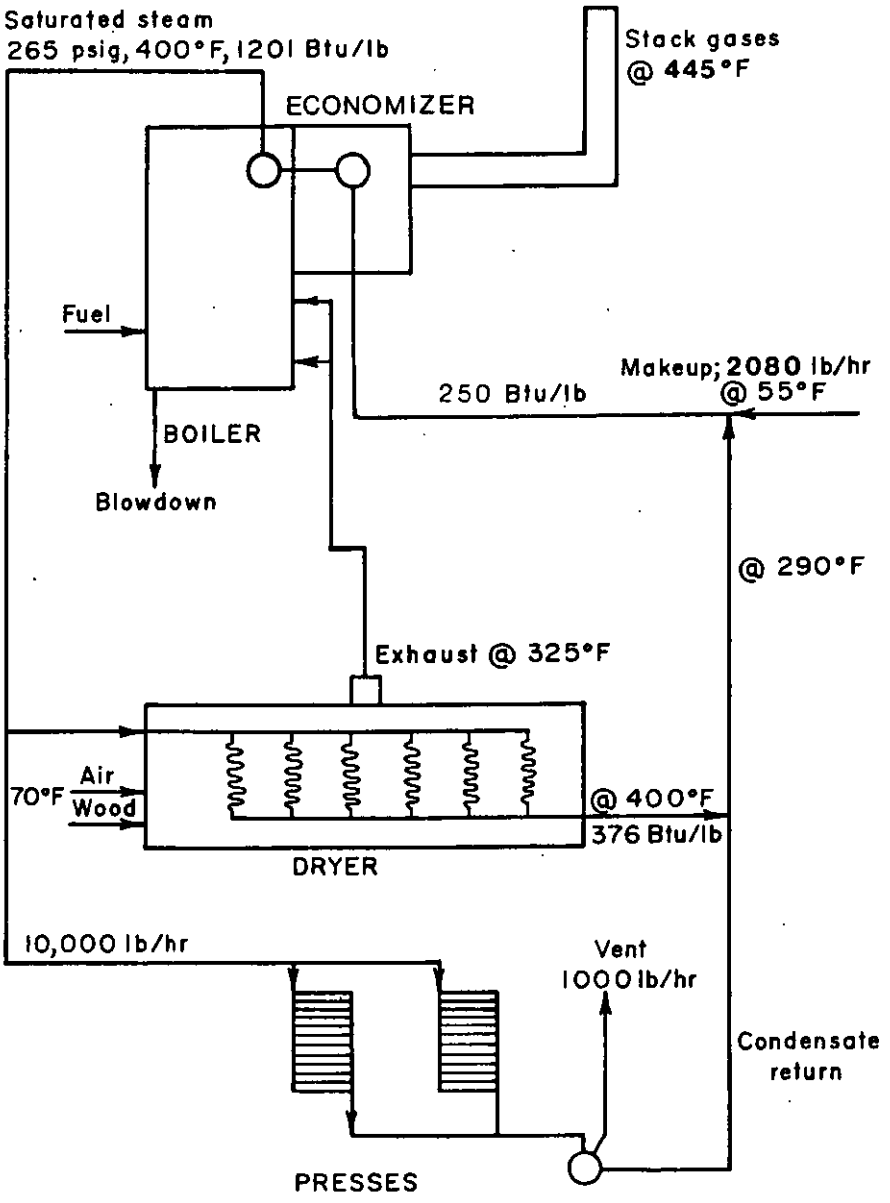

FIGURE D-2

BOILER AND STEAM SYSTEM FOR PLYWOOD MILL
USING VENEER DRYER EMISSIONS AS COMBUSTION AIR

(3) Boiler Efficiency Calculations - The results presented here were found by itterative calculations to result in a calculated efficiency that was the same as the initial assumed efficiency. A summary of the calculations appears in Table D-1. Heat losses per Btu fired are calculated using adjusted excess air levels and using a 445°F flue gas temperature for Douglas fir and 488°F for southern pine and a 300°F combustion air temperature.

The stack temperatures were calculated by a heat balance around the economizers. Hot gases from the boilers are assumed to enter the economizer at 650°F. Calculations of the energy balance for Douglas fir are as follows:

The change in heat content of the gases passing through the economizer is:

O_2: (7.4 Btu/mole °F)(3.19 mole/10^6Btu)(650 - T_o)
CO_2: (10.7 Btu/mole °F)(4.79 mole/10^6 Btu)(650 - T_o)
H_2O: (7.4 Btu/mole °F)(22.79 mole/10^6 Btu)(650 - T_o)
N_2: (7.2 Btu/mole °F)(30.57 mole/10^6 Btu)(650 - T_o)

The total heat change is (464 Btu/10^6 Btu)(650°F - T_o) or
(464 Btu/10^6 Btu)(54,000 lb steam/hr)(952 Btu/lb)/(0.72) =
31,300 Btu/hr (650 - T_o)

The heat used in heating water in the economizer is:

(61,200 lb/hr)(3.48 Btu/lb - 243 Btu/lb) = 6.43 x 10^6 Btu/hr

then:

(31,300 Btu/hr)(650°F - T_o) = 6.43 x 10^6 Btu/hr

T_o = 445°F

Similar calculations for southern pine give:

(42,990 Btu/hr)(650°F - T_o) = 6.96 x 10^6

T_o = 488°F

The boiler efficiency is calculated as follows:

O_2:	DF:	(3.19 mole/10^6 Btu)(145°F)(7.3 Btu/mole °F)	= 0.0034
	SP:	(3.45 mole/10^6 Btu)(188°F)(7.3 Btu/mole°F)	= 0.0048
CO_2:	DF:	(4.79 mole/10^6 Btu)(145°F)(10.1 Btu/mole °F)	= 0.0071
	SP:	(4.79 mole/10^6 Btu)(188°F)(10.1 Btu/mole °F)	= 0.0091
N_2:	DF:	(30.57 mole/10^6 Btu)(145°F)(7.0 Btu/mole °F)	= 0.0310
	SP:	(31.72 mole/10^6 Btu)(188°F)(7.0 Btu/mole °F)	= 0.0417

TABLE D-1 SUMMARY OF BOILER CALCULATIONS

	No Incineration		Incineration	
	DF	SP	DF	SP
Flue Gas, mole/10^6 Btu				
Oxygen	2.23	2.23	3.19	3.49
Nitrogen, Stoichiometric	18.58	18.58	18.58	18.58
Nitrogen, Excess	8.36	8.36	11.99	13.14
Carbon Dioxide	4.79	4.79	4.79	4.79
Water from fuel	8.17	8.17	8.17	8.17
Water from combustion air	0.72	0.72	14.62	19.07
Total flue gas	42.85	42.85	61.34	67.25
Flue Gas Composition, Percent				
Oxygen, wet basis	5.2	5.2	5.2	5.2
Oxygen, dry basis	6.6	6.6	8.3	8.7
Water	20.7	20.7	37.1	40.5
Excess Air, Percent	45	45	65	71
Steam Demand, lb/hr	54,000	65,000	54,000	65,000
Boiler efficiency, percent	73	73	76	73
Boiler heat input, 10^6Btu/hr	70.4	84.8	67.6	84.8
Boiler heat input, 10^6Btu/MSF	2.35	2.82	2.25	2.83
Fuel required, ton/hr	4.05	4.87	3.89	4.87
Total flue gas flow, SCFM	19,400	23,300	26,600	36,600
Flue gas temperature, °F	400	400	445	488
Combustion air required, DSCFM	15,400	18,600	16,800	21,850
Combustion air required, DSCF/MSF	30,800	37,100	33,600	43,700
Boiler size increase, percent	--	--	37	57

H_2O from combustion:

DF: (3.45 mole/10^6 Btu)(145°F)(8.3 Btu/mole °F) = 0.0042
SP: (3.45 mole/10^6 Btu)(188°F)(8.3 Btu/mole °F) = 0.0054

H_2O latent heat from moisture:

(3.45 mole/10^6Btu)(18,720 Btu/mole) = 0.0646

H_2O from wood moisture:

DF: (4.72 mole/10^6 Btu)(145°F)(8.3 Btu/mole °F) = 0.0057
SP: (4.72 mole/10^6 Btu)(188°F)(8.3 Btu/mole °F) = 0.0074

H_2O latent heat from wood moisture:

(4.72 mole/10^6 Btu)(18,720 Btu/mole) = 0.0884

Radiant heat 0.018

H_2O from veneer dryer

DF: (14.62 mole/10^6 Btu)(145°F)(8.3 Btu/mole °F) = 0.0176
SP: (19.07 mole/10^6 Btu)(188°F)(8.3 Btu/mole °F) = 0.0298

Total heat loss

DF: 0.24 Btu/Btu fired
SP: 0.27 Btu/Btu fired

Efficiency:

DF: 76 percent
SP: 73 percent

(3) Boiler Fuel Requirements - Assuming that 952 Btu/lb steam is to be added to the steam condensate returned to the boiler, and the heating value of the fuel is 8700 Btu/lb, the boiler will require 3.89 ton/hr and 4.87 ton/hr wood-residue fuel for the mills processing Douglas fir and southern pine respectively.

(4) Boiler Air Requirements - Air requirements for the boiler using 60 percent excess air for Douglas fir and 65 percent excess air for southern pine are:

DF: (54,000 lb steam/hr)(952 Btu/lb)(38.69 mole/10^6 Btu)
(385.2 ft^3/mole)/(0.76)(60) = 16,800 DSCFM

SP: (65,000 lb steam/hr)(952 Btu/lb)(40.14 mole/10^6 Btu)
(385.2 ft^3/mole)/(0.73)(60) = 21,850 DSCFM

This corresponds to 33,600 DSCF/MSF and 43,700 DSCF/MSF air from the dryers for Douglas fir and southern pine respectively. Dryers can easily operate in these air flow ranges although thermal efficiency will be reduced. Since the flue gas will have 22.79 moles $H_2O/10^6$ Btu, and 27.24 moles $H_2O/10^6$ Btu fired for Douglas fir and southern pine respectively, total gas flows through the boilers will be 26,600 SCFM and 36,600 SCFM respectively. These flows represent increases in gas flow through the boiler due to incineration of veneer dryer emissions of about 37 and 57 percent respectively. To accommodate the additional gas flow, the boiler for the mill processing Douglas fir should be initially rated at 80,000 lb/hr nominal size and derated to 60,000 lb/hr. The boiler for the mill processing southern pine should be initially rated to produce 110,000 lb/hr steam, and be derated to 70,000 lb/hr. Costs for these boilers at 1982 prices are estimated to be $1,760,000 and $2,200,000 respectively. The capital cost portion of these boilers used for pollution control abatement is approximately $260,000 and $590,000 respectively for the mills processing Douglas fir and southern pine.

C. Adiabatic Flame Temperature Calculations

(1) Example 3 - Calculate the effect of veneer dryer emissions on adiabatic flame temperature. Calculate: (a) heat transfer area requirements (b) flame stability.

(2) Solution - Adiabatic flame temperatures are calculated from energy balances around the flame assumming no heat loss.

H prod = H reactants + Heat of reaction.

Case 1: No veneer dryer emissions are being incinerated. Combustion air is preheated to 400°F. Calculations are on a basis of Btu release from heat of reaction and zero energy at 70°F.

Constituent Reactants	Mole/10^6 Btu fired	Cp Btu/mole °F	ΔT °F	Energy Input Btu/Btu Fired
Fuel	117.6	0.55 Btu/lb°F	0	0
O_2 reaction	4.94	7.2	330	0.011
O_2 excess	2.23	7.2	330	0.005
N_2	26.96	7.1	330	0.063
H_2O air	0.72	8.2	330	0.002
H_2O sensible	8.17	8.2	0	0
H_2O latent	8.17	18720 Btu/mole	--	-0.153
Total Energy Input				-0.0720

Constituent Products	Mole/10^6 Btu Fired	Cp Btu/mole °F	mCp Btu/°F 10^6 Btu Fired
O_2 excess	2.28	8.2	18.7
CO_2	4.79	12.5	59.9
N_2	26.96	7.7	207.6
H_2O reaction	3.45	9.7	33.5
H_2O air	0.72	9.7	7.0
H_2O wood moisture	8.17	9.7	79.5
Total			404.2

ΔT ($404.2/10^6$) = 1.0 Btu/Btu fired - 0.072 Btu/Btu fired

ΔT = 2296°F

Adiabatic flame temperature = ΔT + 70 = 2566°F

Case 2: Veneer dryer emission from processing Douglas fir are being used as boiler combustion air at 300°F.

Constituents Reactants	Mole/10^6 Btu Fired	Cp Btu/mole °F	Δ T °F	Energy Input Btu/Btu Fired
Fuel 117.6 lb/10^6 Btu fired		0.55/lb°F	0	0
O_2 reaction	4.94	7.2	230	0.008
O_2 excess	3.19	7.2	230	0.005
N_2	30.57	7.1	230	0.050
H_2O sensible	8.17	8.2	0	0
H_2O latent	8.17	18720 Btu/mole	--	-0.153
H_2O emissions	14.62	8.2	230	0.027
Total heat input:				-0.062

Constituents Products	Mole/10^6 Btu Fired	Cp Btu/mole °F	mCp Btu/°F 10^6 Btu Fired
O_2 excess	3.19	7.9	25.2
CO_2	4.79	12.2	58.4
N_2	30.57	7.5	229.3
H_2O reaction	3.45	9.2	31.7
H_2O air	14.62	9.2	134.5
H_2O wood moisture	4.72	9.2	43.4
Total			522.6

ΔT ($522.6/10^6$) = 1.0 Btu/Btu fired - 0.062 Btu/Btu fired

ΔT = 1795°F

Adiabatic flame temperature = 1795 + 70 = 1865°F

A minimum adiabatic flame temperature of 1700°F is required to support combustion in a spreader stoker wood-residue fired boiler (26). When fuels with moisture contents greater than 100 percent on a dry weight basis are being fired, auxiliary fuel may be required to maintain the flame temperature above 1700°F.

Case 3: Veneer dryer emissions from processing southern pine are being used as boiler combustion air at 300°F.

Constituents Reactants	Mole/10^6 Btu Fired	Cp Btu/mole °F	ΔT °F	Energy Input Btu/Btu Fired
Fuel	117.6 lb/10 Btu Fired	0.55/lb °F	0	0
O_2 reaction	4.94	7.2	230	0.008
O_2 excess	3.49	7.2	230	0.006
N_2	31.72	7.1	230	0.052
H_2O sensible	8.17	8.2	0	0
H_2O latent	8.17	18720	--	-0.153
H_2O emissions	19.07	8.2	230	0.036
Total energy input				-0.0512

Constituents	Mole/10^6 Btu Fired	Cp Btu/mole °F	mCp Btu/°F Btu Fired
O_2 excess	3.49	7.7	26.9
CO_2	4.79	11.7	56.0
N_2	31.72	7.4	234.7
H_2O reaction	3.45	8.9	30.7
H_2O emissions	19.07	8.9	169.7
H_2O wood moisture	4.72	8.9	38.0
Total			556.0

$\Delta T\ (556.0/10^6) = 1.0$ Btu/Btu fired - 0.0512

$\Delta T = 1710°F$

Adiabatic flame temperature = 1780°F

A minimum adiabatic flame temperature of 1700°F is required to support combustion in a spreader stoker wood-residue fired boiler (26). When fuels with moisture contents greater than the design value of 100 percent on a dry basis are being fired, auxiliary fuel may be required to maintain a flame temperature above 1700°F.

(3) Loss of Radiant Heat Transfer Due to Lower Flame Temperature - Calculate the radiant heat transfer with and without veneer dryer emissions:

Without: $(2366 + 460)^4 - (860°R)^4 = 6.32 \times 10^{13}$
With, DF: $(1865 + 460)^4 - (860°R)^4 = 2.86 \times 10^{13}$
With, SP: $(1780 + 460)^4 - (860°R)^4 = 2.46 \times 10^{13}$

The ratios of radiant heats with and without veneer dryer emissions going to the boiler are:

DF: 2.86/6.32 = 0.45
SP: 2.46/6.32 = 0.34

Normally 50 percent of the heat transfer in a boiler is by radiation. Due to the reduced radiant heat transfer, the boiler size needs to be increased by a factor of:

DF: 1/[(0.50)(0.45) + 0.5] = 1.38
SP: 1/[(0.50)(0.34) + 0.5] = 1.44

These increased size requirements are similar to the increased boiler sizes required to handle the increased gas volumes.

D. Summary

(1) A boiler designed to provide steam to a plywood mill that produces 570 MSF/day plywood on a 3/8 in thick basis would need to be able to have a capacity of 60,000 lb steam/hr for drying Douglas fir veneer, and 70,000 lb steam/hr for drying southern pine veneer. The boiler would have an energy utilization efficiency of 72 percent when operated at optimum conditions.

(2) A boiler designed to provide steam for the same mill above but also incinerate the veneer dryer exhaust gases will need to be sized 37 percent larger for when Douglas fir veneer is being dried, and 57 percent larger for when southern pine veneer is being dried to be able to accommodate the moisture load from the dryers. The boiler efficiencies at optimum operation for these curves are 76 and 73 percent respectively.

(3) A minimum adiabatic flame temperature of 1700°F is required to support combustion in a spreader stoker wood-residue fired boiler (26). Incineration of veneer dryer exhaust gases reduces the adiabatic flame temperature from 2570°F for when no exhaust gases are being incinerated to 1870°F for Douglas fir and 1780°F for southern pine for when dryer exhaust gases are being incinerated. Burning of wetter fuels than assumed for these calculations may result in lower flame temperatures and a need to use supplemental fuel to maintain combustion when veneer dryer emissions are being incinerated.