AP42 Section: **11.13 Glass Fiber Manufacturing**

Title: **Miscellaneous reports, comments and submittals**

Note: This material is related to a section in *AP42, Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources.* AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

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KY NAT. RES. & ENV. PROT. CABINET, DIV. FOR AIR QUALITY ADDRESS
18 REILLY RD. CITY
FRANKFORT STATE
KY AGENCY ZIP 40601 PHONE
(502)564-3382

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Oxy-Fuel Firing Improves Plant Operation

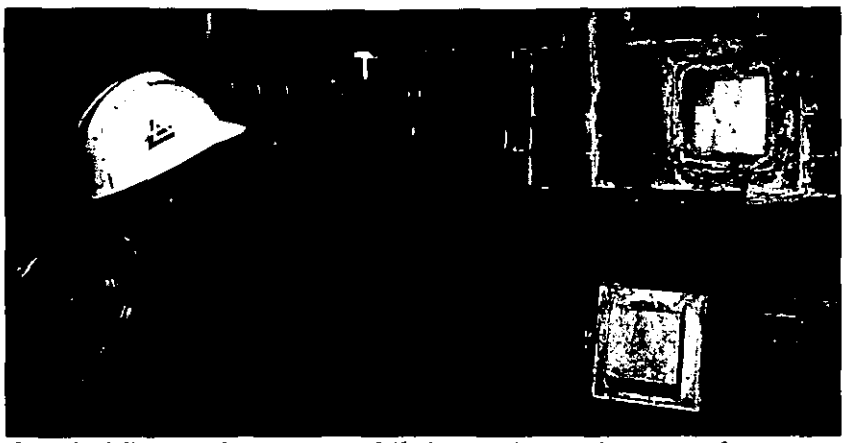
CI Staff Report

Techneglas Inc. (formerly OI-NEG TV Products Inc.), a manufacturer of glass for colored television funnels, wanted to reduce costs in conjunction with rebuilding its furnaces to expand melting capacity.

Techneglas' Columbus, Ohio, glass plant used air-based sideport regenerative furnaces to produce TV funnels. Because lead oxide—a requirement for X-ray protection for the TV viewer—is corrosive in furnace exhaust gases, magnesite checker brick are required to recover heat in the glass melting process. As exhaust gas passed through the regenerators en route to Techneglas' electrostatic precipitator, particulates containing the lead oxide condensed in the regenerators, causing blockage. Particulate matter also accumulated below the checker brick in the canals.

Techneglas had to reduce its operation approximately one week every four months to remove the particulate material that had deposited in the canals. This procedure posed a hazardous waste handling problem and cost the glass manufacturer production time. By eliminating the checker brick typically present in air-based furnace systems, Techneglas realized it could eliminate the waste handling problem, reduce the costs associated with cleaning the canals and avoid reductions in production time.

In evaluating alternatives to traditional combustion methods, Techneglas engineers worked with researchers from Air Products & Chemicals Inc., Allentown, Pa. They compared oxy-fuel combustion to a regenerative furnace using an ammonia injection system. After extensive evaluation, it was concluded that an ammonia injection system would require a large initial capital cost and ongoing operating costs.



Oxy-fuel firing reduces costs while improving environmental performance at Techneglas Inc.

Techneglas decided that oxygen-based combustion would require less up-front capital, eliminate the regenerators and associated maintenance/disposal problems, and thus enable Techneglas to reduce costs significantly.

Techneglas decided to convert to a Cleanfire® oxy-fuel burner system developed jointly by Air Products and Combustion Tec Inc., Orlando, Fla.

The first burner system—which consists of 12 burners for Techneglas' F furnace—was installed in February 1993. Another 12 burners for the C furnace were installed in December 1993.

Since the first set of burners was installed, the plant has achieved lower overall costs.

Techneglas has realized up to a 25% increase in glass production capacity when glass throughput is maximized. A significant portion of this increase can be attributed to the new oxy-fuel burner syster

Production increases are fu realized because regenerators absent from the oxy-fuel com tion furnace. Without the che brick, the glass producer no lo has to reduce operation every months to clean the canals. Pa late-containing flue gases are able to flow freely to the ele static precipitator.

The Cleanfire burners have enabled Techneglas to reduce its waste disposal problem, and reduce its NO_x and particulate emissions by more than 50%. Techneglas' natural gas usage has declined 30%—15% attributed to the switch to oxy-fuel and the other 15% to new furnace design.

Glass quality also has been maintained with the Cleanfire burner system. The burner's flame luminosity enhances heat transfer and maintains temperature consistency throughout the glass. □

For more information on:
Cleanfire® oxy-fuel burner systems ..... ***Circle 201***

GLASS

Traditional Ceramics

Removing Ceramic Contaminants from Cullet

The single biggest obstacle to increased glass recycling is ceramic contaminants. Recent industry studies point to optical techniques as the most suitable near-term technology for removing these contaminants

By: Robert De Saro,
Busek Co. Inc., Needham, Mass.

The trend in the container glass industry is to use as much reasonably priced, furnace-ready cullet as obtainable.

For every 10% increase in cullet use, a furnace energy reduction of 3% and an NO_x reduction of 2.5% occurs. A production increase also is possible.

Additionally, legislative pressure is forcing container plants to use more cullet or to provide increased quantities of recycled bottles.

In 1991, historically high levels of cullet use were reached—2.3 million tons by container plants, up 8% from 1990. On average, 31% of container feedstock is now cullet.

A major impediment to high cullet levels is glass contamination, primarily by ceramics.

Ceramic contaminants enter the cullet stream when misinformed, although well-intentioned, consumers mistakenly recycle these materials with their glass. They also may enter through the distribution chain.

However the contaminants get into the glass, their effect is serious—a reduction in furnace production due to an increase in bottle stone count.

Fig. 1 shows calculations demonstrating the deleterious effect of ceramic contaminants. The amount of foreign cullet that can be used (for a maximum 0.5% pack loss) is plotted against the number of ceramic contaminants. A 0.5% pack loss was chosen since anything larger would be intolerable and result in a cutoff of the cullet suppliers or other drastic action by the plant.

The ceramic size distributions were taken from Grasan crusher data. Four different solubility diameters are shown along with the ceramic type associated with them.

The solubility diameter is the ceramic diameter that will completely dissolve in one furnace pass. It is dependent on ceramic type, furnace residence time, glass melt composition and melt temperature.

Clearly, the effect on cullet use is largely tied to the ceramic type and loading. For instance, at a loading of six, the low-alumina ceramics (tile and brick) allow cullet uses as high as 70%; as one moves to porcelain, only 30% cullet is allowed, and with highly insoluble glass-ceramics only 10% or less is allowed.

Other contaminants also are present in the glass stream, although most of these can be removed with existing beneficiation equipment:

- Paper, plastic, labels and other light materials—vacuum system;
- Magnetic metals—magnetic separation;
- Large contaminants—hand picker;
- Nonferrous metals—eddy current detectors.

Of these, nonferrous metal separation, while easily accomplished, extracts the largest penalty, ≈5-8%

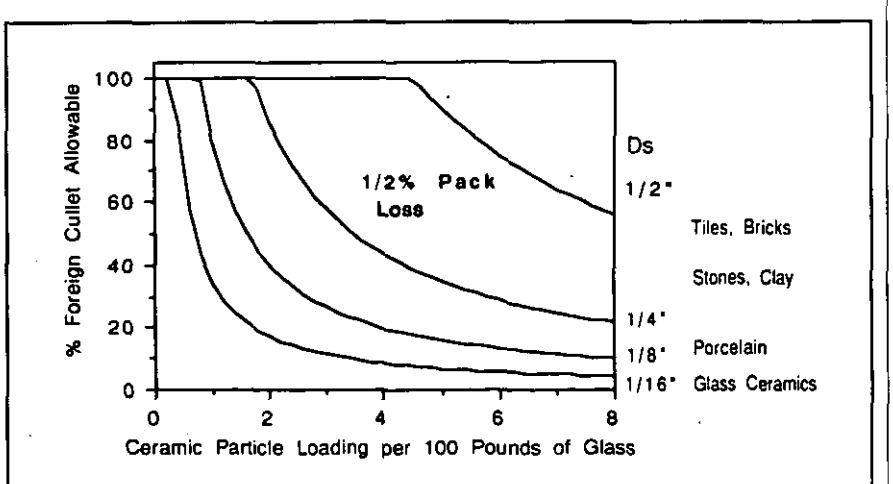


Fig. 1: Effect of ceramic contaminants.

Optical separation techniques selected as most suitable

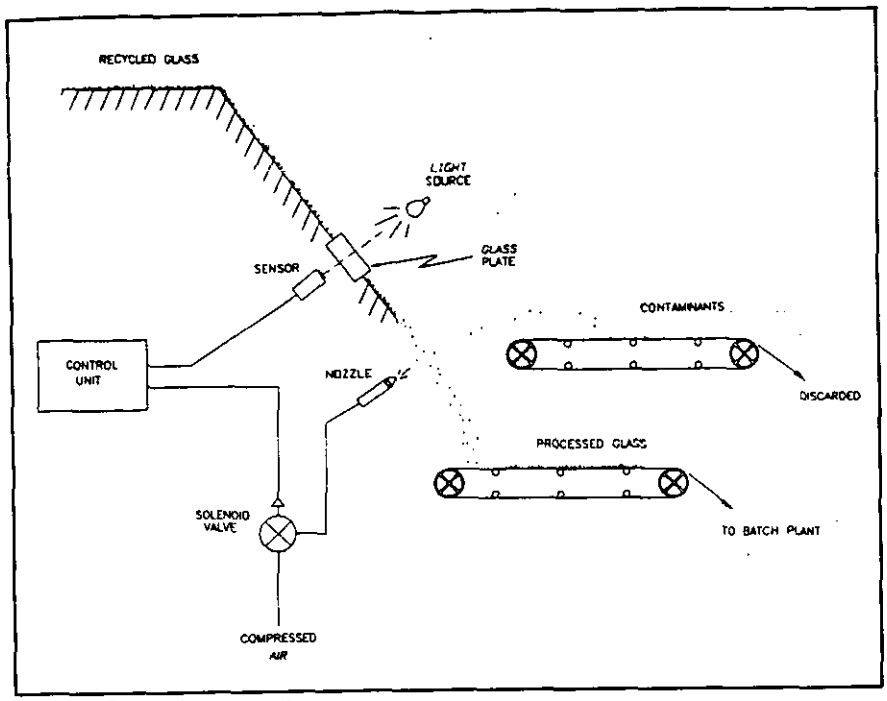


Fig. 2: Ceramic separator.

glass loss.

The two problems faced by container plants wishing to increase cullet usage are, in order of importance, ceramic removal and minimizing glass loss with nonferrous metal removal.

These problems were addressed in an applied R&D program designed to investigate and demonstrate state-of-the-art ceramic separation and nonferrous metal separators. Specific objectives were:

- Assess innovative equipment that can accomplish the separation.
- Develop equipment performance specifications.
- Develop vendor selection criteria.
- Select a vendor.
- Demonstrate the equipment.
- Disseminate the program results.

The program participants are:

- New York State Energy R&D Authority—a major program sponsor.
- Busek Co. Inc.—responsible for program management, the engineering study, equipment evaluation and testing.
- Owens-Brockway and Resource Recycling Technologies (RRT)—sponsor the program, host the demonstration, consult during the selection process and responsible for installing equipment.
- Glass Packaging Institute—a program sponsor that coordinates industry participation.
- EPRI's Center for Materials Production—a program sponsor.

The results of the engineering evaluation and the laboratory testing of each separator are presented.

Ceramic separator

Optical techniques were selected as the most suitable since they have been proved commercially in the food and pharmaceutical industries and more recently used in the European glass industry.

Another option, cullet pulverization, is being explored by a Canadian glass processor and a West Coast bottle manufacturer. Laboratory studies indicated that soda ash might preferentially react with finely crushed cullet rather than with the sand, which could leave unmelted silica stones. The current pulverization work should address this issue as well as fines carryover.

Optical techniques can be either transmissive or reflective; i.e., sensing the light after it passes through the glass or is reflected off it, respectively. Reflective techniques do not work if paper labels are present. With current technology, paper and ceramics have similar reflective properties, and too much glass would be lost as the separator would mistakenly reject the paper. One company avoids the problem by washing off the labels. However, the washing equipment is large, expensive and produces a sludge.

Transmissive techniques were chosen to avoid the paper label problem. Glass first enters a vibratory feeder that spreads the glass evenly over the separator's width, typically 4 ft (see Fig. 2).

The glass then slides down a metal plate, angled to assure a continuous flow of a single layer of glass without much tumbling.

At the bottom of the incline, the glass enters the detector, consisting of a pulsed light source on top, photodiode detectors on the bottom and a glass plate in between. The light either passes through the glass and is sensed by the detectors or is blocked by an opaque ceramic.

The glass then free falls past a series of nozzles. If a ceramic has been detected, one or more of the nozzles will fire a high-pressure air jet, and the ceramic, along with a small amount of glass, is removed.

The balance of the glass leaves the separator as a clean stream.

Approximately 200 photodiodes and light sources may be evenly spaced on 0.25-in. centers. The photodiodes are electronically tied to a small number of nozzles in the same lateral position, which allows the use of only a few nozzles for each contaminant rather than firing all the nozzles simultaneously. This greatly limits the glass loss.

The wavelength of the light is critical and is usually in the IR. The transmissivity of flint, amber and green glass in the IR is 90%, 60% and 85%, respectively, while most ceramics are zero. Furthermore, paper labels have reasonably high transmissivities in the IR, allowing the detectors to see through them.

Anything opaque to IR will be sensed and rejected by this system, including most ceramics, aluminum-coated labels, lead and crushed aluminum rings, as long as they are larger than 0.25 in. Anything smaller will likely pass through undetected.

The key to the economic success of a ceramic separator is the minimization of glass loss and operation at a throughput high enough to supply one or more furnaces continuously. Further, the cost and maintenance must allow a two-year payback.

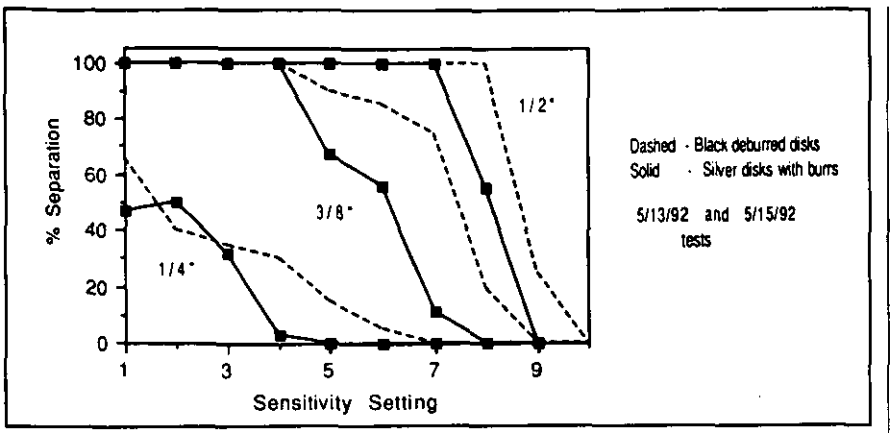


Fig. 3: ELKE separation tests.

A throughput of 25 tons/hr was originally set to provide cullet for two furnaces. However, if there are manual picking stations along the beneficiation equipment, 15 tons/hr is more realistic, as anything faster would make it difficult for the pickers to pull out all but the largest contaminants.

Also, it was stressed that the detectors must see through paper labels that are attached to the glass. The detectors are not designed to see through clumps of paper, since it was felt the vacuum system should be adequate enough to remove these prior to glass entering the detector.

The performance specification and previous description should not give the illusion of a one-stop, cure-all machine for ceramic separation. It is no substitute for consumer awareness, and it will not eliminate hand pickers.

For instance, if a heavily contaminated stream at 100 ceramic pieces/100 lb is processed, it is likely that one or two pieces will get through. At 25 tons/hr, 1000 pieces/hr will enter the otherwise furnace-ready cullet.

The ceramic detector should be thought of as one of several beneficiation steps, all of which are important, but no single one is a panacea.

Advantages

The advantage of the ceramic separator is that it allows an increase in cullet usage leading to:

- Energy savings—a 3% energy savings is realizable for each 10% increase in cullet use.
- A production increase.
- A NO_x reduction of 2.5% for each 10% increase in cullet use.

Initially, 56 companies offering ceramic detection equipment were contacted. The field was narrowed to six, and a detailed review of each was conducted.

In addition, eight European glass recyclers and container plant end users of this equipment were visited.

During the first phase, Owens-Brockway provided glass expertise that guided equipment selection.

Experimental studies were conducted on two models and resulted in tested separation as follows:

Ceramic size (in.)	Separation (%)
0.385 and above	100
0.30	90
0.25	60
0.20	30
0.195 and below	0
Glass loss = 1%	

One model, the ELKE, was installed at RRT, a glass recycler providing furnace-ready cullet to Owens-Brockway.

Laboratory tests

The separator was tested at the supplier's facilities prior to its installation at RRT. Both separation efficiency and glass loss were independently tested, using both flint and amber glasses.

Separation efficiency was measured by passing machined aluminum squares of various sizes, simulating ceramic contaminants, through the ELKE, and counting the number that were rejected. The tests were conducted at various sensitivity settings that can be adjusted on the front panel.

The glass loss was measured by passing either amber or flint glass, seeded with a known number of contaminants. Sensitivity and throughput were varied.

Fig. 3 shows percent separation as a function of the sensitivity setting. The sensitivity setting controls the sensor voltage that will trip a rejection. The sensitivity dial is marked so that increasing the dial setting decreases the sensitivity.

The sensitivity setting for a given glass loss would be lower for amber or green than for flint due to the colored glass's lower transmissivity.

Typical recommended settings are 2.7 for flint and 3.4 for amber, each of which will produce a 1% glass loss. At these settings, the larger contaminants are completely removed, and the 0.25-in. ceramics have a removal rate of 40% and 30% for flint and amber, respectively.

It is not possible to remove more than 65% of the <0.25-in. contaminants. This is partly a result of the photodiode spacing, since some pieces <0.25 in. will inevitably fall between sensors and never be detected. A 65% separation of <0.25 in. can never be achieved in practice since the glass loss associated with it would be unreasonably high.

Apart from the glass loss, it is not possible to increase the sensitivity continuously, as was done in these lab tests, since the solenoid valves have a finite cycle time and the air compressor has a limited capacity.

In an actual stream of glass, as would be encountered at a glass recycling facility, there will be a large number of contaminants and possibly loose paper, depending on the effectiveness of the vacuum system.

As the sensitivity is increased, more objects will be detected, and the solenoid-valve-operated air nozzles will fire with increasing frequency. A point will be reached where increasing the sensitivity will decrease the removal rate since the air pressure will decrease, not allowing sufficient force to eject the contaminant.

Also, ceramic pieces will slip through during the solenoid valve recovery cycle.

The sensitivity setting at which the removal rate starts to decrease in this

Increasing separator sensitivity also increases glass loss

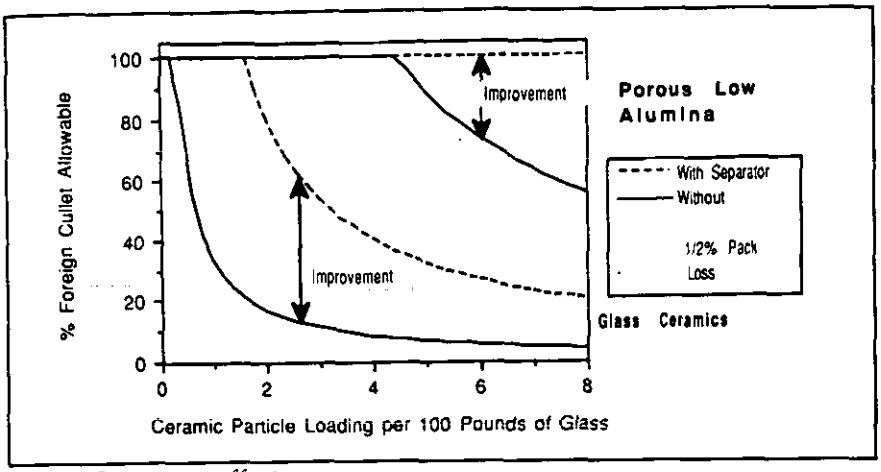


Fig. 4: Separator effect.

manner depends on the ceramic loading, amount of loose paper and compressor capacity, and likely will be plant specific.

As the sensitivity decreases, the removal efficiency of the contaminants is reduced. For the 0.25-in. particles, it is steadily reduced and goes to zero at a setting of seven. For the 0.375- and 0.5-in. particles, the result is qualitatively the same but with a steeper slope.

For the 0.5-in. particles, it is all or nothing: 100% separation at a setting of eight and zero at 10.

If one is interested in 0.5 in. removal, then it is recommended that the setting be no higher than seven since the fall-off point may not be repeatable for different detectors due to differences in the electronics. Going much above seven risks an unpredictable decrease in removal efficiency.

Glass loss tests took place in April 1992 and were run on flint glass with the sensitivity setting at 2.4. Glass loss was just under 1%, up to a throughput of 25 tons/hr and with a contaminant loading of 4.0-15.5. The optics were manually cleaned between test runs.

Inconsistent results were observed on amber glass, primarily because of the large amount of dust in the glass. This has the effect of obscuring the optics, leading to an increase in false rejections. The dusting effect was artificially increased since the same glass was used for repeated tests. It appeared that after each test run the amount of dust increased. The flint glass did not exhibit this tendency.

When the glass was screened to remove the dust, the glass loss was improved: 1.5% at 30 tons/hr and 0.7% at 19.5 tons/hr. At a high throughput of 50 tons/hr, the glass loss was more than 9%, even when the dust was sorted out.

Fig. 4, similar to Fig. 1, shows the beneficial effect the ceramic separator has for a glass container manufacturer. For clarity, two contaminants are shown: porcelain and tile. The allowable cullet use increases appreciably at any ceramic loading.

As a result of the laboratory tests, these conclusions were reached:

- The detector works and can remove a large percentage of ceramics.
- The removal rate will never be complete, with the larger contaminants (0.5 in. and larger) to be removed with a higher efficiency than the smaller ones.
- Increasing the sensitivity improves the separation efficiency but also increases the glass loss.
- Increasing the sensitivity continuously is counterproductive.
- Keeping the optics clean, especially in high glass dust conditions, is of significant importance in minimizing glass loss.
- A maximum throughput of 25 tons/hr has been demonstrated, although lower throughputs may be dictated by specific plant operations. Picking stations, or abnormally high contaminants and paper-burdened glass will force lower throughputs.

Nonferrous metal separator

While the focus of the current program is on ceramic detectors, the opportunity arose to test an advanced design of a nonferrous metal separator to be installed in RRT's facility along with the ELKE. This separator, known as ELPAC, is produced by the same company that makes the ELKE.

The advantage of the ELPAC is not that it can eliminate nonferrous metals—there are several commercially available devices that do so—but that it removes the metals with a greatly reduced glass loss: 0.5% compared to 5-8% with conventional devices. This is attributable to the nozzle-style arrangement of removal compared to the more prosaic diverter valve.

The ELPAC, however, extracts a price—higher costs, larger size and the possibility of missing metal contaminants due to the momentary air pressure lapses, or solenoid valve cycling, as was previously described for the ELKE. Also, the ELPAC cannot remove heavy metal objects—e.g., large bolts—due to the limited removal force the nozzles provide.

ELPAC laboratory tests

Separation efficiency and glass loss were tested. For the separation tests, aluminum tabs, foil, pull tabs, bottle caps and lead foil obtained from RRT were used, as well as simulated contaminants. The simulated contaminants were 0.125- and 0.25-in. aluminum squares 0.025 in. thick, and 0.09, 0.12 and 0.44 in. diameter lead shot.

The test procedure was to first pass individual contaminants through the ELPAC and record the number rejected, which yielded the separation efficiency.

Next, to test glass loss and separation efficiency simultaneously, ≈1000 lb of relatively clean flint glass was seeded with 25 aluminum tabs.

The amount of glass loss as compared to the throughput was measured and related to the number of rejections. The number of contaminants recovered also was used to determine separation efficiency.

For the first set of tests, a threshold voltage of 20 mV was used. A contaminant must induce a signal voltage of at least 20 mV for 3 ms to initiate pneumatic rejection. For the second set of tests, the threshold was increased to 50 mV, reducing the sensitivity to reduce the glass loss.

The test results show that all the contaminants were removed, and for

the simulated contaminants, all of the aluminum squares were removed. For the lead shot, everything at or above 0.12 in. was removed. At 0.09 in., nothing was removed. The threshold setting had no effect on contaminant removal.

The glass loss was 1.5% at a 20-mV threshold and 0.7% when the threshold was increased to 50 mV. Glass throughput was 24 and 34 tons/hr, respectively. In both cases, the contaminant loading was quite high, based on the number of rejections: 14.9/100 lb of glass for the 20-mV setting, and 6.4 for 50 mV.

It is not known how many of the rejections were due to contaminants and how many were false. Nonetheless, the glass loss was well within specifications with a contaminant loading of at least 2.5/100 lb of glass (based on the seeded contaminants).

The conclusions drawn from the ELPAC laboratory tests are:

- ELPAC worked well, eliminating all but the smallest contaminants.
- The dusting and paper label problems described are not an issue since the ELPAC is optically based.
- The cycle time and air pressure problems described for the ELKE could pose similar problems for the ELPAC, but only if an extreme number of metal contaminants are in the glass stream.

Field installation

The detectors installed at RRT's Syracuse recycling plant became operational in July 1992. By the end of August, the plant and detectors were sufficiently debugged so that data collection could begin.

The ELKE is the last beneficiation step, preceded by the ELPAC, vacuum system, screens, crusher, magnetic separator and hand pickers.

It is important that as much glass debris as possible—labels, dust, etc.—be removed prior to the ceramic detector since the optical system will detect and try to reject these items. This will greatly increase glass loss and reduce separation efficiency.

The ceramic detector is attended by manual laborers. The optics are wiped clean and the sensitivity settings are adjusted about every hour, depending on the type of glass and glass frequency changes.

The only unscheduled maintenance during the first three months of operation was replacing the glass optics plate.

Preliminary results show field separation to be lower than the laboratory results although the standard duration is quite high, making interpretation difficult. □

Editor's Note: This article was adapted from a paper presented at the 53rd Conference on Glass Problems and published with the permission of the author.

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Circle 16

GLASS

Recycling of Electrostatic Precipitator Dust from Glass Furnaces

Increasing disposal costs, legislative penalties and spiraling raw material costs require reconsideration of the use of electrostatic precipitator dust as a batch raw material

By: David T. Boothe, President, Harold Severin, Industry Consultant, D. Boothe & Co. Inc., Sylvania, Ohio; Clint Braine, Program Manager, GE Lighting Products, Cleveland, Ohio

Melting fine, inorganic raw materials for the production of glass in fossil-fueled furnaces generates a particulate discharge. This material consists of particulate fines originating from the charged batch and condensed gases that have volatilized out of the glass melt. They are carried out of the furnace by the combustion process waste gases.

The amount of particulates and condensates can be reduced by selecting raw materials with low decrepitation characteristics and controlled particle size distributions. Batch treatments such as wetting, agglomeration, and prereaction also have a positive influence on reducing particulate discharge. In addition, furnace design and carefully controlled furnace operation will decrease the amount of particulate discharge and volatile loss.

In the past, the least expensive disposal method for the relatively small amounts of collected material was disposal into a landfill. However, the loss of these solids from the glassmaking process and subsequent landfill disposal has come under greater economic scrutiny. The cost of dumping these materials into landfills is increasing almost daily.

hanging regulations regarding the toxicity classifica- ı of these materials have sharply decreased the avail- lity of solid waste disposal facilities, and alternative ɔosal, such as use in the agricultural industry, has ɔme less popular.

ke it or not, recycling of abatement discharges into the smaking process has come of age. The discharges ı abatement systems can replace increasingly more ensive raw materials. In the glass industry, economic iderations and stronger legislative pressure have ıpted an increased use of complex abatement sys- . These can be baghouses and electrostatic precipi- tators, either by themselves or in tandem or in combination with additional abatement systems, for the removal of noxious gaseous components from the discharges of glass furnaces.

Design and selection of systems

The material characteristics of abatement system dusts are as follows. Generally, the dry solids discharged from abatement systems, including electrostatic precipitators, are fine and have a low bulk density. They are difficult to handle and to contain within the system. For the successful design of an abatement dust recycling system, both the chemical and physical characteristics must be considered. The properties of the materials also will indicate if agglomeration methods such as pelletizing or compaction are necessary or desirable.

Chemical properties. The chemical properties of the material collected in an abatement system will determine the amount of material that can be recycled. Glass quality, required accuracy of the proportioning or weighing components and compensating batch formula corrections must be taken into consideration.

Physical properties. The physical properties will determine the materials handling equipment, the design of system components and the method of proportioning the abatement material into the glassmaking system. Some of the physical properties to be considered include:

- Particle size distribution;
- Angle of repose;
- Internal cohesion;
- Fluidization potential;
- De-airing characteristics;
- Hygroscopic characteristics.

Process changes, raw material variations and cyclical changes in ambient conditions will have a large effect on the mechanical properties of the collected material and also may affect the operating efficiency of the abatement system. These changes and variations must be determined prior to the design of a practical recycling system. In addition, the system design choices must not only consider the material properties, but must conform to the

method of discharge from the abatement system, the design of the existing batch house equipment, as well as operational sequencing and company operating philosophies.

Finally, the addition of abatement system discharge material to the glass batch must not be detrimental to the final glass properties or cause a decrease in production efficiency.

Recycling of EP dust—System 1

Several methods have been used in the past for modifying and handling the dust generated from electrostatic precipitators (EP). These have included agglomeration, roll compression or wetting and collection in hoppers for manual in-plant transfer or disposal. An example of this system was used at the GE Lighting plant, Niles, Ohio.

A large storage bin under the EP collected the dust. An inclined screw conveyor was used to feed periodically an inclined plate pelletizer. The initial goal of forming pellets was not successful, and the pelletizer was subsequently used to wet the dust uniformly for increasing bulk density and improving handling characteristics by agglomeration. After pelletization the material was loaded in a hopper, manually transported to the batch house, deposited in a storage bin, automatically weighed and added to the other batch materials. This process required constant supervision.

Recycling of abatement discharges into the glassmaking process has come of age.

The pelletizer discharge was inconsistent in particle size. To be safe, only enough water was added to hold down dust and begin particle agglomeration. Actual pelletization required a precise amount of water. Periodic changes in the properties of the EP dust changed the water requirements and the pelletizing behavior. Even a slight excess of water turned the pelletizer charge into mud, requiring disposal in a landfill.

In an effort to improve the operation, reduce cost and retain the recycling concept, D. Boothe & Co. Inc. undertook a turnkey project to study the material and the existing handling, and design a new system. The dust was analyzed and tested for bulk density, sizing and pneumatic conveying characteristics. The results showed that a pneumatic dense-phase transport system could be used to move the collected dust from the EP to the batch house. It also was determined that the existing batch house storage bin, scale feed screw and gain-in-weight minors scale could be used without modification. The hygroscopic nature of the dust required the use of a desiccator dryer to supply transport air, as well as air for the receiving dust collector.

System description

Untreated EP dust from a borosilicate glass melting operation is discharged from the EP with a vane feeder into a hopper located over the pneumatic transporter. A timer actuates a butterfly valve to load periodically the transporter. Pilot plant tests indicated that transporter loading could be a problem because the bulk density and the flow characteristics of the dust change rapidly during storage. Air pads are installed in the hopper to fluidize the dust and promote flow during loading. After a predetermined time, the timer closes the inlet valve and starts the transport sequence. Actual transport takes only 8-12 sec. The pressurized material is deposited directly into the batch house storage bin. The filtered transport air is vented through a dust collector into the batch house. When the batch house control system calls for another batch, EP dust is weighed in combination with other minor ingredients and discharged onto the weighed batch collection belt.

System components in the EP building are:

- EP screw conveyor and vane feeder (existing);
- Connection chute with diverter gate;
- Dust hood for manual collection (emergency bypass);
- Collection hopper with minimum of 70° sloped sides and aeration pads to aid in loading the transporter;
- Dense-phase transporter;
- One-inch transport pipe;
- One-inch transport pipe breaker valve;
- One hundred-cfm desiccated air dryer;
- Control cabinet.

System components in the batch house are:

- Dust collector;
- Fifteen-cfm desiccated air dryer;
- Existing storage hopper, scale and discharge screw.

Installation

The equipment installation took approximately two weeks. Testing and operational fine-tuning required another week. As anticipated, the biggest problem was loading the transporter. The original design had two stacked-inlet butterfly valves. This double arrangement severely restricted flow into the transporter. Removal of the upper butterfly and addition of aeration pads and low-velocity directional air jets eliminated most transporter loading problems.

The addition of aeration jets took care of another potential problem. The fluidization membrane in the transporter has an upper temperature limit of 121°C. Test samples indicated that the EP dust might occasionally exceed this temperature. The air pads, therefore, not only fluidized the dust for better flow, but also cooled the material below the equipment upper temperature limit.

The EP dust from this operation is hygroscopic and is sensitive to atmospheric changes. Several openings were added to the transport piping design for access if any plugging occurred. The system requires no boosters, and all of the collected EP dust is recycled. The system has been in operation since November 1992.

Recycling of EP dust—System 2

The second system was designed for GE Lighting in Lexington, Ky., where GE makes soda-lime incandescent light bulb envelopes. At this facility, the EP dust is designated as hazardous due to chrome contamination.

This presented some interesting challenges. Because of the hazardous nature of the material, great care had to be taken in the design of the system not only to transport the EP dust to the batch house for recycling, but also to prevent dust from escaping into the atmosphere.

Although the dense-phase pneumatic system was working successfully at the Niles plant, the use of a pneumatic vacuum system for material transport was indicated. In this system, the EP dust is carried through the transport pipe in an airstream generated by a vacuum pump.

System description

Collected EP dust is stored in a hopper under the EP. When this material reaches a predetermined level in the hopper, the vacuum pump in the batch house automatically starts up. As soon as a vacuum is established, EP dust material is continually released from the collection hopper into the airstream and transported to the batch house.

In the batch house, the dust is collected in a baghouse-type receiver and drops through a rotary vane feeder into a storage bin under the receiver. A loss-of-weight scale adds the EP dust to the weighed batch material on the collection belt.

The use of these systems has produced substantial cost savings.

This is a closed-loop system. Dust generated by the air jets during the fill cycle of the collection hopper is fed back into the EP via an existing duct, under negative pressure. The dust collection bags in the receiver are 22-oz polyester, backed up by an in-line filter to protect the vacuum pump. The vacuum pump discharge is fed back to the EP inlet. Any dust in the storage bin is captured by a single bag filter with the clean air fed into the weighed material collection belt housing. The entire system is automatic and is controlled by a GE 9030 PLC.

In an emergency, the system is backed up by tote-type storage bins with capacity for about two and one-half days of generated dust. These tote bins are loaded by a manual slide gate at the base of the collection hopper. They can be emptied into the vacuum system after power has been restored or after the system has been repaired or serviced.

System components in the EP building are:

- Connection chute to existing EP screw;
- Collection hopper with air jet pulse jets;
- Isolation slide gate;
- Tote bin;
- Bleeder valve;
- Slide diverter valve;
- Vacuum breaker valve;
- Two-inch transport pipe.

System components in the batch house are:

- Vacuum filter receiver with filter bags, pump and in-line filter;
- Rotary vane feeder;
- Material storage bin with single bag filter;
- Loss-of-weight scale and feeder.

The equipment installation took approximately four weeks. Testing and operational fine-tuning required another week. Problems were experienced with setting up the various air jets, pressures and operational frequencies. The vent duct at the collection hopper and the bags in the filter receiver required additional sealing. Sequencing of controls required time.

The material transports readily and is not as sensitive to atmospheric changes as the EP dust in the Niles plant. The system has been in operation since early August 1993 and has worked well from start-up. The system had to be shut down a few times during start-up for adjustments and plant operational problems. During these periods, the EP dust was collected in tote-type storage bins. Refeeding the dust from the totes into the vacuum transport system went smoothly.

The system in Niles has run since November 1992, and the Lexington system has been in operation since early August 1993. The addition of EP dust to the batch has no reported effect on the glass characteristics at either location. No melting or associated furnace problems have been observed. The collection rate for the EP dust has not increased as a result of recycling.

For both systems, it is extremely beneficial to keep operating on a regular cycle. This prevents the formation of lumps during excessive storage time. In Niles, the lumps are formed by the absorption of water from the atmosphere and cause transporter loading problems and line plugging. At Lexington, large lumps are formed by material compression during excessive storage times. They are rock hard and plug the transfer from the collection hopper to the conveying line. At Niles, automatic operation would be enhanced by the replacement of air pads in the collection hopper with fluidizing air jets, the addition of fluidizing air jets in the batch house storage bin, and installation of level detectors in the batch house storage bin and dust collector.

If water spray is used to cool the waste gas air stream into the EP, it is imperative that the spray nozzles be kept in working condition. The water flow must be monitored and controlled as a function of temperature. Failure to do so will produce a material that is difficult to transport pneumatically.

At this time, it is believed that vacuum pneumatic conveying is the better of the two systems because the plugging potential appears to be lower. Even if plugging occurs, the system can be unplugged with little dust escaping into the immediate surroundings.

Another advantage is that if dust escapes from the system during maintenance in the EP building, it can be vacuumed up immediately and returned to the system. In other words, the system can be used to clean up after itself. Also, the problems of charging material into the transport system are reduced.

Working with EP dust

We have learned that EP dust in its untreated form can be weighed and used in the batching system by loss-of-weight and gain-of-weight scales. For some operations, volumetric proportioning may be suitable. The best method for scale discharge is a screw conveyor with a

variable speed drive. A method for maintaining the dust in a fluidized condition should be included in the scale design.

EP dust clings to everything because of its particle size and the static charge picked up in the precipitator. When possible, the EP dust should be discharged to the batch collection belt by sandwiching it between two major materials, such as sand and limestone or soda ash. This keeps the dust from sticking to the belt and being removed from the process by the belt cleaners. If the dust is added to a cumulative scale, the same procedure should be used. Whenever possible, add the dust between two batch components with good flow characteristics. Vibration must be used with great care to avoid compaction and bridging.

EP dust in furnaces

One point to emphasize is that EP dust is not the same from furnace to furnace, from glass to glass, or from precipitator to precipitator. Each situation presents new challenges as a result of batch composition, furnace operation, precipitator efficiency and ambient conditions. Each case must be studied separately to determine the properties of the dust, that is, particle size distribution, chemical composition, compaction behavior, de-airing characteristics and behavior in pneumatic transport systems.

Cost savings

The use of these systems has produced substantial cost savings in both plants by reduction of labor, elimination of protective equipment during routine handling and disposal, elimination of disposal and avoidance of potential EPA violation fines. A raw material cost savings also can be realized, depending on the raw material that is replaced. At Niles, for instance, the calculated raw material savings by recycling is $77,700/yr, which, by itself, could pay for the system.

Although the return on investment varies with each situation, it is believed that the payback period for a given installation will not exceed two years. The capital costs for these systems will vary widely and will depend on the system design, the existing equipment that can be used and the level of automation. A general cost range is $80,000- $160,000.

Conclusion

Electrostatic precipitator dust is only one of the glass manufacturing by-products that must be handled and recycled. The two systems described show that EP dust can be recycled, in some cases without any pretreatment. Such secondary processes add considerable capital cost and operating expense to the cost of recycling.

These recycling methods also can be adapted to solids generated by other abatement methods for return to the glassmaking process. □

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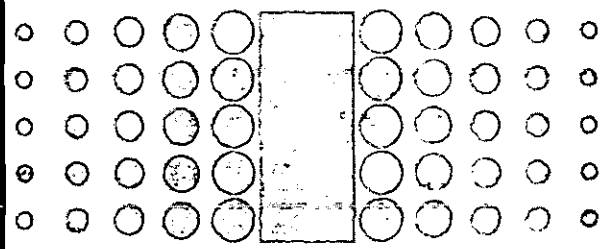

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WILLIAM A. CANDY
LEADER ENVIRONMENTAL AFFAIRS
ROOFING SYSTEM BUSINESS

June 23, 1998

Mr. Juan Santiago
United States Environmental Protection Agency
Emissions Standards Division
Mineral and Inorganic Chemicals Group
Research Triangle Park, N. C. 22711

Dear Juan,

Enclosed are reprints of an article authored by Dr. David Trumbore of Owens Corning and published in "Environmental Progress" The article summarizes the work conducted by Owens Corning in measuring and characterizing our criteria and HAP pollutants. This article is drawn from the data submitted with our ICR's submitted to your group. The data is presented much more concisely then in our ICR's. Please provide a copy of this article to Ken Durkee and others in your group that would find it useful. We would also like to submit this information for inclusion in the next update of AP- 42 for the roofing industry.

Sincerely,

William A. Candy

The Magnitude and Source of Air Emissions from Asphalt Blowing Operations

David C. Trumbore
Owens Corning, Asphalt Technology Laboratory, Summit, IL 60501

The US EPA has developed emission factors for estimating the emissions of filterable particulate, total organic compounds, and carbon monoxide from asphalt blowing operations. These are published by the EPA in a series called AP-42, which contain factors for many manufacturing processes. The emission factors for asphalt blowing are acknowledged by the EPA to be of poor quality. Owens Corning has taken extensive data in various manufacturing facilities and an asphalt Pilot Plant to provide more information on air emissions from these operations. The results of that work clearly show that the current AP-42 emission factors for asphalt processed by air blowing are deficient in that they omit significant emissions of SO_x and HCl, overestimate particulate and CO emissions, and potentially underestimate both VOC and NO_x emissions. In fact, SOx, which is not addressed by AP-42, is the major air emission contributed by the fumes from the asphalt blowing process when those fumes are incinerated. The sources of SO_x from air blowing are discussed in detail in this paper. The impact of incineration temperature on carbon monoxide is also illustrated. With the exception of HCl, the hazardous air pollutants encountered in the asphalt blowing process are minimal.

INTRODUCTION

The use of asphalt as a material is prevalent throughout recorded history. The commercial use of air blown asphalt, also known as oxidized asphalt, dates from the late 19th century [1]. Oxidized asphalt is produced by blowing air through hot petroleum residuum, which can come from vacuum distillation towers, atmospheric towers or solvent extraction units. At the start of the batch, input residuum is typically pumped through a direct fired non-contact preheater to achieve temperatures over 400°F (204°C), and into reaction vessels called oxidizers, or alternately, stills or convertors. Air is injected into the oxidizer and dispersed through perforated pipes. Air flow is typically in the range of 15 to 50 cfm/ton (0.008 to 0.026 m^3/sec/Mg) of asphalt and the oxidizer is typically operated between 400 and 550°F (between 204 and 288°C) [2]. Oxygen is consumed by the reaction of air with the petroleum residuum, resulting in fumes exiting the oxidizer at less than 10% oxygen content. Many theories exist as to the specific chemistry of the asphalt blowing reaction, with no consensus as to what is really happening. It is clear that in the asphalt blowing reaction oxygen functionality is added to the asphalt molecules; the apparent molecular weight of the asphalt increases; and compounds like hydrogen sulfide, methane, water, carbon monoxide, and carbon dioxide are released [3,4,5]. In addition to the gases formed, the high air flows both evaporate and entrain oily materials from the residuum, which can condense further down the process. These are referred to in this article as process oils. Fumes from asphalt blowing processes are typically treated with a variety of separation devices to remove condensing or entrained process oil, and then are incinerated. The most commonly used catalyst for the reaction is ferric chloride, although most oxidized asphalt is produced without any catalyst.

Air blowing of residuum results in an increase in Ring and Ball Softening Point (ASTM D36) and Brookfield Viscosity (ASTM D4402), and a decrease in Penetration (ASTM D5). The product is unique in that its combination of properties cannot be produced by any other refinery process. That is, if the softening point of the residuum is raised by distillation or solvent extraction the material is far more brittle than if the softening point is raised by air blowing. Oxidized asphalt is used for the manufacture of asphalt shingles; and in built-up roof construction, adhesives, corrosion protection, waterproofing, and a wide variety of specialty applications. The two highest volume products made using this process, shingle coating and BURA Type III asphalt, typically see a softening point increase during the blowing process from an initial value of less than 100°F (38°C) to a final value of 200°F (93 °C) or higher.

Title V of the 1990 Clean Air Act required the accurate estimation of emissions from all U.S. manufacturing processes, and placed the burden of proof for that estimate on the process owner. In response to Title V, Owens Corning (OC) analyzed existing data and conducted extensive testing of their asphalt blowing processes in plant and pilot plant scale to develop the best possible emission factors. This paper is the result of that work, and it is our hope that it will lead to improved AP-42 emission factors for the asphalt blowing process.

Table 1. Test Methods Used in Sampling Air Blowing Emissions

EPA Method #	Items Measured Using Method
1	Sample and velocity traverses
2	Stack gas velocity & flow
3	Dry molecular weight
3A	Oxygen & Carbon dioxide
4	Stack moisture
5	Particulate
5A	Particulates
6C	Sulfur oxides
7E	Nitrogen oxides
10	Carbon Monoxide
25A	Total gaseous organic (VOCs)
26	Hydrogen chloride
26A	Hydrogen chloride
29	Inorganic compounds
202	Condensible particulate
0010	Semi-volatile HAPs

TEST METHODS

Testing of emissions from Owens Corning's asphalt blowing processes was done using the EPA test methods outlined in Table 1.

AP-42 Emission Factors

The Emission Factor and Inventory Group (EFIG) in the U. S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) develops and maintains a database of emission factors for manufacturing processes. These emission factors are published in a series known as AP-42 [6]. As part of this process the emission factors have been assigned a quality rating. AP-42 emission factors for limited pollutants exist for the asphalt blowing process [7]. The factors are available for filterable particulates (PM), total organic compounds (VOC), and carbon monoxide (CO). They are summarized in Table 2. These emission factors have been assigned "D" or "E" ratings, indicating they are no better than "Engineering Judgment" in accuracy. More specifically a "D" rating indicates below average quality based on a small number of possibly non-random facilities with evidence of test variation. An "E" rating indicates poor quality based on unproved test methods, and issues with a low number of data points, randomness, and variability. An "E" rating is the lowest rating given to emission factors by AP-42 [6]. The asphalt blowing AP-42 factors are for both saturant and coating asphalt manufacture. The rest of this article only addresses the coating factors, which are larger in proportion to their longer processing times.

Owens Corning Plant Testing Results

The results of emission testing for Criteria Pollutants done on 33 different occasions in 14 different Owens Corning plant locations are shown in Table 3. The processes shared common process conditions: 15 to 30 cfm/ton (0.008 to 0.016 m^3/sec/Mg) air injection and 460 to 510°F (238 to 266°C) reaction temperature, common control equipment (fumes bubbled through a liquid seal in a knock out tank followed by gas fired incineration in an incineration chamber designed for adequate turbulence), and were processed to a common end point (coating asphalt). Widely variable input petroleum residuum were used in the tests. There was no catalyst used in any of the tests reported in Table 3. In all but one case, each data point is the average of three determinations, taken during three separate process times, with the same input residuum, under as similar as possible process conditions. The exception to that is the case of the PM data for plant J from 1984 to 1994. In this case an average of 83 different determinations were used to avoid skewing the overall PM data for only one plant configuration.

Averages and other statistics for each criteria pollutant are given at the bottom of Table 3. The arithmetic mean and median are included for each pollutant. The geometric mean is also included in Table 3, and could in some cases be appropriate because of the exponential nature of the dependence of the emissions data on some process conditions. As can be seen in Table 3, the arithmetic mean is the most conservative estimate and all further analyses in this paper use it as the most representative value of the data set. These data are the basis of what we believe to be improved emission factors for asphalt blowing, and in lieu of other available data, we recommend the arithmetic means be accepted as new emission factors for asphalt blowing with gas incineration. When used to estimate emissions, the emission factors are adjusted depending on the configuration and the amount of data existing for that particular plant. For example, the average value plus two or three standard deviations are often used to ensure that the estimate is greater than the actual emission.

CONTRIBUTION OF INCINERATION FUEL TO EMISSIONS

To apply the data of Table 3 to processes using fuel oil, rather than natural gas, for incineration requires that the contribution of the fuel burned be recognized. This is done by calculating the incremental emissions from the

Table 2. US EPA Emission Factors for Asphalt Blowing Emissions from AP-42 (7)

Pollutant	Method	Control Equipment	Saturant Asphalt	Coating Asphalt	Emission Factor Rating
Filterable PM	EPA 5A	none	6.6 lb/ton[1]	24 lb/ton	E
Filterable PM	EPA 5A	incineration	0.27 lb/ton	0.81 lb/ton	D
Total Organic Compounds	EPA 25A	none	1.3 lb/ton	3.4 lb/ton	E
Total Organic Compounds	EPA 25A	incineration	0.0043 lb/ton	0.017 lb/ton	D
Carbon Monoxide		none		0.27 lb/ton[2]	E
Carbon Monoxide		incineration		3.7 lb/ton[2]	E

[1] 1 lb/ton = 0.5 kg/Mg

[2] unclear what product was manufactured.

Table 3. Emission Factor Data for Asphalt Blowing to Coating with Gas Incineration

Plant	SOx (lb/ton)[1]	CO (lb/ton)	NOx (lb/ton)	VOC (lb/ton)	PM (lb/ton)	Comments	Year Tested
A	0.63	0.43	0.06	0.08		2 oxidizers	1996
A					0.02	2 oxidizers	1996
B		0.72		0.002	0.17		1996
C		0.07					1988
C	0.88	0.11	0.08	0.02	0.06		1994
C					0.08	Incinerator @ 1500F[1]	1992
D		0.95			0.07		1988
F					0.07		1990
F					0.07		1990
F					0.06		1990
H	0.84	0.09	0.02	0.01	0.18	2 oxidizers	1994
I					0.05		1993
I	0.66	0.002	0.08	0.10	0.14	Incinerator @ 1625F	1993
J					0.11	average of 83 PM tests	1984-1994
J		0.01			0.18	Incinerator @ 1550F	1992
J					0.02		1995
K					0.08		1986
L	0.86	0.34	0.10	0.002	0.12	Incinerator @ 1550F	1993
L	0.95	0.77	0.02	0.02	0.11	Incinerator @ 1550F	1994
L	0.65	0.33	0.05	0.001			1997
M					0.23		1992
M					0.25		1988
M	1.03	3.2	0.03	0.04		3 oxidizers	1994
M	0.76				0.03	2 oxidizers	1995
M					0.06	2 oxidizers	1996
M					0.07		1995
M		1.15				Incinerator @ 1400F	1995
M		0.17				Incinerator @ 1450F	1995
M		0.12				Incinerator @ 1500F	1995
N	0.95	0.01	0.02	0.07	0.04		1996
P					0.03	2 oxidizers	1984
P	0.93	0.21	0.12	0.002			1993
S	1.15	2.00	0.04	0.06		4 oxidizers	1993

Summary	SOx	CO	NOx	VOC	PM
Arithmetic Mean	0.86	0.59	0.05	0.03	0.10
Geometric Mean	0.84	0.18	0.04	0.01	0.08
Median	0.87	0.27	0.05	0.02	0.07
Std Dev	0.16	0.83	0.03	0.03	0.06
Arith. Mean+3s	1.34	3.09	0.16	0.14	0.29
Minimum	0.63	0.002	0.02	0.001	0.02
Maximum	1.15	3.20	0.12	0.10	0.25
Number	12	18	11	12	24

[1]1 lb/ton = 0.5 kg/Mg, °C = (°F-32)*5/9

alternate fuel by using AP-42 emissions factors for combustion [8,9] and adding that source of emissions to the data in Table 3 for gas incineration. The incremental emissions subtract the gas combustion emissions from the fuel oil combustion emissions. Table 4 contains asphalt blowing emission factor data measured in four plants using heavy fuel oil. To illustrate the technique described above, the average of the measurements in these plants is compared to an average predicted by adjusting the gas incineration average from Table 3 with fuel oil emissions for a typical fuel oil usage rate.

Table 4. Evaluation of Emission Factors for Air Blowing Coating Asphalt with Heavy Fuel Oil Incineration

Plant	SO_x (lb/ton)[1]	CO (lb/ton)	NO_x (lb/ton)	VOC (lb/ton)	PM (lb/ton)	Year
F		0.31			0.03	1985
Q					0.28	1989
Q	1.38	0.02	0.12	0.01	0.30	1994
Q	1.14	0.00	0.19	0.01	0.35	1994
X	1.50	1.25	0.04	0.01	0.09	1993
P	2.87	0.37	0.15	0.00		1993
Average	1.72	0.39	0.13	0.01	0.21	

[1]1lb/ton = 0.5 kg/Mg

Gas Data Averages from Table 3 Adjusted for Fuel Oil Emissions.

SO_x (lb/ton)1	CO (lb/ton)	NO_x (lb/ton)	VOC (lb/ton)	PM (lb/ton)
1.53	0.60	0.14	0.03	0.14

CRITERIA POLLUTANT SUMMARY

Table 5 summarizes the comparisons between current AP-42 emission factors for asphalt blowing, the data gathered by Owens Corning on 33 occasions in 14 plants using gas incineration, and estimated values for the contribution of the gas fuel that is burned in the incinerator.

The key conclusions from this comparison follow:

1.It is clear from the data in Table 5 that the omission of a sulfur oxide (SO_x) emission factor for the asphalt blowing process from AP-42 ignores what is usually the largest criteria pollutant from this process. The average value in all our testing is 0.86 lb SO_x/ton asphalt (0.43 kg/Mg) with gas fueled incinerators without using catalysts. This represents a significant source of SOx that should be accounted for in all asphalt blowing operations.

2.The AP-42 factor for carbon monoxide (CO) of 3.7 lb/ton (1.85 kg/Mg) is obviously based on poor incineration as it is excessively high for normal processes. In all of our testing on gas systems with adequate incineration turbulence and without any catalyst the average CO factor was 0.59 lb/ton (0.295 kg/Mg). Our one value close to AP-42, 3.2 lb/ton (1.6 kg/Mg) in plant M, was reduced to less than 0.2 lb/ton (0.1 kg/Mg) by raising the incineration temperature 100 °F (38°C). The sensitivity of CO to incineration temperature will be discussed below.

3.The AP-42 factor for volatile organic compounds (VOC) of 0.017 lb/ton (0.0085 kg/Mg) is achievable (5 out of 12 measurements we took were less than that value), but is approximately one half of the average measured value. This factor should be increased.

4. The AP-42 value for particulate material (PM) is much too high. Our largest reading in 24 tests was still less than 1/3 the AP-42 value and our average was 1/8 the AP-42 value.

5. The contribution of fuel burning to nitrogen oxide (NO_x) emissions gives an order of magnitude estimate of NO_x emissions in the asphalt blowing process. Some additive emissions appear to be warranted from the data, but this omission from the AP-42 factors is not a serious one.

6. Based on comparisons in Table 4, asphalt blowing emission factors based on gas incineration systems can be used as approximate estimates for systems using alternate fuels by adding the emission contribution of the alternate fuel calculated using AP-42 for combustion.

SOURCES OF SPECIFIC ASPHALT BLOWING EMISSIONS

Sulfur Oxides

SO_x emissions in the asphalt blowing process come from three sources:

1.The fuel used to incinerate the asphalt blowing fumes contains sulfur compounds which are oxidized on incineration to produce SOx emissions.

2. Some process oil is carried over as condensable vapor or droplets in the fume stream and, when burned, the sulfur, which exists primarily as thiophenes, is oxidized to produce SO_x emissions.

3. Hydrogen sulfide (H_2S) is formed in the asphalt blowing process and that material oxidizes in the fume stream and in the incinerator to produce SOx emissions.

The incineration fuel component is quite small when using natural gas, as shown in Table 5. Estimates of the magnitude of the other two components can be made from observations of results of experiments to reduce these emissions. The use of H_2S scavengers in the asphalt blowing process to tie up the H_2S component of the emission has been seen to give a maximum reduction in SO_x emissions of about 70 to 80% in a gas incineration situation [10]. This would indicate that the contribution of the release of H_2S in the process is about 70 to 80% of the emission in a gas incineration system. Similarly, unpublished work with filtration of pilot scale asphalt blowing fumes indicated that completely eliminating droplet carryover in an asphalt blowing process with gas incineration reduced SO_x emissions by 20 to 30%. Therefore, in a gas incineration system the contributions to SO_x emissions could reasonably be estimated as indicated in Table 6.

Table 5. Summary of Emission Factors for Asphalt Blowing Process Making Coating

	SO_x (lb/ton)[1]	CO (lb/ton)	NO_x (lb/ton)	VOC (lb/ton)	PM (lb/ton)
AP-42 Factor (Table 2)	omitted	3.7	omitted	0.017	0.81
Average OC Emission for Gas Incineration (Table 3)	0.86	0.59	0.05	0.03	0.10
Range of OC Values (Table 3)	0.63 to 1.15	0.002 to 3.2	0.02 to 0.12	0.001 to 0.10	0.02 to 0.25
Contribution from gas fuel estimated with AP-42 (8)	0.0002	0.007	0.03	0.002	0.004

[1]1 lb/ton = 0.5 kg/Mg

Table 6. Sources of SO_x in Asphalt Blowing - Typical Values

Source of SO_x	Typical Contribution
Gas fuel for incinerator	< 0.1% of the total SO_x
H_2S release from Asphalt During Blowing	70 to 80% of the total SO_x
Carryover of process oil containing thiophene sulfur	20 to 30% of the total SO_x

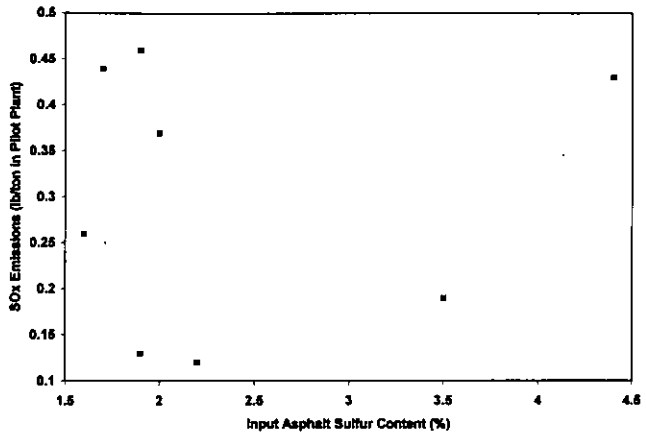

FIGURE 1. Correlation of input asphalt sulfur content With SO_x emissions. Eight different crude sources used in study. Correlation coefficient = 0.09 (1lb/ton = 0.5 kg/Mg).

Because of the strong contribution of some input petroleum residuum sulfur to SO_x, an investigation was done to determine if the total sulfur content of input residuum, which is easily measured, would correlate with SO_x emissions. To determine this a series of input residuum made with different crude oils were brought to Owens Corning's asphalt blowing pilot plant and oxidized under identical conditions, with determination of emission factors for SO_x. The results of these tests are shown in Figure 1, a plot of pilot plant SO_x emissions versus total sulfur content of the input asphalt. It is clear that no correlation exists, implying that only a small, unidentified, component of the sulfur in the asphalt is responsible for the H_2S release and subsequent SO_x emission.

Table 7. Effect of Incineration Temperature on Carbon Monoxide Emissions

Plant	CO Emission Factor (lb/ton)[1]	Incineration Temperature (°F)[1]
M	1.15	1400
M	0.17	1450
M	0.12	1500
L[2]	2.15	1450
L	0.17	1550

[1] 1 lb/ton = 0.5 kg/Mg, °C = (°F-32)*5/9
[2] The L plant data was taken with ferric chloride as a catalyst and is therefore not included in the Table 1 data set.

Carbon Monoxide

Large amounts of carbon monoxide can be emitted from the asphalt blowing process when the incineration conditions are less than optimum in terms of residence time, incineration temperature and fume turbulence. In Table 7 the effect of incineration temperature is shown for two asphalt blowing processes where the incineration residence time and turbulence are acceptable. As can be seen, the emission of carbon monoxide is very sensitive to a relatively small change in temperature. In general, we have found that for incinerators with more than 0.5 seconds of residence time and chambers designed to promote turbulence, incineration temperatures in the 1450 to 1550°F (788 to 843°C) range are necessary to achieve very low CO levels. From the data in Table 7, plant M needs to run at least 1450°F (788°C) while plant L needs to run 1550°F (843°C) to achieve emission factors under 0.2 lb/ton (0.1 kg/Mg).

A small amount of CO is detectable in the fumes prior to the incinerator, but the major source for CO emissions is incomplete combustion of hydrocarbons to carbon dioxide (CO_2).

Hydrocarbon Emissions – Particulate and VOCs

From the description of the asphalt blowing process, it is not surprising that the fumes entering the incinerator contain significant amounts of hydrocarbons. The reactions that occur in the process create lower molecular weight hydrocarbons that remain as vapor or condense at some point in the fume system. The incineration process does a good job of combusting these

Table 8. Measured Incineration Destruction Efficiencies for Hydrocarbons in the Air Blowing Process

Plant	# Samples Averaged	Residence Time (seconds)	Incineration Temperature (°F)[1]	Destruction Efficiency
C	3	1.8	1500	98.9%
S	4	1.9	1500	98.1%
S	4	1	1500	97.9%
S	5	0.7	1500	98.7%
S	4	0.5	1500	99.2%

[1] °C = (°F-32)*5/9

Table 9. Sampling Data for HAPs Emissions from Asphalt Blowing (1 lb/ton = 0.5 kg/Mg).

Plant	C	O	P	L	L	Q	Q	M	M
Year	1992	1990	1984	1994	1994	1994	1994	1995	1995
Fuel	gas	gas	gas	gas	gas	BD Oil	#5 Fuel	gas	gas
Comments				Ferric	No Ferric			Ferric	No Ferric
Hazardous Air Pollutant	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)	(lb/ton)
Hydrogen chloride			8.2E-03	2.5E-01	3.6E-02	8.4E-03	7.7E-03	1.9E-01	4.0E-02
General Inorganic HAPS									
Antimony				1.0E-06	7.7E-07				
Arsenic		0.0E+00		8.5E-07	2.8E-06	6.3E-07	6.3E-07		
Beryllium				8.5E-09	6.2E-09				
Cadmium		0.0E+00		5.7E-07	6.2E-09				
Chromium				3.2E-05	4.3E-06	4.1E-06	7.3E-06		
Cobalt						7.4E-07	8.9E-06		
Lead				3.2E-06	2.2E-06	1.3E-05	4.7E-05		
Manganese				5.5E-06	4.1E-06	9.9E-05	2.4E-04		
Nickel		4.2E-05		2.8E-04	6.3E-06				
Phosphorus				4.1E-06	2.2E-06				
Selenium		0.0E+00		8.1E-07	2.5E-06	6.3E-07	6.3E-07		
General Organic HAPs									
Benzene	2.6E-04	1.3E-02		8.2E-04	1.5E-03	9.0E-04	1.2E-05		
Toluene				1.3E-04	8.8E-05	3.4E-04	1.2E-05		
Ethyl Benzene						1.0E-02	1.2E-02		
Xylene						1.7E-04	9.0E-06		
111 TCE						2.1E-05	2.2E-05		
methyl chloride				2.1E-04	7.9E-04				
vinyl chloride				8.7E-05	9.7E-05				
ethyl chloride				5.5E-05	7.7E-05				
methylene chloride				1.3E-03	1.3E-03				
chloroform				1.0E-04	1.2E-04				
Di-n-butylphthalate				2.5E-06	3.0E-06				
Dibenzofuran				3.8E-05	6.1E-06				
bis(2-ethylhexyl)phthalate				9.6E-06	8.4E-06				
isophorone				3.0E-06	2.5E-06				
4-nitrophenol				1.6E-05	1.1E-05				
phenol				1.4E-05	7.4E-06				
o-cresol				2.4E-06	2.5E-06				
p-cresol				8.7E-06	5.7E-06				
Polycyclic Organic Matter									
2-methylnaphthalene				2.1E-05	4.7E-06	4.6E-08	8.2E-08		
Acenaphthene (ACEP)	0.0E+00			3.6E-05	2.5E-06	2.7E-07	8.4E-08		
Acencphthylene (ACEY)	6.7E-09					2.5E-08	6.7E-09		
Anthracene (ANTH)	0.0E+00					2.5E-09	5.6E-08		
Benz (A) anthracene (BENA)	0.0E+00					8.0E-09	6.2E-09		
Benzo (B) Fluoranthene (BENB)	0.0E+00					7.1E-09	7.9E-09		
Benzo(G,H,I) Preylene (BENG)	0.0E+00								
Benzo (K) Floouranthene (BENK)	0.0E+00								
Benzo (A) Pyrene (BEZA)	0.0E+00								
Benzo(e)pyrene						2.0E-08	2.2E-08		
Chrysene (CHRY)	0.0E+00					1.0E-08	1.4E-08		
Dibenz (A,H) Anthracene (DIBN)	0.0E+00								
Fluoranthene (FLUO)	0.0E+00			1.3E-05	2.5E-06	6.5E-09	2.0E-08		
Indeno (1,2,3-C,D) Pyrene (INDE)	0.0E+00								
Naphthalene (NAPH)	5.9E-06			5.3E-05	2.5E-05	8.9E-07	9.9E-07		
Phenathrene (PHEA)	0.0E+00			8.0E-05	6.9E-06	6.4E-08	6.4E-07		
Pyrene (PYRE)	0.0E+00			7.3E-06	2.5E-06	7.8E-09	1.8E-08		

to CO and CO_2 as indicated by the data in Table 8, which was taken by measuring total hydrocarbons entering the incinerator and total leaving to get a destruction efficiency. Because of the nature of the process there is an insignificant amount of inorganic components in the particulate emissions.

HAZARDOUS AIR POLLUTANTS TEST RESULTS

In addition to testing on criteria pollutants, Owens Corning has done extensive testing on the emissions of hazardous air pollutants (HAPs) from the asphalt blowing process. This testing, done in six plants on nine occasions, is summarized in Table 9. On different occasions four basic classes of HAPs have been measured: 1. hydrogen chloride, 2. general inorganic HAPs, 3. general organic HAPs, and 4. polycyclic organic matter (POM). Table 9 is organized around those groupings.

The data show that the use of ferric chloride as a catalyst significantly increases hydrogen chloride emissions from the 0.007 to 0.04 lb/ton (0.0035 to 0.02 kg/Mg) emission factor level without ferric chloride use to 0.19 to 0.25 lb/ton (0.095 to 0.125 kg/Mg) with the catalyst. This is an important omission from AP-42 and should be added for ferric chloride catalyzed asphalt blowing. The source of this chloride is free HCl in the ferric solution and the reaction of ferric chloride to ferrous chloride as part of the mechanism of catalysis [11]. Only a fraction of the HCl available from these two sources is actually evolved. The rest takes part in as yet unidentified reactions in the asphalt.

Emissions of general inorganic materials can be seen to be very small, in the range of 0.000000006 to 0.0002 lb/ton (0.000000003 to 0.0001 kg/Mg).

Emissions of general organic materials were very low with the exception of ethyl benzene and one measurement of benzene, which were in the range of 0.01 to 0.013 lb/ton (0.005 to 0.0065 kg/Mg). Clearly more severe incineration conditions can reduce these values, and this is indicated in other measurements of benzene emissions which were as low as 0.000012 lb/ton (0.000006 kg/Mg).

Emissions of POM were all extremely low ranging in measurement from 0.000000005 to 0.00008 lb/ton (0.0000000025 to 0.00004 kg/Mg).

CONCLUSIONS

From the data presented in this paper the following conclusions have been reached:

1. Current AP-42 emission factors for asphalt blowing ignore important emissions of sulfur oxides. This is usually the largest emission from the process. The emission of sulfur oxides are not correlated with total sulfur in the input residuum. In a gas incineration system the source of sulfur oxides are approximately 70 to 80% from H_2S released in the asphalt blowing reaction, 20 to 30% from entrained or condensing oils, and almost no contribution from the fuel used for incineration.

2. Current AP-42 emission factors for asphalt blowing ignore hydrogen chloride emissions, which are important when ferric chloride is used as a catalyst in the process.

3. Current AP-42 emission factors for asphalt blowing overestimate the emissions of particulate and carbon monoxide in a well designed process. Carbon monoxide emissions can be dramatically reduced with small increases in incineration temperature above a certain threshold temperature, in an incinerator with adequate residence time and turbulence. In our experience that threshold temperature is approximately 1400 to 1500 °F (760 to 816 °C).

4. Emissions of hazardous air pollutants, other than hydrogen chloride, from the asphalt blowing process are insignificant.

LITERATURE CITED

1. **Byerley, F.X.**, U.S. Patent 524,130 (Aug. 1894).
2. **Corbett, L.W.**, "Manufacture of Petroleum Asphalt", Chapter 4, in "Bituminous Materials: Asphalts, Tars and Pitches, Volume II: Asphalts", edited by Arnold Hoiberg, Robert Krieger Publishing Co., Huntington, New York (1979).
3. **Boduszynski, M.M.**, "Asphaltenes in Petroleum Asphalt: Composition and Formation", Chapter 7, in "The Chemistry of Asphaltenes", pp. 119 to 135, American Chemical Society, Washington, D.C. (1981).
4. **Haley, G.A.**, "Changes in Chemical Composition of a Kuwait Short Residue during Air Blowing", *Analytical Chemistry*, 47 (14), pp. 2432-2437, (Dec. 1975).
5. **Corbett, L.W.**, "Reaction Variables in the Air Blowing of Asphalt", *Ind. Eng. Chem. Process. Des. Dev.*, **14** (2), pp. 181-187, (1975).
6. **U.S. Environmental Protection Agency**, "Introduction to 5th edition of AP-42 Emission Factors", U.S. EPA, January, 1995, from the Internet at http://www.epa.gov/ttn/chief/ap42menu.html (accessed 8/8/97).
7. **U.S. Environmental Protection Agency**, Chapter 11 of the 5th edition of AP-42 Emission Factors, U.S. EPA, "Mineral Products Industry, Section 2, Asphalt Roofing" Tables 11-2.2 and 11-2.4, January, 1995, from the Internet at http://www.epa.gov/ttn/chief/ap42menu.html (accessed 8/8/97).
8. **U.S. Environmental Protection Agency**, Chapter 1 of the 5th edition of AP-42 Emission Factors, U.S. EPA, "External Combustion Sources – Section 4, Natural Gas", Tables 1.4-1,2 &3, October, 1996, from the Internet at http://www.epa.gov/ttn/chief/ap42menu.html (accessed 8/8/97).
9. **U.S. Environmental Protection Agency**, Chapter 1 of the 5th edition of AP-42 Emission Factors, U.S. EPA, "External Combustion Sources – Section 3, Fuel Oil", Tables 1.3-1,2, October, 1996, from the Internet at http://www.epa.gov/ttn/chief/ap42menu.html (accessed 8/8/97).
10. **Marzari, J. A., M. Franzen, and J. Smith**, "Method for reducing sulfur emissions in processing air-blown asphalt", U.S. Patent 5,611,910 (Mar.18, 1997).
11. **Kudryavtseva, I.N., D. Rozental, and V. Proskuryakov**, "Influence of ferric chloride on oxidation of bitumens and their components", Lensovet Leningrad Technological Institute. Translated from *Zhurnal Prikladnoi Khimii*, 44 (10), pp. 2229-2235, (Oct. 1971).

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NAIMA
NORTH AMERICAN INSULATION
MANUFACTURERS ASSOCIATION

March 24, 1992

Ron Myers
Emission Inventory Branch (MD-14)
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

Dear Mr. Myers:

In January you sent us a letter and a copy of Section 8.11 of the publication "Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources (AP-42)". Section 8.11 pertains to Glass Fiber Manufacturing. The purpose of your letter was to inform our organization of ongoing revisions to AP-42 and to invite our participation in the revision process. You requested a response from our organization by February 12, 1992. On February 4, 1992 we agreed to extend the response date to March 15, 1992 in order to give our members a chance to review Section 8.11 in more detail.

Your letter and attachments were given to our Environmental Affairs Committee. They have thoroughly reviewed Section 8.11 and have had several conference calls to discuss the accuracy and representativeness of the information contained in this section. They recognize the importance of this document in estimating emissions from glass fiber manufacturing. Because of its importance, we would like to propose a sampling program to update existing emission factors and include new factors for other pollutants emitted. This is particularly true for the emission factors in Table 8.11-1 which we believe are not representative for todays operations. Our plan is to meet with member companies during the first week in April to finalize a sampling strategy. We would then like to meet with you during the later part of April or the first part of May to review the plan and get your concurrence. If we can agree to a program in May, we anticipate that the testing and analysis can be completed by the end of 1992.

Please give this proposal your consideration and advise if the timing is acceptable. We look forward to working with you on this project.

Sincerely,

George R. Phelps
Director, Government Affairs

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Ron Myers
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U.S. Environmental Protection Agency
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Rich:

For your inpu and files

North American Insulation Manufacturers Association

MEETING OF THE ENVIRONMENTAL AFFAIRS COMMITTEE

EPA Office 2:00 PM
Research Triangle Park, NC Thursday, January 23, 1992

.....

The meeting of the Environmental Affairs Committee convened at 2:00 PM on Thursday, January 23, 1992 with the following in attendance:

Committee: Chairman: D. Schlaudecker, Owens-Corning Fiberglas
S. Aldridge, Knauf Fiberglass
B. Harlan, Owens-Corning Fiberglass
A. Jankousky, Manville
D. Kutys, CertainTeed
F. Schmidt, Manville
E. Switala, Owens-Corning Fiberglas

EPA and RTI:
C. Chin, EPA/ESD/ISB
D. Cornstubble, RTI
J. Crowder, EPA/ESD/ISB
K. Durkee, EPA/ISB
J. Farmer, RTI
M. Laney, RTI
E. McCarley, EPA/TBD
M. McKeever, EPA/OSDB
R. Myers, EPA/TSD/EIB
J. Santiago, EPA/ESD/ISB
J. Telander, EPA/OAQPS

NAIMA: G. Phelps

.....

1. Standards Development - EPA selected Research Triangle Institute (RTI) as a contractor to gather data for the first phase of the standards development process. EPA estimates that this phase will take approximately six months to complete. The project manager for RTI is Jack Farmer. Data generated from phase 1 will be used to select plants for further evaluation.

2. Proposed Standard - EPA plans to issue a proposed standard by 1995. The final standard will be promulgated by 1997. New facilities will have to comply immediately. Existing facilities will have three years to comply from the date the standard becomes effective.

3. Development of FTIR - EPA is in the development state of a FTIR (fourier transform infrared spectrophotometry) method for identification of hazardous air pollutants. This work was actually started last year. To date, EPA has footprints for 80 of the 189 hazardous air pollutants (HAPs) listed in the Clean Air Act. EPA feels that it can footprint about 130

HAPs. EPA is building a mobile van to house the FTIR equipment and expect to have it ready by April or May '92. EPA's plans are to do a screening test at 8 to 10 plants, two of which will be fiber glass plant sites. They would like to use OCF's Fairburn plant and CertainTeed's Athens plant for this purpose. It was agreed that a separate meeting will be held with EPA to review the technical aspects of this method.

4. State Data - The states are telling EPA that they have a lot of data and want to help EPA set the standards. After some discussion it was agreed that the states likely have only data that the various companies have supplied them and therefore it may not be necessary to canvas every state.

5. EPA Data Requirements - EPA addressed its data needs. It was agreed that the data base generated for fine fibers is a current representation of sources in the industry. EPA requested that we add binder ingredients and design parameters for control equipment to this data base. EPA will attempt to put together a common questionnaire for all the industry and hopefully bypass the 114 process.

6. Definition of Floor - A "floor" was defined by EPA as: standards cannot be less stringent than the five best controlled sources, for 30 or less plants. This applies to existing sources. For new sources, the best controlled similar source in a category or subcategory must be used.

*7. Agreed Upon Assignments:

- Each company will identify process chemicals on the HAP list and substances on the list that result from reactions that may occur.

- Each company will review the data and information supplied as part of the fine fiber project and update as necessary. Control equipment design data will be supplied after EPA issues its questionnaire.

- EPA will provide a common questionnaire for its data and information needs.

- Industry technical representatives will meet with EPA on measurement methods by late February.

8. Site Visits - EPA and RTI are planning some site visits.

9. Draft Technical Document - EPA expects to have a draft technical background document in 2 years.

10. Next Meeting - The next meeting will be in Denver, Colorado February 27 and 28, 1992.

11. Adjournment - The meeting adjourned at 3:30 PM.

Respectfully submitted,

Dave Schlaudecker

Dave Schlaudecker, Chairman
Environmental Affairs Committee

* Action Assignments

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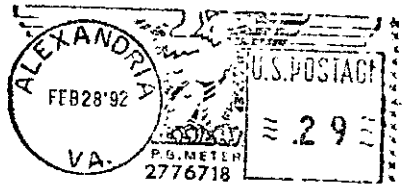


Mr. Ron Myers
Mail Drop 13
US Environmental Protection Agency
Research Triangle Park, NC 27711

#010

AN ASSESSMENT OF EMISSIONS AND AMBIENT CONCENTRATIONS FROM TOXIC AIR POLLUTANTS DISCHARGED BY XERXES CORPORATION

April 3, 1989

Prepared for:

U.S. Environmental Protection Agency

Maryland Department of the Environment
Air Management Administration
Air Toxics Control Division
2500 Broening Highway
Baltimore, Maryland 21224

EXECUTIVE SUMMARY

Maryland Air Management Administration performed an air toxics review of a proposed fiber glass manufacturing facility to be built by Xerxes Corporation. The initial review indicated that styrene emissions would not result in concentrations below screening levels. Xerxes modified the plant design by eliminating the high bay production area and increasing the stack height to 60 feet. The analysis of the proposed plant after these changes were made showed that no adverse health impact is expected to be caused by the emissions from the proposed plant. This means that Xerxes would meet the requirements under Maryland's proposed air toxics regulation.

I PURPOSE

This report presents the Maryland Air Management Administration's analysis of the toxic air pollutant emissions discharged by the Xerxes Corporation's proposed fiberglass facility in Washington County, Maryland. The facility was reviewed to determine compliance with Maryland's proposed air toxic regulations (COMAR 10.18.15 Toxic Air Pollutants) to provide information on air toxics to concerned citizens who requested a public hearing as provided in Maryland law.

II BACKGROUND

In 1986 the United States Environmental Protection Agency (EPA) proposed an air toxics policy (EPA, 1985). The policy relies on State and local air pollution control agencies to evaluate and, if appropriate, control certain sources of toxic air pollutants that EPA feels do not warrant regulation at the national level (GCA, 1985).

In support of State initiatives, EPA provides money and technical assistance to State or local agencies in the form of performance-based grants. The grant stipulates that the money must be used to evaluate a source or sources that have the potential to create high risks from emissions of toxic air pollutants.

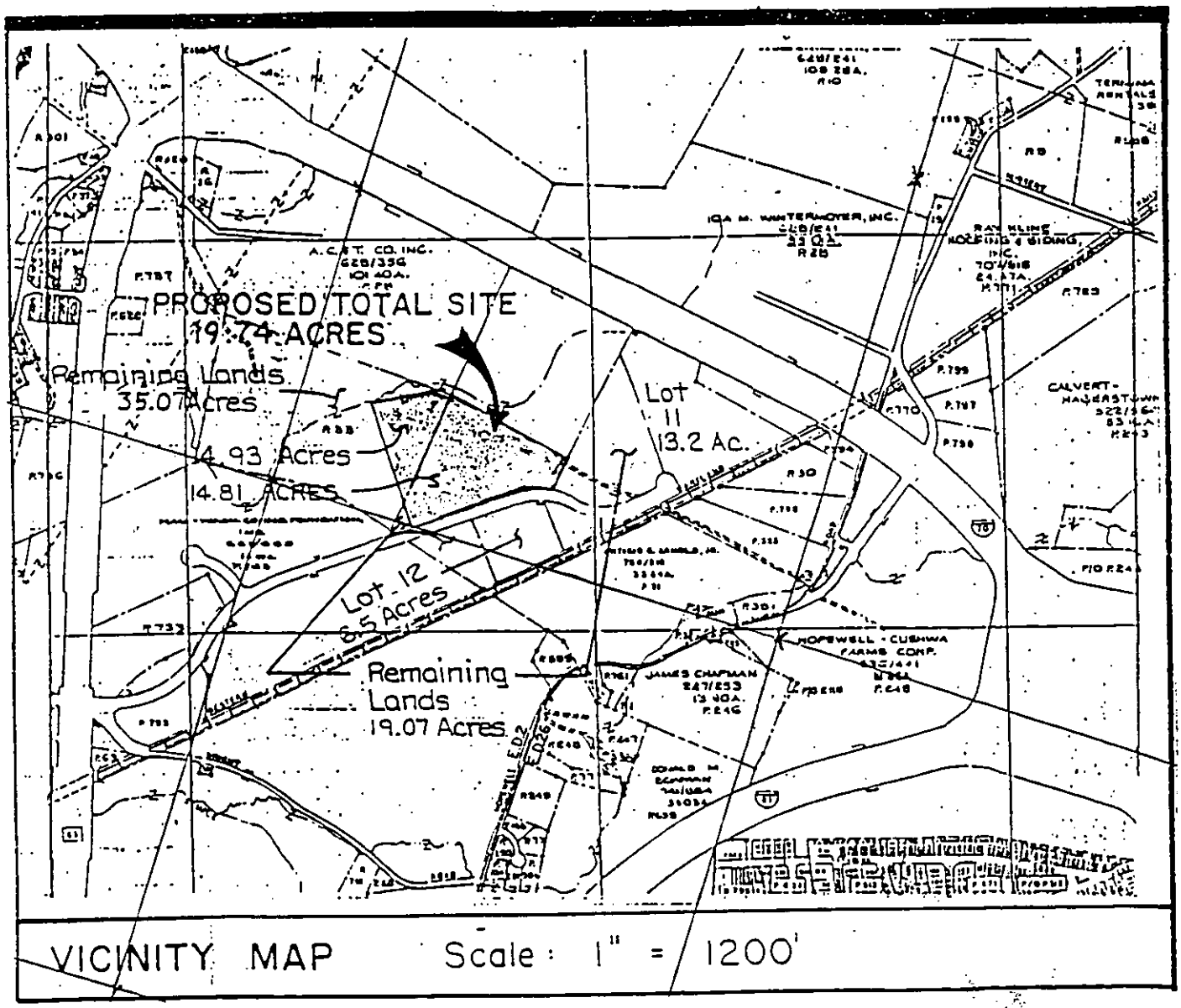
In its fiscal year 1987 grant from EPA, the State of Maryland Air Management Administration (AMA) elected to evaluate emissions of toxic air pollutants from the Xerxes Corporation's proposed fiber glass tank manufacturing plant. This report summarizes the evaluation of this plant and discusses the practical application of the evaluation.

III FACILITY DESCRIPTION

The Xerxes Corporation proposes to construct a manufacturing facility in the I - 70/81 Industrial Park located outside of Williamsport in Washington County, Maryland. This facility will manufacture fiber glass underground petroleum storage tanks and other fiber glass products. The facility will consist of raw material storage vessels and a processing building that will house 17 resin spray guns and other processing areas for grinding, repairing, and testing the fiber glass tanks. Figure 3.1 is a plot plan of the Xerxes facility.

FIGURE 3.1

XERXES FACILITY - PLOT PLAN



IV PROCESS DESCRIPTION

A reinforced plastic molding operation will be used to make various products at the plant, principally fiber glass underground petroleum storage tanks. Each of the products will be molded using the same process. A spray applicator is used to spray resin, chopped fiber glass, and a small amount of catalyst against a rotating steel or fiber glass mold. The size and shape of the mold vary depending on the product being fabricated. The underground storage tanks are built in sections. When finished, the tanks can be up to 30 ft. in length and up to 10 ft. in diameter. A typical tank is shown in figure 4.1.

The spray applicator used for this purpose is known as a "spray gun" or "chopper gun", since it simultaneously chops the fiber glass roving and sprays the mixture of fiber glass and catalyzed polyester resin against the mold. The type of gun used by Xerxes, an "airless" spray gun, is designed to minimized emissions of styrene to:

1. minimize emissions to the outdoor environment
2. protect workers, and
3. conserve material usage.

This type of an emission control represents the best way to control emissions and could be considered T-BACT (Best Available Control Technology for Toxics) under Maryland's proposed air toxics regulations.

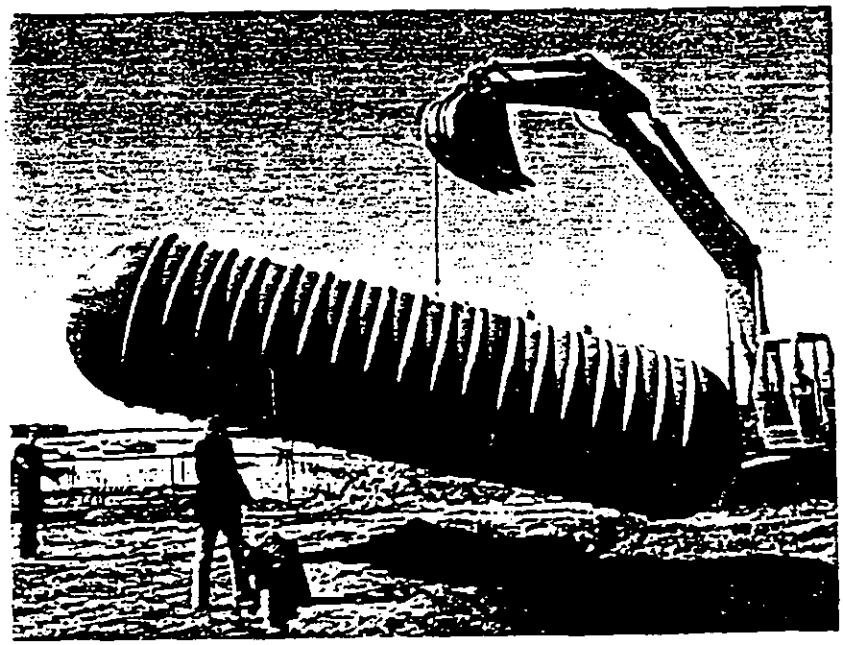


FIGURE 4.1
UNDERGROUND
STORAGE TANK

V TOXIC AIR POLLUTANT EMISSIONS.

5.1 Overview

Detailed estimates of all Toxic Air Pollutant (TAP) emissions were provided by Xerxes Corporation and are included as Appendix A. These estimates are based on a material balance analysis and were reviewed by the Engineering Division of the Air Management Administration.

The plant will discharge four compounds to the atmosphere:

1. Styrene
2. Methyl Ethyl Ketone Peroxide (MEKP)
3. Dimethyl Phthalate (DP)
4. Acetone

Benzaldehyde, acetophenone, and styrene oxide will form as secondary pollutants when styrene emissions are oxidized after their release into the atmosphere (Pfaffli, 1979).

For these seven pollutants, worst-case hourly emission estimates were used to evaluate non-cancer health effects while maximum annual emissions were used to evaluate cancer risks.

5.2 Direct Emissions From Spray Application

The resin spraying operation will primarily discharge styrene. A thermosetting polyester resin liquid, which contains styrene monomer (approximately 45%) and methyl ethyl ketone peroxide and dimethyl phthalate in equal portions (.75% by weight) is sprayed on the mold. A portion of the liquid evaporates during the application and curing process. Styrene emissions are vented for operator comfort and safety through the general ventilation system and exhausted directly to the atmosphere through a 60 ft. stack. Styrene emissions are limited by permit conditions to less than 250 tons per year.

Small quantities of methyl ethyl ketone peroxide, dimethyl phthalate (components of the catalyst) and glass fibers are also discharged. The air collecting system will have intercept filters on all inlets. Assuming 50% removal efficiency, the emissions of glass fiber particles will be less than one pound per day.

5.3 Emissions From Oxides

Several styrene decomposition products are formed when styrene emissions are oxidized after they are released into the air. These are styrene oxide, acetophenone, and benzaldehyde.

Styrene oxide, acetophenone, and benzaldehyde emissions were assumed to be proportional to styrene emissions. Using mean concentrations of styrene and styrene oxide found in the air during lamination processes in the reinforced plastics industry, a best estimate of the ratio of styrene oxide to styrene was made (Pfaffli, 1979). This ratio is 1 to 675 (or .0015).

This emission estimate for styrene oxide, the only TAP in this analysis that is treated as a carcinogen, is very uncertain. However, the ratio of styrene oxide to styrene could be as high as one part styrene oxide to 15 parts styrene (1/15 or 0.068) and emissions would still result in concentrations below the screening level. The worst possible ratio supported by the Pfaffli study is one part styrene oxide to 117 parts styrene. This ratio assumes that styrene oxide always equals the highest mean concentration found and styrene the lowest.

5.4 Fugitive Emissions

Acetone, a common solvent, is used to clean tools and equipment. Emissions will be routinely released inside the building and discharged to the atmosphere by ventilation fans and open doors and windows.

VI DISPERSION MODELING

6.1 Overview

Dispersion modeling is used to estimate off-site concentrations of Toxic Air Pollutants (TAPs) using stack, emission, and meteorological data. Two levels of air quality dispersion modeling were used to estimate off-site concentrations resulting from toxic air pollutant emissions.

Simple screening dispersion models are used first, to "screen out" emissions that are clearly not causing problems. Screening models will generally overpredict concentrations. They are overly conservative.

More complex modeling was conducted for emissions of TAPs that did not screen out using the screening dispersion model. When emissions of a substance screen out it means that they would comply with the requirements proposed in Maryland draft air toxics regulations.

6.2 Screening Models

A computerized version of AMA TM 86-02 (AMA, 1986) was used to screen all TAP emissions. TM 86-02 is a conservative screening procedure based on Gaussian dispersion concepts of the Industrial Source complex (ISC) model and worst-case assumptions about meteorology.

Emissions of methyl ethyl ketone peroxide (MEKP) and dimethyl phthalate (DP) screened out based on this modeling. No further analysis of these TAPs was necessary. The five remaining TAPs required more complex modeling.

6.3 Complex Modeling

Complex modeling was then conducted for the five remaining substances using the Industrial Source Complex Long Term (ISC - LT) model for annual concentrations and the Industrial Source Complex - Short Term (ISC - ST) for 1-hour and 8-hour concentrations

(EPA 1979a, EPA 1979b). The model source parameters used in this modeling analysis are shown in Table 6.1. With the exception of styrene, all of the emissions screened out at this point.

To further reduce the styrene concentrations, Xerxes modified their original construction design to improve dispersion. In the original design, the stack was not high enough to avoid downwash, the downward pull on air that an adjacent structure exerts which prevents pollutants from dispersing normally. Downwash can occur when stack heights are less than 1.5 times the building height.

To avoid the high styrene concentrations resulting from downwash, Xerxes Corporation redesigned the plant to eliminate a 50 foot high production bay and reduced the number of stacks. The height of the remaining stacks was increased to 60 feet to prevent downwash. Table 6.2 shows styrene emission rates using the modified source parameters.

TABLE 6.1
SOURCE PARAMETERS BEFORE PLANT MODIFICATION

Source Number	Bldg. Ht(m)	Stack Ht.(m)	Stack Diam. (m)	Exit Temp. (^{0}K)	Vel. (m/s)	Substance	Emission Rate (g/s) 1-hr & 8-hr	Annual
101-110	15.24	10.05	.61	293	6.25	Styrene	.7875	.3591
	15.24		.61	293	6.25	MEKP	.00023	
	15.24		.61	293	6.25	DP	.00023	
201	15.24	9.14	.61	293	6.25	Styrene	1.575	.7190
301-302	15.24	6.09	.61	293	6.25	Styrene	.3937	.1798
	15.24		.61	293	6.25	MEKP	.000118	
	15.24		.61	293.	6.25	DP	.000118	
303-304	15.24	12.19	.61	293	6.25	Sytrene	.3937	.1798
	15.24		.61	293	6.25	MEKP	.000118	
	15.24		.61	293	6.25	DP	.000118	
401	15.24	8.76	.61	293	6.25	Styrene	.7875	.1798
	15.24		.61	293	6.25	MEKP	.000236	
	15.24		.61	293	6.25	DP	.000236	
	15.24		.61	293	6.25	Styrene	.7875	.3591
402	15.24	9.29	.61	293	6.25	MEKP	.000236	
	15.24		.61	293	6.25	DP	.000236	

	Area Source Dimensions	Height	Substance	Emission Rate (g/s) 1 hr. & 8 hr.
501-502	51.81 m X 51.81 m	9.14 m	Acetone	1.57

TABLE 6.2
SOURCE PARAMETERS AFTER PLANT MODIFICATION

Source Number	Bldg. Ht.(m)	Stack Ht.(m)	Stack Diam.(m)	Stack Temp.(^{0}K)	Exit Vel.(m/s)	Styrene Emission Rate (g/s)
103	10.97	18.29	.61	293	6.25	3.94
108	10.97	18.29	.61	293	6.25	3.94
304	10.97	18.29	.61	293	6.25	1.57
402	10.97	18.29	.61	293	6.25	3.15

VII SUMMARY OF RESULTS

Maryland's draft air toxics regulations were used in this analysis to determine if emissions of Toxic Air Pollutants (TAPs) are acceptable. There are three basic requirements established in the draft regulations. These are:

1. All sources covered must report emissions of TAPs;
2. New sources must use Best Available Control Technology for Toxics (T-BACT) and
3. All sources must demonstrate that allowable emissions do not result in levels of TAPs off their property that are unacceptable.

This third requirement is called the "Ambient Impact Requirement." There are several ways to make this demonstration. The easiest way is to use a screening level analysis. "Screening levels" are compared to concentrations resulting from a source's emissions. They are intended to be conservative and protective of public health.

If concentrations of TAPs resulting from emissions are less than screening levels, then the emissions are considered acceptable. If not, a more detailed review must be conducted. Appendix B provides a more detailed explanation of Marylands proposed program.

The Xerxes Corporation plant will discharge four TAPs directly to the atmosphere; styrene, acetone, methyl ethyl ketone peroxide (MEKP), and dimethyl phthalate (DP). Three other pollutants: styrene oxide, acetophenone, and benzaldehyde will form as secondary pollutants.

The preliminary analysis indicated that styrene emissions would not result in concentrations below screening levels. This would mean that a more complex, expensive and time consuming "Second Tier Analysis" would be required.

However, as mentioned earlier, much of the problem seemed to result from poor dispersion caused by the high bay production area and short stacks included as part of the original Xerxes application. Xerxes modified the plant design by eliminating the high bay

and increasing stack height to 60 feet. The analysis of the proposed plant after these changed were made showed that no adverse health inpact is expected to be caused by the emissions from the proposed plant.

Table 7.1 and 7.2 show the results of this analysis using the original and modified designs. Table 7.1 is based upon stack and building heights contained in the permit to construct application (Table 6.1). Table 7.2 uses stack and building height data after modification (Table 6.2).

Table 7.1 compares concentrations predicted using the conservative computerized T.M. or complex modeling to screening levels. Based on this screening level analysis MEKP and DP screened out using the T.M. All other substances besides styrene screened out using the more complex modeling.

Table 7.2 shows that styrene levels resulting from emissions after the proposed modification would be below styrene screening levels. More complex modeling was used to predict these styrene levels. None of the other TAPs were included in this modeling because they had already screened out. With the modified stack and building heights actual concentrations resulting from Xerxes emissions would be well below those reported in Table 7.1.

With the modified stack and building heights all substances discharged by Xerxes would result in concentrations below screening levels. This means that Xerxes would meet the requirements under Maryland's proposed air toxics regulation.

TABLE 7.1 COMPARISON OF SCREENING LEVELS TO CONCENTRATIONS RESULTING FROM EMISSIONS BEFORE PLANT MODIFICATIONS

SUBSTANCE (CAS NUMBER)	OFF-SITE CONCENTRATION HIGHEST 1-HR. AVERAGE	1-HR SCREENING LEVEL	OFF-SITE CONCENTRATION HIGHEST 8-HR. AVERAGE	8-HR. SCREENING LEVEL	OFF-SITE CONCENTRATION HIGHEST ANNUAL AVERAGE	ANNUAL SCREENING LEVEL
Styrene (100-42-5)	7428	4250	2803	2150	(2)	None
Styrene Oxide (96-09-3)	(2)	None	4.2	175	.23	10
MEKP (1338-23-4)	4.39	15	(2)	None	(2)	None
DP (131-11-3)	(2)	None	3.074	50	(2)	None
Acetone (67-64-1)	2149	23750	756	17800	(2)	None
Benzaldehyde (100-52-7)	(2)	None	16.4	53	(2)	None
Acetophenone (98-86-2)	(2)	None	9.5	39	(2)	None

1. All values in ug/m^3.
2. Not applicable

TABLE 7.2 COMPARISON OF SCREENING LEVELS TO STYRENE CONCENTRATIONS AFTER PLANT MODIFICATION (1)

SUBSTANCE (CAS NUMBER)	OFF-SITE CONCENTRATION HIGHEST 1-HR. AVERAGE	1-HR. SCREENING LEVEL	OFF-SITE CONCENTRATION HIGHEST 8-HR. AVERAGE	8-HR. SCREENING LEVEL	OFF-SITE CONCENTRATION HIGHEST ANNUAL AVERAGE	ANNUAL SCREENING LEVEL
Styrene (100-42-5)	3818	4250	1289	2150	(2)	None

1. All values in ug/m^3.
2. Not applicable

VIII REFERENCES

1. Air Management Administration, Maryland Department of the Environment (AMA); November 1986, Ambient Air Quality Impact Screening Model Procedures for Toxic Air Pollutants

2. GCA Corporation, September 1985, Assessment of Acrylonitrile Emissions from American Cyanamid Company, Milton, Florida

3. Office of the Secretary of State, Division of State Documents; January 1989, Code of Maryland Regulations, Title 26 Department of the Environment, Subtitle 11 Air Quality, Chapter 15 Toxic Air Pollutants (COMAR 26.11.15), Annapolis, Maryland.

4. Pfaffli, P., Vanio H., and Hesso, A.; 1979, Styrene and styrene oxide concentrations in the air during the lamination process in the reinforced plastic industry; Scandinavian Journal of Work Environment and Health, Vol. 5, pp. 158-161

5. Rogozen, M.B., Science Applications, Inc.; June 1982, Control Techniques for Organic Gas Emissions from Fiberglass Impregnation and Fabrication Processes

6. U.S. Environmental Protection Agency (EPA); December 1979a, Industrial Source Complex (ISC) Dispersion Model Users Guide, Volume I. Office of Air Quality Planning and Standards. EPA-450/4-79-030. Research Triangle Park, North Carolina.

7. U.S. Environmental Protection Agency (EPA); December 1979b, Industrial Source Complex (ISC) Dispersion Model Users Guide, Volume II. Office of Air Quality Planning and Standards. EPA-450/4-79-031. Research Triangle Park, North Carolina.

8. U.S. Environmental Protection Agency (EPA); June 1985, A Strategy to Reduce Risks to Public Health from Air Toxics.

APPENDIX A

EMISSION CALCULATIONS

Hourly and annual emission rates calculated from material balance analysis.

This appendix provides hourly and annual emission rates for four airborne contaminants:

Styrene (S)
Methyl Ethyl Ketone Peroxide (MEKP)
Dimethyl Phthalate (DP)
Acetone (A)

Constants for all calculations

Addition rate of MEKP to resin

W_{MEKP} = 0.0075 lbs MEKP/lb resin

Addition rate of dimethyl phthalate to resin = W_{DP} = 0.75% by weight

W_{DP} = 0.0075 lbs DP/lb resin

Evaporation rate of MEKP = E_{MEKP} = 0.2% of MEKP by weight

or E_{MEKP} = 0.002 lbs vapor/lb MEKP

Evaporation rate of DP = E_S = 0.2% of DP by weight

or E_{DP} = 0.002 lb vapor/lb DP

Evaporation rate styrene = E_{DP} = 11% of styrene component of resin (45% by weight)*

or E_S = 5% of resin weight

or E_S = 0.05 lb vapor/lb resin

* 11% is average of rates ranging from 9%-13% in California EPA study (Rogozen, 1982)

Procedures for determining hourly emissions

Resin consumption of process corresponding to each spray gun:

R_H = 125 lbs/hr

Hourly emission for styrene H_s = resin usage x evaporation rate or:

$$= \frac{\text{lbs resin}}{\text{hour}} \times \frac{\text{lbs vapor}}{\text{lb resin}} = \frac{\text{lbs vapor}}{\text{hour}}$$

$H_S = R_H \times E_S$

$= (125)(0.05)$

$H_S = 6.25$ lbs/hour per spray gun

or For sixteen (16) spray guns, total hourly emissions are 16 x 6.25 = 100 lbs/hr., assuming all guns may be in use simultaneously.

Hourly emissions for MEKP and DP: H_{MEKP}; H_{DP}

Hourly emission rate, H_x = Resin usage x addition rate x evaporation rate or:

$$= \frac{\text{lbs resin}}{\text{hour}} \times \frac{\text{lbs x}}{\text{lb resin}} \times \frac{\text{lbs vapor}}{\text{lb x}} = \frac{\text{lbs vapor}}{\text{hour}} \text{ (per spray gun)}$$

For MEKP

$H_{MEKP} = R_H \times W_{MEKP} \times E_{MEKP}$

$= (125) \times (0.0075) \times (0.002)$ lbs vapor/hour

$H_{MEKP} = 0.001875$ lbs vapor/hour per spray gun

or For sixteen (16) spray guns, total hourly emissions are 0.030 lbs/hr.

For DP

$H_{DP} = R_H \times W_{DP} \times E_{DP}$

$= (125)(0.0075)(0.002)$

$H_{DP} = 0.001875$ lbs vapor/hour per spray gun

or For sixteen (16) spray guns, total hourly emissions are 0.030 lbs/hr.

For ACETONE

Consumption records indicate that approximately 1 lb. of acetone is used for each 80 lbs. of resin. 100% evaporation rate is assumed for acetone.

H_A = Hourly resin usage x 1 lb. acetone vapor/80 lbs. resin

or $$= \frac{\text{lbs. resin}}{\text{hour}} \times \frac{\text{1 lb. vapor}}{\text{80 lbs. resin}} = \frac{\text{lbs. vapor}}{\text{hour}}$$

$H_A = \frac{R_H}{80}$ lbs/hour per spray gun

$= 125/80$

$= 1.5625$ lbs/hour per spray gun

or For sixteen (16) spray guns, total hourly emissions are 25 lbs/hr.

ANNUAL EMISSIONS

STYRENE

Maximum resin consumption proposed for facility is 8,000,000 lbs/yr = N_S

Annual emission rate A_S = usage x evaporation rate

A_S = lbs. resin/year x lbs. vapor/lbs. resin = lbs. vapor/year

$A_S = N_S \times E_S$

$= (8{,}000{,}000) \times (0.05)$

A_S = 400,000 lbs. vapor (sytrene)

For MEKP AND DP

$A_{MEKP/DP} = N_S \times W_{MEKP/DP} \times E_{MEKP/DP}$

$= (800{,}000)\ (0.0075)\ (0.002)$

A_{MEKP} = 120 lbs. vapor/year

A_{DP} = 120 lbs. vapor/year

ACETONE

Annual consumption = 100,000 lbs

100% evaporation loss is assumed.

APPENDIX B

BRIEF SUMMARY OF MARYLAND'S AIR TOXICS REGULATIONS

January 1989

This summary describes Maryland's air toxics regulations (COMAR 26.11.15). It discusses the pollutants and sources covered as well as the three major requirements.

TOXIC AIR POLLUTANTS COVERED

Toxic air pollutants (TAPs) include a large number of carcinogens and non-carcinogens for which no national or state ambient air quality standards have been established. The regulations call carcinogens "Class I TAPs" and other toxics "Class II TAPs."

The number of substances regulated as toxic air pollutants is larger for new than for existing sources. For existing sources, the regulations contain a specific list of pollutants. For new sources, there is a somewhat longer list of Class I TAPs (carcinogens) and an open-ended definition of Class II TAPs that is based on the term "health hazard" in the State Right-to-Know laws.

SOURCES COVERED

The sources governed by the regulations are identified in the sections concerning applicability. In general, the regulations will apply to any source required to get an air quality permit. Certain small sources are exempt, and there are specific exemptions for fuel burning equipment, char-broilers, and gasoline stations.

GENERAL REQUIREMENTS

There are three major requirements:

1. Quantify emissions of toxic air pollutants.
2. Use the best available control technology for toxics (T-BACT).
3. Do not unreasonably endanger human health.

The requirement to quantify TAP emissions requires new sources to quantify any TAP discharged. For existing sources, the requirement is limited to specifically listed TAPs. Existing sources must submit emissions information by January 1, 1989 for Class I and highly toxic Class II TAPs and by Janaury 1, 1991 for other Class II TAPs.

The T-BACT requirement applies to new sources. It allows the Department to consider both the toxicity of substances discharged and the costs of controlling emissions on a case-by-case basis.

The third requirement is also called the "ambient impact" requirement, because in order to demonstrate compliance, a source must show that it will not increase concentrations of TAPs in the ambient air by more than certain levels. Existing sources must comply with the ambient impact requirement by July 1, 1990 for Class I and highly toxic Class II TAPs, and by January 1, 1992 for other Class II TAPs.

THE AMBIENT IMPACT REQUIREMENT

The ambient impact requirement is the most complex part of the regulations, because there are several options a source may use to demonstrate that its emissions do not unreasonably endanger human health. The primary option is to demonstrate that the source will not increase ambient concentrations by more than applicable "Screening Levels." The second option is a "Second Tier Analysis." There is a third option for Class I sources, involving a "Special Permit."

Screening Levels are established for both carcinogens and for other toxic effects. Screening Levels for carcinogenic effects are called "Risk-Based Screening Levels" since they are developed using risk assessment. The Risk-Based Screening Level represents a maximum increase in individual lifetime cancer risk of one in 100,000.

Screening Levels for other toxic effects may be based on Threshold Limit Values (TLVs). TLV-Based Screening Levels are equal to the TLV divided by 100 and are either 1- or 8-hour average concentrations. If no TLV is available, the regulations contain procedures for developing Screening Levels based on toxicity data establishing thresholds for various health effects (Threshold-Based Screening Levels). Since these Screening Levels are developed using methods that may not be appropriate for every substance, the regulations also provide that the Department may adopt Special Screening Levels to more adequately reflect toxic effects other than cancer.

Screening Levels are intended to be conservative so that public health will be protected even though only one source is evaluated at a time. However, a mechanism is provided in the "Second Tier Analysis" to consider multiple sources of a TAP and to develop a less conservative though still protective Acceptable Ambient Level to replace a Screening Level for noncarcinogenic effects.

The Second Tier option also provides for the development of "Insignifcant Risk Concentrations" in cases where new data indicates that a Risk-Based Screening Level should be revised. This option will involve a re-analysis of the dose response data for a carcinogen.

Finally, the Special Permit option for Class I TAPs involves a reassessment of the exposure to a carcinogen and the acceptable risk level. Screening Level analysis assumes that a person will be continuously exposed for 70 years to the highest TAP concentration predicted to occur off the source's property. Since this assumption is very conservative, the Special Permit option provides for the opportunity to use more realistic exposure assumptions. In addition, if necessary, the Special Permit provides the opportunity to accept risks that may exceed one in 100,000.

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GLASS PB62

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STATIONARY SOURCE SAMPLING REPORT

REFERENCE NO. 5729

PPG INDUSTRIES, INC.

SHELBY, NORTH CAROLINA

PARTICULATE EMISSIONS TESTING

NO. 526 MELTING FURNACE

NORTH STACK

NOVEMBER 24, 1987

REPORT CERTIFICATION

The sampling and analysis performed for this report was carried out under my direction and supervision.

Date December 7, 1987 Signature Neill M Harden

Neill M. Harden

I have reviewed all testing details and results in this test report and hereby certify that the test report is authentic and accurate.

Date December 7, 1987 Signature D James Grove

D. James Grove, P.E.

TABLE OF CONTENTS

INTRODUCTION

1.1 Outline of Test Program. Stationary source sampling was performed for PPG Industries in Shelby, North Carolina, on November 24, 1987. Three EPA Method 5 runs were performed at the north stack of the No. 526 melting furnace to determine the particulate emissions for engineering purposes.

1.2 Test Participants. Table 1-1 lists the personnel present during the test program.

TABLE 1-1
TEST PARTICIPANTS

PPG Industries, Inc.	Dennis Hubbard Test Coordinator
	Billy McFarland Test Observer
Entropy Environmentalists, Inc.	Neill M. Harden Project Supervisor
	Anthony L. Mastrianni Engineering Technician

SUMMARY OF RESULTS

2.1 Presentation. Table 2-1 presents the particulate emissions from the testing performed November 24, 1987, at the north stack of the No. 526 melting furnace. Detailed test results are given in Appendix A; field and analytical data are presented in Appendix B.

2.2 Emission Rate. The average particulate emission rate for the three runs was 4.43 pounds per hour.

2.3 Aborted Run. Run 3 was aborted due to a broken nozzle. The run was repeated and three runs were performed. No data from run 3 appears in this report.

2.4 Impinger Catches. The impinger catches were weighed at the test site by Entropy Environmentalists, Inc. personnel; the results were later combined with those of the silica gel catches. The impinger catches were then given to PPG Industries, Inc. personnel for local analysis.

TABLE 2-1

PARTICULATE TESTS SUMMARY OF RESULTS

No. 526 Melting Furnace, North Stack

	1	2	4
Run Date	11/24/87	11/24/87	11/24/87
Test Train Parameters:			
Volume of Dry Gas Sampled, SCF*	32.119	34.631	32.884
Percent Isokinetic	106.0	107.3	105.7
Flue Gas Parameters:			
Temperature, Degrees F	1,499	1,494	1,494
Volumetric Air Flow Rates SCFM*, Dry	8,840	9,379	9,072
ACFM, Wet	42,981	46,083	43,944
Method 5 Results:			
Catch, Milligrams	120.5	117.0	128.7
Concentration, Grains/DSCF*	0.05790	0.05214	0.06040
Emission Rate, Lbs/Hour	4.387	4.192	4.697

* 68 Degrees F -- 29.92 Inches of Mercury (Hg)

PROCESS DESCRIPTION AND OPERATION

3.1 General. The PPG Industries, Inc. plant in Shelby, North Carolina, uses gas-fired melting furnaces in the production of glass fibers. Raw materials are charged continuously to the melting furnace and generally are made up of sand, soda, limestone, feldspar, fluorspar, salt cake, and cullet.

3.2 Source Air Flow. Figure 3-1 is an air flow schematic showing the test location and the passage of the flue gases exhausted by the No. 526 melting furnace.

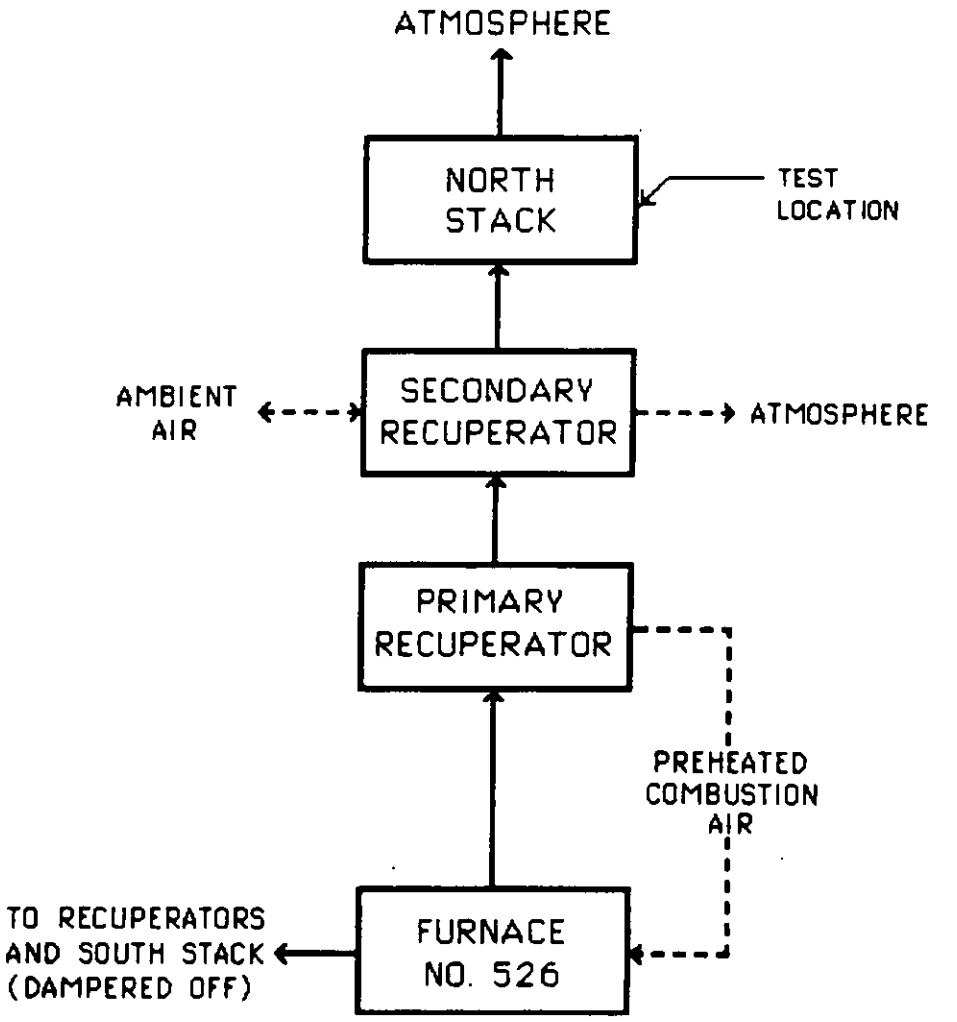


FIGURE 3-1. FURNACE NO. 526 AIR FLOW SCHEMATIC SHOWING TEST LOCATION.

SAMPLING AND ANALYTICAL PROCEDURES

4.1 General. All sampling and analytical procedures were those recommended by the United States Environmental Protection Agency and the North Carolina Department of Natural Resources and Community Development. Descriptions of the sampling equipment and procedures (extracted from 40 CFR 60) are provided in Appendix D.

4.2 Sampling Points. The number and location of the sampling points were determined according to EPA Method 1. The stack cross section was divided into 24 equal areas with 12 traverse points on each of two axes, as shown in Figure 4-1.

4.3 Volumetric Air Flow Rates

4.3.1 Flue Gas Velocity. EPA Method 2 was used to take the velocity measurements during the traverses of the stack cross section.

4.3.2 Flue Gas Composition. During run 4, a multipoint, integrated flue gas sample was collected and analyzed using EPA Method 3; the analytical results were used to determine the flue gas composition and molecular weight for all three runs.

4.3.3 Flue Gas Moisture. Moisture content was determined by analyzing the sampling train impinger reagents according to the procedures outlined in EPA Method 5.

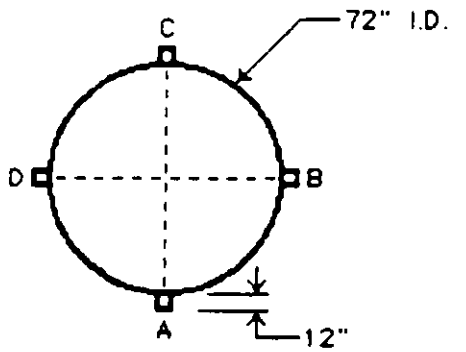
4.4 Emissions Determinations. EPA Method 5 sampling and analytical procedures were used to determine the particulate emissions. Each of the 24 points was sampled for 2.5 minutes, resulting in a net run time of 60 minutes.

4.5 Equipment Calibration. Pertinent calibration data are provided in Appendix C.

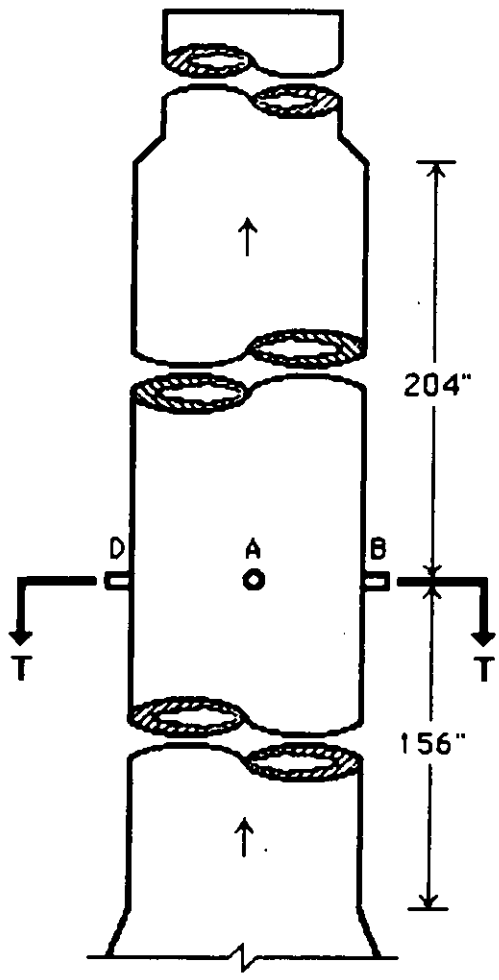
TRAVERSE POINTS

2 AXES
12 POINTS/AXIS
24 TOTAL POINTS

NOTE: PORTS C AND D NOT TESTED.



SECTION T-T



FROM SECONDARY RECUPERATOR

FIGURE 4-1. NORTH STACK TEST LOCATION

APPENDIX A

TEST RESULTS AND EXAMPLE CALCULATIONS

ISOKINETIC SAMPLING TRAIN FIELD DATA & RESULTS TABULATION

PLANT: PPG Industries, Inc., Shelby, North Carolina

RUN #	DATE	SAMPLING LOCATION	OPERATOR
1	11/24/87	No. 526 Melting Furnace, North Stack	Neill M. Harden
2	11/24/87	No. 526 Melting Furnace, North Stack	Neill M. Harden
4	11/24/87	No. 526 Melting Furnace, North Stack	Neill M. Harden

		1	2	4
	Run Start Time	830	1045	1358
	Run Finish Time	940	1152	1503
	Net Sampling Points	24	24	24
Theta	Net Run Time, Minutes	60.00	60.00	60.00
Dia	Nozzle Diameter, Inches	0.544	0.545	0.544
Cp	Pitot Tube Coefficient	0.840	0.840	0.840
Y	Dry Gas Meter Calibration Factor	0.986	0.986	0.986
Pbar	Barometric Pressure, Inches Hg	29.30	29.30	29.30
Delta H	Avg. Pressure Differential of Orifice Meter, Inches H2O	0.971	1.120	1.020
Vm	Volume of Metered Gas Sample, Dry ACF	34.014	36.389	35.013
tm	Dry Gas Meter Temperature, Degrees F	81	77	84
Vm(std)	Volume of Metered Gas Sample, Dry SCF*	32.119	34.631	32.884
Vlc	Total Volume of Liquid Collected in Impingers & Silica Gel, mL	194.0	221.5	197.5
Vw(std)	Volume of Water Vapor, SCF*	9.132	10.426	9.296
%H2O	Moisture Content, Percent by Volume	22.1	23.1	22.0
Mfd	Dry Mole Fraction	0.779	0.769	0.780
%CO2	Carbon Dioxide, Percent by Volume, Dry	15.1	15.1	15.1
%O2	Oxygen, Percent by Volume, Dry	0.8	0.8	0.8
%CO+N2	CO + N2, Percent by Volume, Dry	84.1	84.1	84.1
Md	Dry Molecular Weight, Lb/Lb-Mole	30.45	30.45	30.45
Ms	Wet Molecular Weight, Lb/Lb-Mole	27.69	27.57	27.70
Pg	Flue Gas Static Pressure, Inches H2O	+0.45	+0.45	+0.45
Ps	Absolute Flue Gas Press., Inches HG	29.33	29.33	29.33
ts	Flue Gas Temperature, Degrees F	1,499	1,494	1,494
Delta p	Average Velocity Head, Inches H2O	0.0516	0.0592	0.0541
vs	Flue Gas Velocity, Feet/Second	25.33	27.16	25.90
A	Stack/Duct Area, Square Inches	4,072	4,072	4,072
Qsd	Volumetric Air Flow Rate, Dry SCFM*	8,840	9,379	9,072
Qaw	Volumetric Air Flow Rate, Wet ACFM	42,981	46,083	43,944
%I	Isokinetic Sampling Rate, Percent	106.0	107.3	105.7

* 68 Degrees F -- 29.92 Inches of Mercury (Hg)

(continued next page)

		1	2	4
	Method 5 Results:			
mg	Catch, Milligrams	120.5	117.0	128.7
gr/DSCF	Concentration, Grains per DSCF*	0.05790	0.05214	0.06040
Lb/Hr	Emission Rate, Lbs/Hour (PMRc)	4.387	4.192	4.697

* 68 Degrees F -- 29.92 Inches of Mercury (Hg)

4.4

EXAMPLE TEST CALCULATIONS NO. 1

No. 526 Melting Furnace, North Stack

VOLUME OF DRY GAS SAMPLED AT STANDARD CONDITIONS

$$Vm(std) = 17.64 * Y * Vm * \frac{(Pbar + Delta\ H/13.6)}{(460 + tm)}$$

$$Vm(std) = 17.64 * 0.986 * 34.014 * \frac{(29.30 + 0.971/13.6)}{(460 + 81)} = 32.119 \text{ DSCF}$$

VOLUME OF WATER VAPOR AT STANDARD CONDITIONS

$$Vw(std) = 0.04707 * Vlc$$

$$Vw(std) = 0.04707 * 194.0 = 9.132 \text{ SCF}$$

PERCENT MOISTURE, BY VOLUME, AS MEASURED IN FLUE GAS

$$\%H2O = 100 * Vw(std) / (Vw(std) + Vm(std))$$

$$\%H2O = \frac{9.132}{9.132 + 32.119} * 100 = 22.1\ \%$$

DRY MOLE FRACTION OF FLUE GAS

$$Mfd = 1 - \%H2O/100$$

$$Mfd = 1 - 22.1/100 = 0.779$$

DRY MOLECULAR WEIGHT OF FLUE GAS

$$Md = \%CO2 * 0.44 + \%O2 * 0.32 + \%CO+N2 * 0.28$$

$$Md = 15.1*0.44 + 0.8*0.32 + 84.1*0.28 = 30.45 \text{ LB/LB-MOLE}$$

WET MOLECULAR WEIGHT OF FLUE GAS

$$Ms = (Md * Mfd) + (0.18 * \%H2O)$$

$$Ms = 30.45 * 0.779 + (0.18 * 22.1) = 27.69 \text{ LB/LB-MOLE}$$

ABSOLUTE FLUE GAS PRESSURE

$$Ps = Pbar + Pg / 13.6$$

$$Ps = 29.30 + (0.4 / 13.6) = 29.33 \text{ IN. HG.}$$

AVERAGE FLUE GAS VELOCITY [Note: (Delta p)avg is square of avg sq. root]

$$vs = 85.49 * Cp * SQRT\left[\frac{(\text{Delta p})avg * (460 + ts)}{Ps * Ms}\right]$$

$$vs = 85.49 * 0.840 * SQRT\left[\frac{0.0516 * (460 + 1499)}{29.33 * 27.69}\right] = 25.3 \text{ FT/SEC}$$

DRY VOLUMETRIC FLUE GAS FLOW RATE @ STANDARD CONDITIONS

$$Qsd = \frac{60}{144} * Mfd * vs * A * \frac{Tstd}{ts + 460} * \frac{Ps}{Pstd}$$

$$Qsd = \frac{60}{144} * 0.779 * 25.3 * 4,072.0 * \frac{528}{1499 + 460} * \frac{29.33}{29.92}$$

$$Qsd = 8,840 \text{ SCFM}$$

WET VOLUMETRIC STACK GAS FLOW RATE @ FLUE GAS CONDITIONS

$$Qaw = 60 / 144 * vs * A$$

$$Qaw = 60 / 144 * 25.3 * 4,072.0 = 42,981 \text{ ACFM}$$

PERCENT ISOKINETIC OF SAMPLING RATE

$$\%I = \frac{Pstd}{Tstd} * \frac{100}{60} * \frac{(ts + 460) * Vm(std)}{Ps * vs * Mfd * Theta * \text{Area-nozzle, sq.ft.}}$$

$$\%I = \frac{29.92}{528} * \frac{100}{60} * \frac{(1499 + 460) * 32.119}{29.33 * 25.3 * 0.779 * 60.00 * 0.0016141}$$

$$\%I = 106.0 \ \%$$

GRAINS PER DRY STANDARD CUBIC FOOT

$$gr/DSCF = \frac{7000}{453,592} * \frac{mgs}{Vm(std)}$$

$$gr/DSCF = \frac{7000}{453,592} * \frac{120.5}{32.119} = 0.0579 \text{ gr/DSCF}$$

POUNDS PER HOUR

$$Lb/Hr = 60 / 7000 * gr/DSCF * Qsd$$

$$Lb/Hr = 60/7000 * 0.0579 * 8,840 = 4.39 \text{ LB/HR}$$

APPENDIX B

FIELD AND ANALYTICAL DATA

Preliminary Field Data

PLANT NAME PPG

LOCATION SHELBY, NC

SAMPLING LOCATION GLASS FURNACE #526 OUTLET STACK-NORTH

DUCT DEPTH
FROM INSIDE FAR WALL TO OUTSIDE OF PORT 84"

NIPPLE LENGTH 12

DEPTH OF DUCT 72

WIDTH (RECTANGULAR DUCT) _____

EQUIVALENT DIAMETER:

$D_E = \frac{2 \times \text{DEPTH} \times \text{WIDTH}}{\text{DEPTH} + \text{WIDTH}} = \frac{2(\quad)(\quad)}{(\quad + \quad)} = $ _____

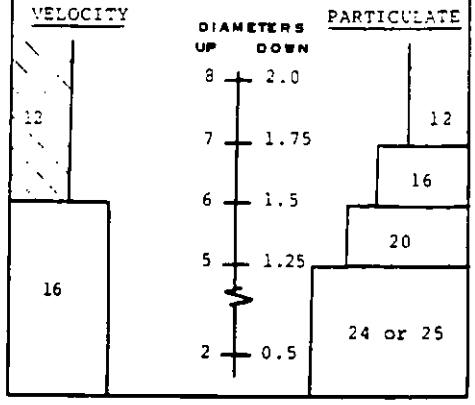
DISTANCE FROM PORTS TO NEAREST FLOW DISTURBANCE

	UPSTREAM	DOWNSTREAM
	13'	17'
DIAMETERS	2.2	2.8

STACK AREA = $\pi(36)^2$ = 4071.5 IN^2

DRAW HORIZONTAL LINE THROUGH DIAMETERS

If more than 8 and 9 diameters and if duct dia. is less than 24", use 8 or 9 points.



LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

	4	6	8	10	12	14	16	18	20	22	24
1	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3	75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4	93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5		85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6		95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7			89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8			96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9				91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10				97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11					93.3	85.4	78.0	70.4	61.2	39.3	32.3
12					97.9	90.1	83.1	76.4	69.4	60.7	39.8
13						94.3	87.5	81.2	75.0	68.5	60.2
14						98.2	91.5	85.4	79.6	73.8	67.7
15							95.1	89.1	83.5	78.2	72.8
16							98.4	92.5	87.1	82.0	77.0
17								95.6	90.3	85.4	80.6
18								98.6	93.3	88.4	83.9
19									96.1	91.3	86.8
20									98.7	94.0	89.5
21										96.5	92.1
22										98.9	94.5
23											96.8
24											98.9

LOCATION OF TRAVERSE POINTS IN RECTANGULAR STACKS

	2	3	4	5	6	7	8	9	10	11	12
1	25.0	16.7	12.5	10.0	8.3	7.1	6.3	5.6	5.0	4.5	4.2
2	75.0	50.0	37.5	30.0	25.0	21.4	18.8	16.7	15.0	13.6	12.5
3		83.3	62.5	50.0	41.7	35.7	31.3	27.8	25.0	22.7	20.8
4			87.5	70.0	58.3	50.0	43.8	38.9	35.0	31.8	29.2
5				90.0	75.0	64.3	56.3	50.0	45.0	40.9	37.5
6					91.7	78.6	68.8	61.1	55.0	50.0	45.8
7						92.9	81.3	72.2	65.0	59.1	54.2
8							93.8	83.3	75.0	68.2	62.5
9								94.4	85.0	77.3	70.8
10									95.0	86.4	79.2
11										95.5	87.5
12											95.8

Point	% OF DUCT DEPTH	DISTANCE FROM INSIDE WALL	DISTANCE FROM OUTSIDE OF PORT
1	2.1	1 1/2"	13 1/2"
2	6.7	4 3/4	16 3/4
3	11.8	8 1/2	20 1/2
4	17.7	12 3/4	24 3/4
5	25.0	18	30
6	35.6	25 5/8	37 5/8
7	64.4	46 3/8	58 3/8
8	75.0	54	66
9	82.3	59 1/4	71 1/4
10	88.2	63 1/2	75 1/2
11	93.3	67 1/4	79 1/4
12	97.9	70 1/2	82 1/2
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			

ENTROPY ENVIRONMENTALISTS, INC

ORSAT FIELD DATA

Plant Name PPG - SHELBY

Sampling Location GLASS FURNACE #526 OUTLET STACK Fuel Type NAT. GAS

Run and/or Sample No. 4 Leak Test? ✓ Date 11-24-87 Operator MH

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
1358	2130	15.1	15.9	—	0.8	—	
TO		15.1	15.9		0.8		
1503		15.2	16.0		0.8		
	Avg.	15.1		Avg.	0.8		84.1

Run and/or Sample No. _____ Leak Test? _____ Date _____ Operator _____

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
	Avg.			Avg.			

Run and/or Sample No. _____ Leak Test? _____ Date _____ Operator _____

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
	Avg.			Avg.			

ENTROPY ENVIRONMENTALISTS, INC.
SPECIALISTS IN SOURCE SAMPLING

PARTICULATE FIELD DATA

COMPANY NAME PPG — RUN NUMBER 1
ADDRESS SHELBY, NC — TIME START 0830
SAMPLING LOCATION GLASS FURNACE #526 OUTLET STACK (NORTH) — TIME FINISH 0940
DATE 11-24-87 — TEAM LEADER MH — TECHNICIANS ACM
BAROMETRIC PRESSURE, IN. HG 29.3 — STATIC PRESSURE, IN. H_2O +0.65
SAMPLING TRAIN LEAK TEST VACUUM, IN. HG 15 — 5① — 7(F) — ____ — ____ — ____
SAMPLING TRAIN LEAK RATE, CU. FT./MIN. 0.003 — 0.001 — 0.001 — ____ — ____ — ____

EQUIPMENT CHECKS

- ✓ PITOTS, PRE-TEST
- ✓ PITOTS, POST-TEST
- = ORSAT SAMPLING SYSTEM
- = TEDLAR BAG
- ✓ THERMOCOUPLE @ 1500 °F

IDENTIFICATION NUMBERS

REAGENT BOX 601 — NOZZLE Q23 — DIAMETER 0.544
METER BOX N6 — T/C READOUT FG
UMBILICAL ____ — T/C PROBE HT-6
SAMPLE BOX ____ — ORSAT PUMP —
PROBE Q23 — TEDLAR BAG —

FILTER #	TARE
E6299	0.4799

NOMOGRAPH SET-UP — NOMOGRAPH # MH

$\Delta H_@$ 1.76 — C FACTOR 0.72
METER TEMP 85 — STACK TEMP 1500
% MOISTURE 22 — REF. ΔP 0.10

SAMPLE POINT	CLOCK TIME, MIN.	DRY GAS METER READING, CU. FT.	PITOT READING (ΔP), IN. H_2O	ORIFICE SETTING (ΔH), IN. H_2O IDEAL	ORIFICE SETTING (ΔH), IN. H_2O ACTUAL	GAS METER TEMP. °F	PUMP VACUUM IN. HG GAUGE	FILTER BOX TEMP. °F	IMP. EXIT TEMP. °F	STACK TEMP. °F	LK. CHECK READINGS
A 1	0	975.969	0.030	0.58	0.58	74	1	260	50	1497	
2	2½	976.82	0.045	0.82	0.82	77	1	260	50	1497	
3	5	978.26	0.055	1.02	1.02	78	1	260	50	1498	
4	7½	979.80	0.055	1.02	1.02	79	1	260	50	1498	
5	10	981.22	0.060	1.12	1.12	81	1	270	50	1499	
6	12½	982.75	0.060	1.12	1.12	82	1	270	50	1499	
7	15	984.24	0.060	1.12	1.12	82	1	270	50	1500	
8	17½	985.64	0.055	1.02	1.02	83	1	265	50	1500	
9	20	987.29	0.055	1.02	1.02	83	1	265	55	1500	
10	22½	988.66	0.055	1.02	1.02	83	1	260	55	1500	
11	25	990.12	0.050	0.95	0.95	83	1	260	55	1499	
12	27½	991.69	0.040	0.76	0.76	83	1	260	55	1499	LT①
B 1	30/0	992.852	0.045	0.82	0.82	82	1	260	55	1499	992.887 − 992.852 = .035
2	2½	994.19	0.050	0.95	0.95	82	1	260	55	1497	
3	5	996.51	0.050	0.95	0.95	82	1	260	55	1498	
4	7½	997.10	0.050	0.95	0.95	82	1	260	55	1498	
5	10	998.51	0.050	0.95	0.95	82	1	260	55	1499	
6	12½	999.91	0.055	1.02	1.02	82	1	270	55	1499	
7	15	1001.36	0.055	1.02	1.02	82	1	275	55	1500	
8	17½	2.78	0.060	1.12	1.12	82	1	275	55	1500	
9	20	4.26	0.060	1.12	1.12	83	1	270	55	1501	
10	22½	5.83	0.060	1.12	1.12	82	1	270	55	1501	
11	25	7.31	0.050	0.95	0.95	82	1	270	55	1500	
12	27½	8.74	0.040	0.76	0.76	82	1	270	55	1500	
	60/OFF	1010.018									

34.084 / 34.014 = V_M — .0516 = $(\sqrt{\Delta P})^2$ — .971 = ΔH — 81 = T_M — 1499 = T_S

F-1010
8/86

ENTROPY

PARTICULATE FIELD DATA

COMPANY NAME PPG — RUN NUMBER 2
ADDRESS SHELBY NC — TIME START 1045
SAMPLING LOCATION GLASS FURNACE #526 OUTLET STACK (NORTH) — TIME FINISH 1152
DATE 11-24-87 — TEAM LEADER MM — TECHNICIANS ALM
BAROMETRIC PRESSURE, IN. HG 29.23 — STATIC PRESSURE, IN. H_2O +0.45
SAMPLING TRAIN LEAK TEST VACUUM, IN. HG 15 | 10 | 10
SAMPLING TRAIN LEAK RATE, CU. FT./MIN. 0.002 | 0.001 | 0.001

EQUIPMENT CHECKS

- ✓ PITOTS, PRE-TEST
- ✓ PITOTS, POST-TEST
- = ORSAT SAMPLING SYSTEM
- = TEDLAR BAG
- ✓ THERMOCOUPLE @ 1500 °F

IDENTIFICATION NUMBERS

REAGENT BOX 601 — NOZZLE QZZ — DIAMETER 0.545
METER BOX N6 — T/C READOUT F6
UMBILICAL — T/C PROBE HJ 6
SAMPLE BOX — ORSAT PUMP —
PROBE QZZ — TEDLAR BAG —

FILTER # / TARE

E 6122 — 0.4686

NOMOGRAPH SET-UP — NOMOGRAPH # N4

$\Delta H_@$ 1.76 — C FACTOR 0.72
METER TEMP 85 — STACK TEMP 1500
% MOISTURE 22 — REF. ΔP 0.10

SAMPLE POINT	CLOCK TIME, MIN.	DRY GAS METER READING, CU. FT.	PITOT READING (ΔP), IN. H_2O	ORIFICE SETTING (ΔH), IN. H_2O IDEAL	ORIFICE SETTING (ΔH), IN. H_2O ACTUAL	GAS METER TEMP. °F	PUMP VACUUM IN. HG GAUGE	FILTER BOX TEMP. °F	IMP. EXIT TEMP. °F	STACK TEMP. °F	LK. CHECK READINGS
B 1	0	10,134	0.050	0.95	0.95	66	1	250	65	1492	
2	2½	11.54	0.060	1.14	1.14	68	2	250	65	1492	
3	5	13.03	0.065	1.22	1.22	69	2	250	65	1492	
4	7½	14.65	0.060	1.14	1.14	70	2	250	65	1494	
5	10	16.22	0.060	1.14	1.14	70	2	250	65	1494	
6	12½	17.82	0.065	1.22	1.22	72	2	250	65	1494	
7	15	19.19	0.065	1.22	1.22	72	2	250	65	1495	
8	17½	20.78	0.065	1.22	1.22	73	2	250	65	1495	
9	20	22.28	0.065	1.22	1.22	74	2	250	65	1496	
10	22½	23.92	0.065	1.22	1.22	75	2	250	65	1496	
11	25	25.46	0.060	1.14	1.14	76	2	250	65	1496	
12	27½	27.11	0.050	0.95	0.95	77	2	250	65	1496	
A 1	30/0	28.394	0.045	0.86	0.86	78	2	250	60	1493	469 28.394 .095
2	2½	29.88	0.050	0.95	0.95	79	2	250	60	1493	
3	5	31.22	0.055	1.02	1.02	80	2	250	60	1493	
4	7½	32.69	0.060	1.14	1.14	80	2	250	60	1494	
5	10	34.24	0.060	1.14	1.14	81	2	250	60	1494	
6	12½	35.69	0.065	1.22	1.22	82	2	250	60	1494	
7	15	37.42	0.065	1.22	1.22	82	2	250	60	1495	
8	17½	38.89	0.065	1.22	1.22	82	2	250	60	1495	
9	20	40.48	0.065	1.22	1.22	83	2	250	60	1495	
10	22½	42.17	0.060	1.14	1.14	83	2	250	60	1496	
11	25	43.69	0.055	1.02	1.02	84	2	250	60	1496	
12	27½	45.16	0.050	0.95	0.95	84	2	250	60	1495	
	60/OFF	46.598								MM90	

~~36.559~~ 36.389 V_M — .0592 $(\sqrt{\Delta P})^2$ — 1.12 ΔH — 77 T_M — 1494 T_S

F-1010
8/86

ENTROPY

PARTICULATE FIELD DATA

Plant PPG - SHELBY, NC

Run No. 4

Location GLASS FURNACE #526 STACK

Date 11-24-87

Operator MH

~~Sample Box~~ NOZZLE No. 024

Meter Box No. N6

Meter $\Delta H_@$ 1.76

C Factor 0.72

VERY IMPORTANT - FILL IN ALL BLANKS

Read and record at the start of each test point.

REMARKS: BEGINNING LT AT 15" -0.002
MID POINT LT AT 76 -0.002
FINAL LT AT

Static Pres., in H_2O: +0.45
Start: 1358
Finish: 1503
Filter # E 6300 0,4847
REAGENT BOX 0602

Ambient Temp °F 70

Bar. Press. in. Hg. 29.3

Assumed Moisture % 22

Heater Box Setting, °F 250

Probe Tip Dia., In. 0.544

Probe Length 9'

Probe Heater Setting —

Average Δp

Average ΔH

Point	Clock Time	Dry Gas Meter, Cu.Ft.	Pitot Manometer (Δp) in. H_2O	Orifice Manometer (ΔH) in. H_2O Desired	Orifice Manometer (ΔH) in. H_2O Actual	Dry Gas Temp. °F Inlet	Dry Gas Temp. °F Outlet	Pump Vacuum in. Hg Gauge	Box Temp. °F	Impinger Temp °F	Stack Temp °F
A 1	0	~~64.953~~	0.030	0.58	0.58	/	80	1	235	55	1493
2	2½	65.14	0.040	0.74	0.74		80	1	235	55	1493
3	5	66.45	0.050	0.94	0.94		81	1	235	55	1494
4	7½	67.82	0.055	1.02	1.02		82		235	55	1494
5	10	69.38	0.055	1.02	1.02		83		~~246~~	55	1494
6	12½	70.90	0.060	1.12	1.12		83		260	55	1494
7	15	72.36	0.060	1.12	1.12		83		255	55	1495
8	17½	73.92	0.055	1.02	1.02		83		260	55	1495
9	20	75.36	0.055	1.02	1.02		83		265	55	1495
10	22½	76.80	0.055	1.02	1.02		84		265	55	1496
11	25	78.15	0.055	1.02	1.02		84		255	55	1494
12	27½	79.76	0.045	0.86	0.86		84		250	55	1494
B 1	30/0	81.027	0.055	1.02	1.02		84		250	55	1494
2	2½	82.55	0.055	1.02	1.02		84		250	55	1494
3	5	83.92	0.055	1.02	1.02		84		250	55	1496
4	7½	85.51	0.050	0.94	0.94		85		250	55	1495
5	10	86.76	0.055	1.02	1.02		85		240	55	1495
C	12½	88.29	0.060	1.12	1.12		85		240	55	1495
7	15	89.86	0.060	1.12	1.12		85		240	55	1495

LT ①
.069
81.027
.042

Point	Clock Time	Dry Gas Meter, Cu.Ft.	Pitot Manometer (Δp) in. H_2O	Orifice Manometer (ΔH) in. H_2O		Dry Gas Temp. °F		Pump Vacuum in. Hg Gauge	Box Temp. °F	Impinger Temp °F	Stack Temp °F
				Desired	Actual	Inlet	Outlet				
8	17½	91.46	0.065	1.22	1.22		86	2	245	55	1494
9	20	92.97	0.065	1.22	1.22		87	2	245	55	1494
10	22½	94.53	0.060	1.12	1.12		87	3	245	55	1494
11	25	96.25	0.060	1.12	1.12		87	3	245	55	1493
12	27½	97.69	0.050	0.94	0.94		87	3	245	55	1493
	60/OFF	99.150									
		35.013									
		~~35.137~~ V_m	ΔP .0541		ΔH 1.02		T_M 84			T_S	1494

PARTICULATE SAMPLING LABORATORY RESULTS

Plant Name PPG SHELBY EEI Ref. # 5729

Sampling Location No. 526 MELTING FURNACE, NORTH STACK

Date Received 11/25 Date Analyzed 12/2 Reagent Box(es) 0601/0602

Run Number	1	2	4
Run Date	11/24	11/24	11/24

SUMMARY OF PARTICULATE ANALYSES

Sum of Particulate, mg.	600.8	586.0	613.7
Total Filter Tare mg.	479.9	468.6	484.7
Blank Residue, mg.	(200 mL) 0.4	(200 mL) 0.4	(125 mL) 0.3
TOTAL PARTICULATE CATCH, mg.	120.5	117.0	128.7

ANALYSIS OF MOISTURE CATCH

Reagent 1 (DI H_2O):			
Final Weight, g.	377.0	406.0	383.0
Tared Weight, g.	200.0	200.0	200.0
Water Catch, g.	177.0	206.0	183.0
Reagent 2 ( ):			
Final Weight, g.	—	—	—
Tared Weight, g.	—	—	—
Water Catch, g.	—	—	—
CONDENSED WATER, g.	177.0	206.0	183.0
Silica Gel:			
Final Weight, g.	217.0	215.5	214.5
Tared Weight, g.	200.0	200.0	200.0
ADSORBED WATER, g.	17.0	15.5	14.5
TOTAL WATER COLLECTED, g.	194.0	221.5	197.5

Blank Beaker # 2124

Final wt. mg. 99496.2

Tare wt. mg. 99495.8

Residue, mg. 0.4

Volume, mL. 200

Concen., mg/mL 0.002

--- Legend ---

= Final Weight

L = Loose Particulate

F = Filter D = Dish

R = Rinse P = Pan

Notes and Comments

LABORATORY SAMPLE WEIGHT CALCULATIONS

Plant Name PPG SHELBY EEI Ref. # 5729

Run Number	1	2	4
Run Date	11/24	11/24	11/24
Sample ID/Container #	F&R 2145	F&R 2147	F&R 2148
Tare Wt., g.	✓99.4783 99.4788 99.4795 98.8775	✓99.9373 99.9378 99.9384 99.3513	✓99.1306 99.1309 98.5169
SAMPLE WT., g.	0.6008	0.5860	0.6137
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			

CUSTODY SHEET FOR REAGENT BOX # 0601

Date of Makeup 10/29 Initials CEM Locked? ✓

Individual Tare of Reagent: 200 mls. of DI H_2O

Individual Tare of Reagent: _____ mls. of _____

Individual Silica Gel Tare Weight 200 gms.

PLANT NAME PPG - SHELBY, NC

SAMPLING LOCATION GLASS FURNACE #526 OUTLET STACK

Run Number	Date Used	Initials	Locked?	Date Cleanup	% S. Gel Spent	Initials	Locked?
1	11-24-89	MK	✓	11-24	65	MK	✓
2	11-24	MK	✓	11-24	65	MK	✓
~~3A~~	~~11-24~~	~~MK~~	✓	~~11-24~~	~~40~~	~~MK~~	✓
	RUN 3 ABORTED						

Received in Lab Date 11/25 Initials SAW Locked? ✓

Sampling Method: 5

Remarks:

ABORTED

Zero & Span Balance Initials ✓

Filter #	Tare Weight (grams)	Used on Test
E6299	0.4799	1
E6122	0.4686	2
~~E6300~~	~~0.4847~~	~~3~~

ENTROPY ENVIRONMENTALISTS, INC.

CUSTODY SHEET FOR REAGENT BOX # 0602

Date of Makeup 10/29 Initials CEM Locked? ✓

Individual Tare of Reagent: 200 mls. of DI H2O

Individual Tare of Reagent: _____ mls. of _____

Individual Silica Gel Tare Weight 200 gms.

PLANT NAME PPG - SHELBY

SAMPLING LOCATION GLASS FURNACE #526 OUTLET STACK

Run Number	Date Used	Initials	Locked?	Date Cleanup	% S. Gel Spent	Initials	Locked?
4	11-24	MK	✓	11-24	50	MK	✓

Received in Lab Date 11/25 Initials SAW Locked? ✓

Sampling Method: _____

Zero & Span Balance Initials ✓

Filter #	Tare Weight (grams)	Used on Test
E6300	0.4847	4

Remarks:

ENTROPY ENVIRONMENTALISTS, INC.

APPENDIX C

CALIBRATION DATA

QUALITY ASSURANCE PROCEDURES

General. Each item of field test equipment purchased or constructed by Entropy is assigned a unique, permanent identification number. New items for which calibration is required are calibrated before initial field use. Equipment whose calibration status may change with use or with time is inspected in the field before testing begins, and again upon return from each field use. When an item of equipment is found to be out of calibration, it is adjusted and recalibrated or retired from service. All equipment is periodically recalibrated in full, regardless of the outcome of these regular inspections.

Calibrations are conducted in a manner and at a frequency which meet or exceed U. S. EPA specifications. Entropy follows the calibration procedures outlined in EPA Reference Methods, and those recommended within the Quality Assurance Handbook for Air Pollution Measurement Systems: Volume III (EPA-600/4-77-027b, August, 1977). When the Reference Methods are inapplicable, Entropy uses methods such as those prescribed by the American Society for Testing and Materials (ASTM).

Data obtained during calibrations are recorded on standardized forms, which are checked for completeness and accuracy by the Quality Assurance Manager or the Quality Assurance Director. Data reduction and subsequent calculations are performed using Entropy's in-house computer facilities. Calculations are generally performed at least twice as a check for accuracy. Copies of calibration data are included in the test or project reports.

Inspection and Maintenance. An effective preventive maintenance program is necessary to ensure data quality. Each item of equipment returning from the field is inspected before it is returned to storage. During the course of these inspections, items are cleaned, repaired, reconditioned, and recalibrated where necessary.

Each item of equipment transported to the field for this test program was inspected again before being packed. Entropy performs these quality assurance activities prior to departure for the job site to detect equipment problems which may originate during periods of storage. This minimizes lost time on site due to equipment failure.

Occasional equipment failure in the field is unavoidable despite the most rigorous inspection and maintenance procedures. For this reason, Entropy routinely transports sufficient backup equipment to the job site to have complete redundancy of all critical sampling train components.

Calibration. Emissions sampling equipment that requires calibration includes the nozzle, pitot tube, pressure gauges, thermometers, flow meters, dry gas meters, and barometers. The following sections elaborate on the calibration procedures followed by Entropy for these items of equipment. Calibration data for the specific items of equipment used for this test program follow the text.

Nozzles. Each probe nozzle is uniquely and permanently identified at the time of purchase, and calibrated before initial field use. The inside diameter of the nozzle is measured to the nearest 0.001 in. using a micrometer. Five measurements are made using different diameters each time. If the difference between the high and the low numbers does not exceed 0.004 inch, the average of the five measurements is used. If the difference exceeds this amount, or when the nozzle becomes nicked, dented, or corroded, the nozzle is reshaped, sharpened, and recalibrated.

Pitot Tubes. All Type S pitot tubes used by Entropy, whether separate or attached to a sampling probe, are constructed in-house or by Nutech Corporation. Each pitot is calibrated when new in accordance with the geometry standards contained in EPA Reference Method 2. A Type S pitot tube, constructed and positioned according to these standards, will have a coefficient of 0.84 $\pm$ 0.02. This coefficient should not change as long as the pitot tube is not damaged.

Each pitot tube is inspected visually before it is transported to the field. If this inspection indicates damage or raises doubt that the pitot remains in accordance with the EPA geometry standards, the pitot tube is not used until it has been refurbished and recalibrated.

Differential Pressure Gauges. Some meter consoles used by Entropy are equipped with 10 in. W.C. inclined-vertical manometers. Fluid manometers

do not require calibration other than leak checks. Manometers are leak-checked in the field prior to each test series, and again upon return from the field.

Most of Entropy's meter consoles are equipped with Magnehelic differential pressure gauges. Each set of gauges is calibrated initially over its full range, 0-10 inches W.C. After each field use, the calibration of the gauge set is checked against an inclined manometer at the average delta p encountered during the test. If the agreement is within $\pm$ 5 percent, the calibration is acceptable.

Thermometers

Impinger Thermometer. On site, prior to the start of testing, the thermometer used to monitor the temperature of the gas leaving the last impinger is compared with a mercury-in-glass thermometer which meets ASTM E-1 specifications. The impinger thermometer is adjusted if necessary until it agrees within 2°F of the reference thermometer. (If the thermometer is not adjustable, it is labeled with a correction factor).

Dry Gas Meter Thermometer. The thermometer used to measure the temperature of the metered gas sample is checked prior to each field trip against an ASTM mercury-in-glass thermometer. The dry gas meter thermometer is acceptable if the values agree within 5.4°F. Thermometers not meeting this requirement are adjusted or labeled with a correction factor.

Flue Gas Temperature Sensor. All thermocouples employed by Entropy for the measurement of flue gas temperatures are calibrated upon receipt. Initial calibrations are performed at three points (ice bath, boiling water, and hot oil). An ASTM mercury-in-glass thermometer is used as a reference. The thermocouple is acceptable if the agreement is within 1.5 percent (absolute) at each of the three calibration points.

On site, prior to the start of testing, the reading from the stack gas thermocouple-potentiometer combination is compared with a mercury-in-glass reference thermometer. If the two agree within 1.5 percent (absolute), the thermocouple and potentiometer are considered to be in proper working order for the test series.

After each field use, the thermocouple-potentiometer system is compared with an ASTM mercury-in-glass reference thermometer at a temperature within 10 percent of the average absolute flue gas temperature. If the absolute temperatures agree within 1.5 percent, the temperature data are considered valid.

Dry Gas Meter and Orifice. The dry gas meter and orifice are calibrated simultaneously. There are two calibration procedures. The full calibration is a complete laboratory procedure used to obtain the calibration factor of the dry gas meter before its first use and periodically thereafter. Full calibrations are performed at three different orifice settings (flow rates). A simpler procedure, the posttest calibration, is designed to check whether the calibration factor has changed. Posttest calibrations are performed after each field test series at an intermediate orifice setting (based on the test data) and at the maximum vacuum reached during the test.

Entropy uses as a transfer standard a dry gas meter that is calibrated annually against a spirometer. During the annual calibration, triplicate calibration runs are performed at seven flow rates ranging from 0.25 to 1.40 cfm.

Dry Gas Meter. Each metering system receives a full calibration at the time of purchase, and a posttest calibration after each field use. If the calibration factor, Y, deviates by less than five percent from the initial value, the test data are acceptable. If Y deviates by more than five percent, the meter is recalibrated and the meter coefficient (initial or recalibrated) that yields the lowest sample volume for the test runs is used.

EPA Reference Method 5 calls for another full calibration anytime the posttest calibration check indicates that Y has changed by more than five percent. Standard practice at Entropy is to recalibrate the dry gas meter anytime Y is found to be outside the range $0.98 \leq Y \leq 1.02$.

Orifice. An orifice calibration factor is calculated for each flow setting during a full calibration. If the range of values does not vary by more than 0.15 in. H_2O over the range of 0.4 to 4.0 in. H_2O, the arithmetic average of the values obtained during the calibration is used.

Barometer. Each field barometer is adjusted before each test series to agree within ± 0.1 inches of a reference aneroid barometer. The reference barometer is checked weekly against the station pressure value (corrected for elevation difference) reported by the National Weather Service station at the Raleigh-Durham airport, approximately 2.5 miles from Entropy's location.

Dry Gas Meter Identification: 6838323 Calibration by: MH

Date: 3-26-86 Barometric Pressure (P_b): 30.12 in. Hg

*Date: 3-27-86 *Barometric Pressure (P_b): 29.85 in. Hg

ENTROPY ENVIRONMENTALISTS, INC.

Approx. Flow Rate (Q) cfm	Spirometer Gas Volume (V_s) ft^3	Spirometer Temp. (t_s) °F	Dry Gas Meter Gas Volume (V_{ds}) ft^3	Dry Gas Meter Temp. (t_{ds}) °F	Pressure (Δp) in. H_2O	Time (θ) min.	Flow Rate (Q) cfm	Meter Meter Coeff. (Y_{ds})	Avg. Meter Coeff. ($\bar{Y}_{ds}$)
	2.924	82.4	2.906	81	0.40	10.00	0.2864	1.0026	
0.30	2.969	82.8	2.869	81	.40	19.00	.2906	1.0304	
	3.652	83.3	3.501	81	.40	12.00	.3571	1.0377	
*	4.235	80.6	4.330	77	0.85	10.00	.4125	.9700	
0.40	4.545	80.6	4.370	78	.85	10.00	.4427	1.0328	
	4.417	80.6	4.345	79	.85	10.00	.4302	1.0114	
	5.328	78.8	5.206	75	1.10	10.00	.5271	1.0135	
0.50	5.383	79.7	5.212	77	1.15	10.00	.5317	1.025	
	5.301	79.7	5.166	78	1.15	10.00	.5219	1.020	
*	8.288	81	8.216	79	2.65	10.00	.8067	.9985	
0.80	8.397	82	8.214	80	2.65	10.00	.8258	1.0119	
	8.352	82.4	8.199	80	2.65	10.00	.8108	1.0075	
	10.638	83.3	10.472	81	4.15	10.00	1.040	1.0014	
1.00	10.656	83.3	10.534	81.5	4.15	10.00	1.042	.9981	
	10.528	83.3	10.450	81.5	4.15	10.00	1.0296	.9941	

$$Y_{ds} = \frac{(V_s)\ (t_{ds} + 460)\ (P_b)}{(V_{ds})\ (t_s + 460)\ (P_b + (\ p\ /\ 13.6))}$$

$$Q = (17.64)\ \frac{(P_b)\ (V_s)}{(t_s + 460)\ (\theta)}$$

Dry Gas Meter Identification: 6836373 Calibration by: MH

Date: [illegible] Barometric Pressure (P_b): 30.12 in. Hg

*Date: [illegible] *Barometric Pressure (P_b): 29.85 in. Hg

ENTROPY ENVIRONMENTALISTS, INC.

Approx. Flow Rate (Q) cfm	Orifice Gas Volume (V_s) ft^3	Orifice Temp. (t_s) °F	Dry Gas Meter Gas Volume (V_{ds}) ft^3	Dry Gas Meter Temp. (t_{ds}) °F	Pressure (Δp) in. H_2O	Time (θ) min.	Flow Rate (Q) cfm	Meter Meter Coeff. (Y_{ds})	Avg. Meter Coeff. ($\bar{Y}_{ds}$)
*	12.304	82.4	12.168	80	5.50	10.00	1.1945	0.9937	
1.20	12.177	82.4	12.065	80	5.50	10.00	1.1821	.9914	
	12.186	82.4	12.100	80	5.50	10.00	1.1830	.9892	
	13.698	82.4	13.494	79.5	6.85	10.00	1.3418	.9931	
1.35	13.557	82.4	13.505	80	6.85	10.00	1.33	.9832	
	13.752	81.5	13.712	80	7.00	10.00	1.35	.9833	
					$\bar{Y}_s$ =	1.0042			

$$Y_{ds} = \frac{(V_s)\ (t_{ds} + 460)\ (P_b)}{(V_{ds})\ (t_s + 460)\ (P_b + (\Delta p / 13.6))}$$

$$Q = (17.64)\ \frac{(P_b)\ (\ \ )}{(t_s + 460)\ (\theta)}$$

Meter Box Number: 16 Calibration by: T McDonald

Standard Meter Number: 6838323 Standard Meter Gamma: 1.0042

Date: 10-19-87 Barometric Pressure (P_b): 29.70 in. Hg

*Date: _____ *Barometric Pressure (P_b): _____ in. Hg

METERBOX CALIBRATION

Standard Meter			Meter Box Metering System				
Gas Volume (V_{ds}) ft^3	Temp. (t_{ds}) °F	Time (θ) min.	Orifice Setting (ΔH) in. H_2O	Gas Volume (V_d) ft^3	Temp. (t_d) °F	Coeff. (Y_d)	$\Delta H_@$ in. H_2O
4.028	67	10:00	0.50	4.068	75	1.0082	1.69
4.044	70	10:00	0.50	4.171	84	0.9981	1.67
8.066	69	10:00	2.10	8.291	75	0.9829	1.79
8.037	69	10:00	2.10	8.291	77	0.9830	1.79
12.037	69	10:00	4.50	12.554	81	0.9731	1.81
11.997	70	10:00	4.50	12.587	84	0.9709	1.82
					Average	0.9860	1.76

$$Y_d = \frac{Y_{ds} * V_{ds} * (t_d + 460) * P_b}{V_d * (t_{ds} + 460) * (P_b + H/13.6)}$$

$$\Delta H_@ = \frac{0.0317 * \Delta H}{P_b * (t_d + 460)} * \left[\frac{(t_{ds} + 460) * \theta}{Y_{ds} * V_{ds}}\right]^2$$

ENTROPY

Meter Box Number: N6 Calibration by: JG

Meter Box Vacuum: 3 in. Hg Job 5729
PPG - Shelby NC

Standard Meter Number: 6838323 Standard Meter Gamma: 1.0042

Date: 11-30-87 Barometric Pressure (P_b): 30.0 in. Hg

POSTTEST CALIBRATION

Standard Meter			Meter Box Metering System				
Gas Volume (V_{ds}) ft^3	Temp. (t_{ds}) °F	Time (θ) min.	Orifice Setting (ΔH) in. H_2O	Gas Volume (V_d) ft^3	Temp. (t_d) °F	Coeff. (Y_d)	$\Delta H_@$ in. H_2O
5.623	68	10.0	1.00	5.801	72	0.978	1.74
5.618	68	10.0	1.00	5.782	75	0.986	1.73
5.629	69	10.0	1.00	5.831	79	0.985	1.72
					Average	0.983	1.73

$$Y_d = \frac{Y_{ds} * V_{ds} * (t_d + 460) * P_b}{V_d * (t_{ds} + 460) * (P_b + \Delta H/13.6)}$$

$$\Delta H_@ = \frac{0.0317 * \Delta H}{P_b * (t_d + 460)} * \left[\frac{(t_{ds} + 460) * \theta}{Y_{ds} * V_{ds}}\right]^2$$

NOZZLE NUMBER: Q22

Date	Initials	Dia. 1	Dia. 2	Dia. 3	Dia. 4	Dia. 5	Average
11-23-87	SWS	.554	.545	.545	.544	.545	.545

NOTE: All diameters measured in inches.

ENTROPY ENVIRONMENTALISTS, INC

NOZZLE NUMBER: Q23

Date	Initials	Dia. 1	Dia. 2	Dia. 3	Dia. 4	Dia. 5	Average
11-23-87	SWS	.545	.543	.544	.545	.544	.544

NOTE: All diameters measured in inches.

ENTROPY ENVIRONMENTALISTS, INC

NOZZLE NUMBER: Q24

Date	Initials	Dia. 1	Dia. 2	Dia. 3	Dia. 4	Dia. 5	Average
11-23-81	SDS	.542	.545	.545	.545	.543	.544

NOTE: All diameters measured in inches.

ENTROPY ENVIRONMENTALISTS, INC.

SAMPLING AND ANALYTICAL PROCEDURES

8. *Bibliography*

1. Addendum to Specifications for Incinerator Testing at Federal Facilities. PHS, NCAPC. Dec. 6, 1967.

2. Martin, Robert M. Construction Details of Isokinetic Source-Sampling Equipment. Environmental Protection Agency. Research Triangle Park, N.C. APTD-0581. April 1971.

3. Rom, Jerome J. Maintenance, Calibration, and Operation of Isokinetic Source Sampling Equipment. Environmental Protection Agency. Research Triangle Park, N.C. APTD-0576. March, 1972.

4. Smith, W. S., R. T. Shigehara, and W. F. Todd. A method of Interpreting Stack Sampling Data. Paper Presented at the 63d Annual Meeting of the Air Pollution Control Association, St. Louis, Mo. June 14-19, 1970.

5. Smith, W. S., et al. Stack Gas Sampling Improved and Simplified With New Equipment. APCA Paper No. 67-119. 1967.

6. Specifications for Incinerator Testing at Federal Facilities. PHS, NCAPC. 1967.

7. Shigehara, R. T. Adjustments in the EPA Nomograph for Different Pitot Tube Coefficients and Dry Molecular Weights. Stack Sampling News *2*:4-11, October, 1974.

8. Vollaro, R. F. A Survey of Commercially Available Instrumentation For the Measurement of Low-Range Gas Velocities. U.S. Environmental Protection Agency, Emission Measurement Branch. Research Triangle Park, N.C. November, 1976 (unpublished paper).

9. Annual Book of ASTM Standards. Part 26. Gaseous Fuels; Coal and Coke; Atmospheric Analysis. American Society for Testing and Materials. Philadelphia, Pa. 1974. pp. 617-622.

10. Felix, L. G., G. I. Clinard, G. E. Lacey, and J. D. McCain. Inertial Cascade Impactor Substrate Media for Flue Gas Sampling. U.S. Environmental Protection Agency. Research Triangle Park, N.C. 27711. Publication No. EPA-600/7-77-060. June 1977. 83 p.

11. Westlin, P. R. and R. T. Shigehara. Procedure for Calibrating and Using Dry Gas Volume Meters as Calibration Standards. Source Evaluation Society Newsletter. *3*(1):17-30. February 1978.

12. Lodge, J.P., Jr., J.B. Pate, B.E. Ammons, and G.A. Swanson. The Use of Hypodermic Needles as Critical Orifices in Air Sampling. J. Air Pollution Control Association. *16*:197-200. 1966.

[FR Doc. 87-6551 Filed 3-25-87; 8:45 am]

7.2.2.2.1 Allow a warm-up time of 15 minutes. This step is important to equilibrate the temperature conditions through the DGM.

7.2.2.2.2 Leak check the system as in Section 7.2.2.1.1. The leakage rate shall be zero.

7.2.2.2.3 Before calibrating the critical orifice, determine its suitability and the appropriate operating vacuum as follows: Turn on the pump, fully open the coarse adjust valve, and adjust the by-pass valve to give a vacuum reading corresponding to about half of atmospheric pressure. Observe the meter box orifice manometer reading, H. Slowly increase the vacuum reading until a stable reading is obtained on the meter box orifice manometer. Record the critical vacuum for each orifice.

Orifices that do not reach a critical value shall not be used.

7.2.2.2.4 Obtain the barometric pressure using a barometer as described in Section 2.1.9. Record the barometric pressure, P_{bar}, in mm Hg (in. Hg).

7.2.2.2.5 Conduct duplicate runs at a vacuum of 25 to 50 mm Hg (1 to 2 in. Hg) above the critical vacuum. The runs shall be at least 5 minutes each. The DGM volume readings shall be in increments of 0.00283 m^3 (0.1 ft^3) or in increments of complete revolutions of the DGM. As a guideline, the times should not differ by more than 3.0 seconds (this includes allowance for changes in the DGM temperatures) to achieve ± 0.5 percent in K'. Record the information listed in Figure 5-11.

7.2.2.2.6 Calculate K' using Equation 5-9.

K' = Critical orifice coefficient,

T_{amb} = Absolute ambient temperature, °K (°R).

Average the K' values. The individual K' values should not differ by more than ±0.5 percent from the average.

$$K' = \frac{K_1 V_m Y (P_{bar} + \Delta H/13.6) \sqrt{T_{amb}}}{P_{bar} T_m \Theta} \quad \text{Eq. 5-9}$$

$$\frac{(m^3)(°K)^{1/2}}{(mm.\ Hg)(min)} \left[\frac{(ft^3)(°R)^{1/2}}{(in.\ Hg)(min)} \right]$$

Sections 7.2.2.2.1 to 7.2.2.2.5. Record the information listed in Figure 5.12.

7.2.3 Using the Critical Orifices as Calibration Standards.

7.2.3.1 Record the barometric pressure.

Date _____ Train ID _____ DGM cal. factor _____ Critical orifice ID _____

Dry gas meter		Run No. 1	Run No. 2
Final reading	m^3 (ft^3)		
Initial reading	m^3 (ft^3)		
Difference, V_m	m^3 (ft^3)		
Inlet/Outlet temperatures:			
Initial	°C (°F)	/	/
Final	°C (°F)	/	/
Avg. Temperature, t_m	°C (°F)		
Time, Θ	min/sec	/	/
	min		
Orifice man. rdg., ΔH	mm (in.) H_2O		
Bar. pressure, P_{bar}	mm (in.) Hg		
Ambient temperature, t_{amb}	°C (°F)		
Pump vacuum	mm (in.) Hg		
K' factor			
Average			

Figure 5-11. Data sheet for determining K' factor.

7.2.3.2 Calibrate the metering system according to the procedure outlined in

7.2.3.3 Calculate the standard volumes of air passed through the DGM and the critical orifices, and calculate the DGM calibration factor, Y, using the equations below:"

$$V_m(std) = K_1 V_m \frac{P_{bar} + (\Delta H/13.6)}{T_m} \quad \text{Eq. 5-10}$$

$$V_{cr}(std) = K' \frac{P_{bar} \Theta}{T_{amb}} \quad \text{Eq. 5-11}$$

$$Y = \frac{V_{cr(std)}}{V_{m(std)}} \quad \text{Eq. 5-12}$$

where:

$V_{cr(std)}$ = Volume of gas sample passed through the critical orifice, corrected to standard conditions, dsm^3 (dscf).

K_1 = 0.3858 °K/mm Hg for metric units = 17.64 °R/in. Hg for English units.

7.2.3.4 Average the DGM calibration values for each of the flow rates. The calibration factor, Y, at each of the flow rates should not differ by more than ±2 percent from the average.

7.2.3.5 To determine the need for recalibrating the critical orifices, compare the DGM Y factors obtained from two adjacent orifices each time a DGM is calibrated; for example, when cheching 13/2.5, use orifices 12/10.2 and 13/5.1. If any critical orifice yields a DGM Y factor differing by more than 2 percent from the others, recalibrate the critical orifice according to Section 7.2.2.2.

Date _____ Train ID _____ Critical orifice ID _____ Critical orifice K' factor _____

Dry gas meter		Run No. 1	Run No. 2
Final reading	m^3 (ft^3)		
Initial reading	m^3 (ft^3)		
Difference, V_m	m^3 (ft^3)		
Inlet/outlet temperatures:			
Initial	°C (°F)	/	/
Final	°C (°F)	/	/
Avg. Temperature, t_m	°C (°F)		
Time, Θ	min/sec	/	/
	min		
Orifice man. rdg., ΔH	mm (in.) H_2O		
Bar. pressure, P_{bar}	mm (in.) Hg		
Ambient temperature, t_{amb}	°C (°F)		
Pump vacuum	mm (in.) Hg		
$V_{m(std)}$	m^3 (ft^3)		
$V_{cr(std)}$	m^3 (ft^3)		
DGM cal. factor, Y			

Figure 5-12. Data sheet for determining DGM Y factor.

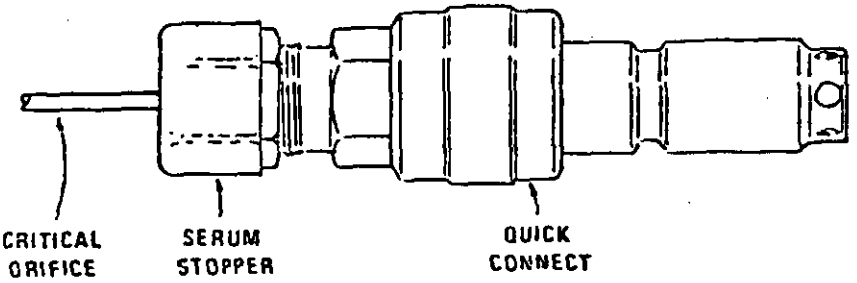


Figure 5-9. Critical orifice adaptation to Method 5 metering system.

7.2.2 Critical Orifice Calibration. The procedure described in this section uses the Method 5 meter box configuration with a DGM as described in Section 2.1.8 to calibrate the critical orifices. Other schemes may be used, subject to the approval of the Administrator.

7.2.2.1 Calibration of Meter Box. The critical orifices must be calibrated in the same configuration as they will be used; i.e., there should be no connections to the inlet of the orifice.

7.2.2.1.1 Before calibrating the meter box, leak check the system as follows: Fully open the coarse adjust valve, and completely close the by-pass valve. Plug the inlet. Then trun on the pump, and determine whether there is any leakage. The leakage rate shall be zero; i.e., no detectable movement of the DGM dial shall be seen for 1 minute.

7.2.2.1.2 Check also for leakages in that portion of the sampling train between the pump and the orifice meter. See Section 5.6 for the procedure; make any corrections, if necessary. If leakage is detected, check for cracked gaskets, loose fittings, worn O-rings, etc., and make the necessary repairs.

7.2.2.1.3 After determining that the meter box is leakless, calibrate the meter box according to the procedure given in Section 5.3. Make sure that the wet test meter meets the requirements stated in Section 7.1.1.1. Check the water level in the wet test meter. Record the DGM calibration factor, Y.

7.2.2.2 Calibration of Critical Orifices. Set up the apparatus as shown in Figure 5–10.

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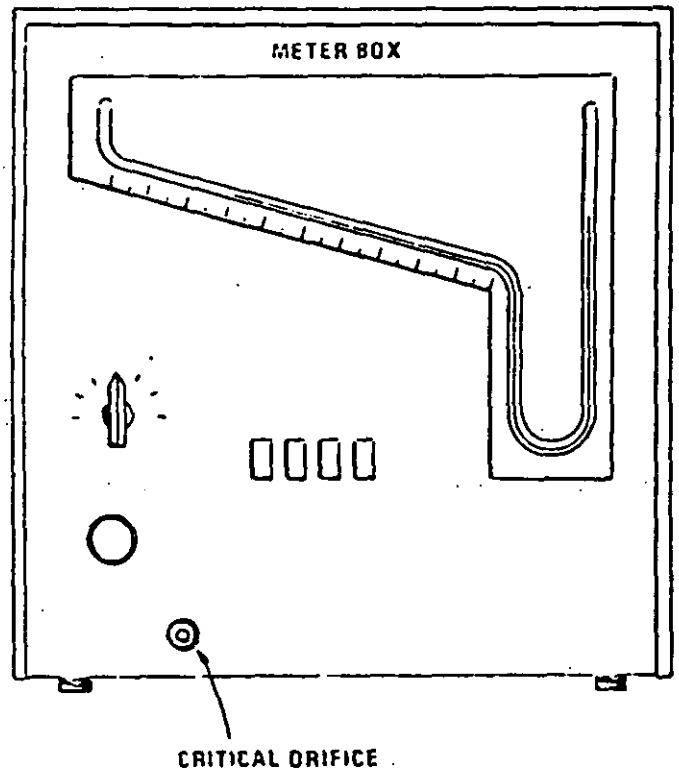


Figure 5-10. Apparatus setup.

7.1.1.4 Calculate flow rate, Q, for each run using the wet test meter gas volume, V_w, and the run time, θ. Calculate the dry gas meter coefficient, Y_{dm}, for each run. These calculations are as follows:

$$Q = K_1 \frac{P_{bar}}{t_w + t_{std}} \frac{V_w}{\theta}$$

$$Y_{dm} = \frac{V_w}{V_{dm}} \frac{(t_{dm} + t_{std})}{(t_w + t_{std})} \frac{P_{bar}}{\left(P_{bar} + \frac{\Delta p}{13.6}\right)}$$

Where:

K_1 = 0.3858 for international system of units (SI); 17.64 for English units.

V_w = Wet test meter volume, liters (ft^3).

V_{dm} = Dry gas meter volume, liters (ft^3).

t_{dm} = Average dry gas meter temperature, °C (°F).

t_{std} = 273° C for SI units; 460° F for English units.

t_w = Average wet test meter temperature, °C (°F).

P_{bar} = Barometric pressure, mm Hg (in. Hg).

Δp = Dry gas meter inlet differential pressure, mm H_2O (in. H_2O).

θ = Run time, min.

7.1.1.5 Compare the three Y_{dm} values at each of the flow rates and determine the maximum and minimum values. The difference between the maximum and minimum values at each flow rate should be no greater than 0.030. Extra sets of triplicate runs may be made in order to complete this requirement. In addition, the meter coefficients should be between 0.95 and 1.05. If these specifications cannot be met in three sets of successive triplicate runs, the meter is not suitable as a calibration standard and should not be used as such. If these specifications are met, average the three Y_{dm} values at each flow rate resulting in five average meter coefficients, $\overline{Y}_{dm}$.

7.1.1.6 Prepare a curve of meter coefficient, $\overline{Y}_{dm}$, versus flow rate, Q, for the dry gas meter. This curve shall be used as a reference when the meter is used to calibrate other dry gas meters and to determine whether recalibration is required.

7.1.2 Standard Dry Gas Meter Recalibration.

7.1.2.1 Recalibrate the standard dry gas meter against a wet test meter or spirometer annually or after every 200 hours of operation, whichever comes first. This requirement is valid provided the standard dry gas meter is kept in a laboratory and, if transported, cared for as any other laboratory instrument. Abuse to the standard meter may cause a change in the calibration and will require more frequent recalibrations.

7.1.2.2 As an alternative to full recalibration, a two-point calibration check may be made. Follow the same procedure and equipment arrangement as for a full recalibration, but run the meter at only two flow rates [suggested rates are 14 and 28 liters/min (0.5 and 1.0 cfm)]. Calculate the meter coefficients for these two points, and compare the values with the meter calibration curve. If the two coefficients are within ±1.5 percent of the calibration curve values at the same flow rates, the meter need not be recalibrated until the next date for a recalibration check.

7.2 Critical Orifices As Calibration Standards. Critical orifices may be used as calibration standards in place of the wet test meter specified in Section 5.3, provided that they are selected, calibrated, and used as follows:

7.2.1 Section of Critical Orifices.

7.2.1.1 The procedure that follows describes the use of hypodermic needles or stainless steel needle tubings which have been found suitable for use as critical orifices. Other materials and critical orifice designs may be used provided the orifices act as true critical orifices; i.e., a critical vacuum can be obtained, as described in Section 7.2.2.2.3. Select five critical orifices that are appropriately sized to cover the range of flow rates between 10 and 34 liters/min or the expected operating range. Two of the critical orifices should bracket the expected operating range.

A minimum of three critical orifices will be needed to calibrate a Method 5 dry gas meter (DGM); the other two critical orifices can serve as spares and provide better selection for bracketing the range of operating flow rates. The needle sizes and tubing lengths shown below give the following approximate flow rates:

Gauge/cm	Flow rate (liters/min)	Gauge/cm	Flow rate (liters/min)
12/7.6	32.56	14/2.5	19.54
12/10.2	30.02	14/5.1	17.27
13/2.5	25.77	14/7.6	16.14
13/5.1	23.50	15/3.2	14.16
13/7.6	22.37	15/7.6	11.61
13/10.2	20.67	15/10.2	10.48

7.2.1.2 These needles can be adapted to a Method 5 type sampling train as follows: Insert a serum bottle stopper, 13- by 20-mm sleeve type, into a ½-inch Swagelok quick connect. Insert the needle into the stopper as shown in Figure 5-9.

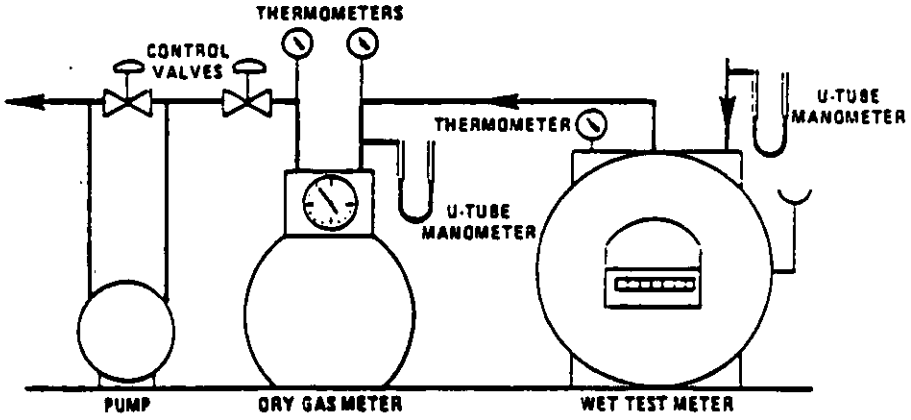


Figure 5.7 . Equipment arrangement for dry-gas meter calibration.

7.1.1.3 Collect the data as shown in the example data sheet (see Figure 5-8). Make triplicate runs at each of the flow rates and at no less than five different flow rates. The range of flow rates should be between 10 and 34 liters/min (0.35 and 1.2 cfm) or over the expected operating range.

DATE:_____

DRY GAS METER IDENTIFICATION:_____

BAROMETRIC PRESSURE (P_b):_____ in. Hg

APPROXIMATE FLOW RATE ($\bar{Q}$) cfm	SPIROMETER (WET METER) GAS VOLUME (V_s) ft^3	DRY GAS METER VOLUME (V_{dg}) ft^3	TEMPERATURES: SPIROMETER (WET METER) (t_s) °F	TEMPERATURES: DRY GAS METER: INLET (t_i) °F	TEMPERATURES: DRY GAS METER: OUTLET (t_o) °F	TEMPERATURES: DRY GAS METER: AVERAGE ($\bar{t}_d$) °F	DRY GAS METER PRESSURE (Δp) in. H_2O	TIME (Θ) min.	FLOW RATE (Q) cfm	METER METER COEFFICIENT (Y_{ds})	AVERAGE METER COEFFICIENT ($\bar{Y}_{ds}$)
0.40											
0.60											
0.80											
1.00											
1.20											

$$Q = 17.65 \cdot \frac{V_s}{\Theta} \cdot \frac{P_b}{(t_s + 460)}$$

$$Y_{ds} = \frac{V_s}{V_{dg}} \cdot \frac{(\bar{t}_d + 460)}{(t_s + 460)} \cdot \frac{P_b}{\left(P_b + \frac{\Delta p}{13.6}\right)}$$

Figure 5.8. Example data sheet for calibration of a standard dry gas meter for method 5 sampling equipment (English units).

ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).
θ = Total sampling time, min.
θ_1 = Sampling time interval, from the beginning of a run until the first component change, min.
θ_i = Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min.
θ_p = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min.
13.6 = Specific gravity of mercury.
60 = Sec/min.
100 = Conversion to percent.

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 5-2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C, 760 mm Hg or 68° F, 29.92 in. Hg) by using Equation 5-1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right)\left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}}\right]$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 5-1

where:
K_1 = 0.3858 °K/mm Hg for metric units
= 17.64 °R/in. Hg for English units

NOTE: Equation 5-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (i.e., the post-test leak check or leak checks conducted prior to component changes) exceeds L_a. If L_p or $_i$ exceeds L_a, Equation 5-1 must be modified as follows:

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 5-1 with the expression:

$$V_m - (L_p - L_a)\theta]$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_m in Equation 5-1 by the expression:

$$\left[V_m - (L_1 - L_a)\theta_1 - \sum_{i=2}^{n} (L_i - L_a)\theta_i - (L_p \quad L_a)\theta_p\right]$$

and substitute only for those leakage rates (L_i or L_p) which exceed L_a.

6.4 Volume of water vapor.

$$V_{w(std)} = V_{lc}\left(\frac{\rho_w}{M_w}\right)\left(\frac{RT_{std}}{P_{std}}\right) = K_2 V_{lc}$$

Equation 5-2

where:
K_2 = 0.001333 m³/ml for metric units
= 0.04707 ft³/ml for English units.

6.5 Moisture Content.

$$B_{ws} = \frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}}$$

Equation 5-3

NOTE: In saturated or water droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one from the impinger analysis (Equation 5-3), and a second from the assumption of saturated conditions. The lower of the two values of B_w shall be considered correct. The procedure for determining the moisture content based upon assumption of saturated conditions is given in the Note of Section 1.2 of Method 4. For the purposes of this method, the average stack gas temperature from Figure 5-2 may be used to make this determination, provided that the accuracy of the in-stack temperature sensor is ±1° C (2° F).

6.6 Acetone Blank Concentration.

Equation 5-4

$$C_a = \frac{m_a}{V_a \rho_a}$$

6.7 Acetone Wash Blank.

$W_a = C_a V_{aw} \rho_a$ Equation 5-5

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1 and 2 less the acetone blank (see Figure 5-3).

NOTE: Refer to Section 4.1.5 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

6.9 Particulate Concentration.

$C_s = (0.001\ g/mg)\ (m_a / V_{m(std)})$ Equation 5-6

6.10 Conversion Factors:

From	To	Multiply by
scf	m³	0.02832.
g/ft³	gr/ft³	15.43.
g/ft³	lb/ft³	2.205×10^{-3}.
g/ft³	g/m³	35.31.

6.11 Isokinetic Varition.

6.11.1 Calculation From Raw Data.

$$I = \frac{100\ T_s[K_3 V_{lc} + (P_m/T_m)(P_{bar} + \Delta H/13.6)]}{60\theta_v\ P_s\ A_n}$$

Equation 5-7

where:
K_3 = 0.003454 mm Hg−m³/ml−°K for metric units.
= 0.002669-in. Hg−ft³/ml−°R for English units.

6.11.2 Calculation From Intermediate Values.

$$I = \frac{T_s V_{m(std)} P_{std}\, 100}{T_{std} v_s \theta\, A_n P_s\, 60(1 - B_{ws})}$$

$$= K_4 \frac{T_s V_{m(std)}}{P_s V_s A_n \theta (1 - B_{ws})}$$

Equation 5-8

where:
K_4 = 4.320 for metric units
= 0.09450 for English units.

6.12 Acceptable Results. If 90 percent < I < 110 percent, the results are acceptable. If the particulate results are low in comparison to the standard, and I is over 110 percent or less than 90 percent, the Administrator may accept the results. Citation 4 in the bibliography section can be used to make acceptability judgments. If I is judeged to be unacceptable, reject the particulate results and repeat the test.

7. *Alternative Procedures*

7.1 Dry Gas Meter as a Calibration Standard. A dry gas meter may be used as a calibration standard for volume measurements in place of the wet test meter specified in Section 5.3, provided that it is calibrated initially and recalibrated periodically as follows:

7.1.1 Standard Dry Gas Meter Calibration.

7.1.1.1 The dry gas meter to be calibrated and used as a secondary reference meter should be of high quality and have an appropriately sized capacity, e.g., 3 liters/rev (0.1 ft³/rev). A spirometer (400 liters or more capacity), or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should have a capacity of 30 liters/rev (1 ft³/rev) and capable of measuring volume to within ±1.0 percent; wet test meters should be checked against a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained.

7.1.1.2 Set up the components as shown in Figure 5.7. A spirometer, or equivalent, may be used in place of the wet test meter in the system. Run the pump for at least 5 minutes at a flow rate of about 10 liters/min (0.35 cfm) to condition the interior surface of the wet test meter. The pressure drop indicated by the manometer at the inlet side of the dry gas meter should be minimized [no greater than 100 mm H_2O (4 in. H_2O) at a flow rate of 30 liters/min (1 cfm)]. This can be accomplished by using large diameter tubing connections and straight pipe fittings.

ing procedure is suggested (see Figure 5-4): Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing atached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

5.7 Barometer. Calibrate against a mercury barometer.

6. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

6.1 Nomenclature

A_n = Cross-sectional area of nozzle, m^2 (ft^2).
B_{ws} = Water vapor in the gas stream, proportion by volume.
C_a = Acetone blank residue concentration, mg/g.
c_s = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dscm (g/dscf).
I = Percent of isokinetic sampling.
L_a = Maximum acceptable leakage rate for either a pretest leak check or for a leak check following a component change; equal to 0.0057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.
L_i = Individual leakage rate observed during the leak check conducted prior to the "i^{th}" component change (i=1, 2, 3....n), m^3/min (cfm).
L_p = Leakage rate observed during the post-test leak check, m^3/min (cfm).
m_a = Total amount of particulate matter collected, mg.
M_w = Molecular weight of water, 18.0 g/g-mole (18.0lb/lb-mole).
m_n = Mass of residue of acteone after evaporation, mg.
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_i = Absolute stack gas pressure, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
R = Ideal gas constant, 0.06236 mm Hg-m^3/°K-g-mole (21.85 in. Hg-ft^3/°R-lb-mole).
T_m = Absolute average dry gas meter temperature (see Figure 5-2), °K (°R).
T_s = Absolute average stack gas temperature (see Figure 5-2), °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of acetone blank, ml.
V_{aw} = Volume of acetone used in wash, ml.
V_{lc} = Total volume of liquid collected in impingers and silica gel (see Figure 5-3), ml.
V_m = Volume of gas sample as measured by dry gas meter, dcm (dscf).
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dscm (dscf).
$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard conditions, scm (scf).
v_s = Stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 5, m/sec (ft/sec).
W_a = Weight of residue in acetone wash, mg.
Y = Dry gas meter calibration factor.
ΔH = Average pressure differential across the orifice meter (see Figure 5-2), mm H_2O (in. H_2O).
ρ_a = Density of acetone, mg/ml (see label on bottle).

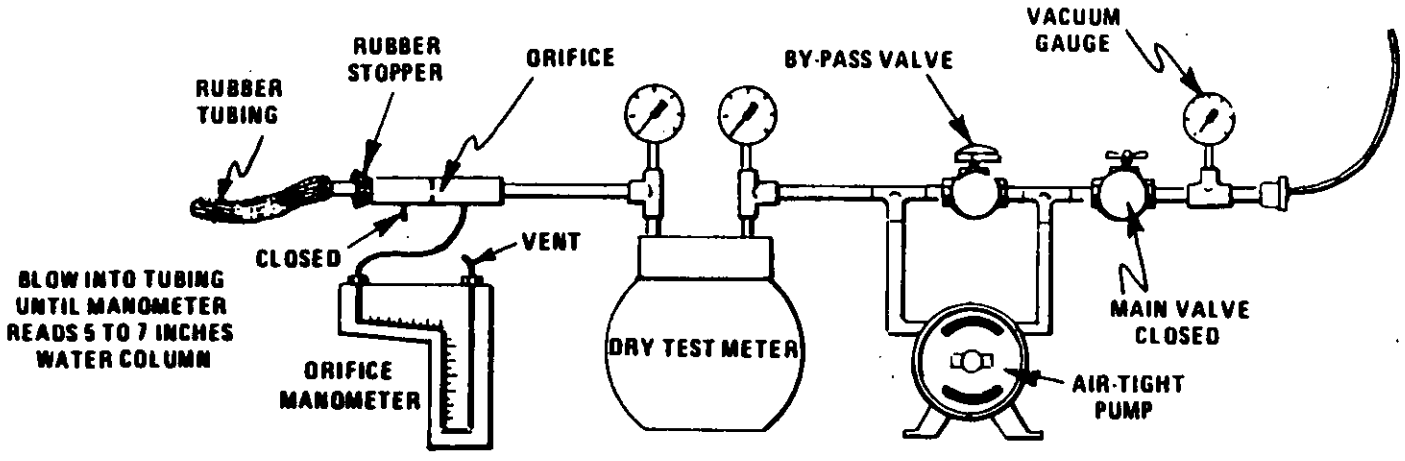


Figure 5-4. Leak check of meter box.

Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.00057m³/min (0.02 cfm); at the end of the run, take the difference of the measured wet test meter and dry gas meter volumes; divided the difference by 10, to get the leak rate. The leak rate should not exceed 0.00057 m³/min (0.02 cfm).

5.3.2 Calibration After Use. After each filed use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, inset a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the dry gas meter calibration factor. If the value has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as previously detailed.

Alternative procedures, e.g., rechecking the orifice meter coefficient may be used, subject to the approval of the Administrator.

5.3.3 Acceptable Variation in Calibration. If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.4 Probe Heater Calibration. The probe heating system shall be calibrated before its initial use in the field.

Use a heat source to generate air heated to selected temperatures that approximate those expected to occur in the sources to be sampled. Pass this air through the probe at a typical simple flow rate while measuring the probe inlet and outlet temperatures at various probe heater settings. For each air temperature generated, construct a graph of probe heating system setting versus probe outlet temperature. The procedure outlined in APTD-0576 can also be used. Probes constructed according to APTD-0581 need not be calibrated if the calibration curves in APTD-0576 are used. Also, probes with outlet temperature monitoring capabilities do not require calibration.

5.5 Temperature Gauges. Use the procedure in Section 4.3 of Method 2 to calibrate in-stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

5.6 Leak Check of Metering System Shown in Figure 5-1. That portion of the sampling train from the pump to the orifice meter should be leak checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The follow-

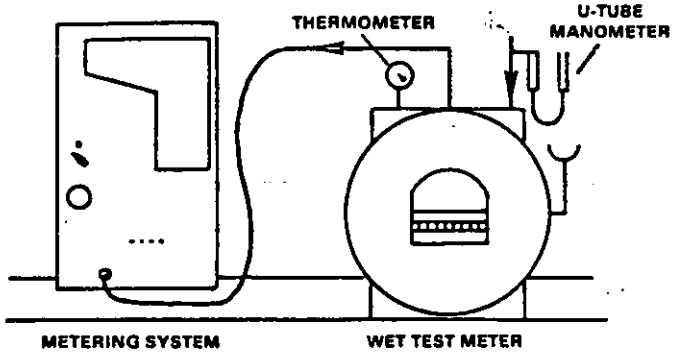


Figure 5.5 Equipment arrangement for metering system calibration.

Date _____ Metering System Identification: _____

Barometric pressure, P_b = _____ in. Hg

Orifice manometer setting ΔH in. H_2O	Spirometer (wet meter) gas volume (V_w) ft^3	Dry gas meter volume (V_m) ft^3	Temperatures: Spirometer (wet meter) (t_w) °F	Dry Gas Meter: Inlet (t_o) °F	Dry Gas Meter: Outlet (t_f) °F	Dry Gas Meter: Average (t_m) °F	Time (θ) min

Calculations

ΔH in. H_2O	Y: $\frac{V_w P_b (t_m + 460)}{V_m (P_b + \frac{\Delta H}{13.6}) (t_w + 460)}$	$\Delta H_@$: $\frac{0.0317 \, \Delta H}{P_b (t_o + 460)} \left[\frac{(t_w + 460)\theta}{V_w}\right]^2$
Average		

Y = Ratio of reading of wet test meter to dry test meter; tolerance for individual values ±0.02 from average.

$\Delta H_@$ = Orifice pressure differential that equates to 0.75 cfm of air @ 68°F and 29.92 inches of mercury, in. H_2O; tolerance for individual values ±0.20 from average.

Figure 5.6. Example data sheet for calibration of metering system (English units).

Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 4.3, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

Alternatively, the sample may be oven dried at 105° C (220° F) for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The tester may also opt to oven dry the sample at 105° C (220° F) for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

Container No. 2. Note the level of liquid in the container and confirm on the analysis sheet whether or not leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ±1 ml or gravimetrically to ±0.5 g. Transfer the contents to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 3. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. This step may be conducted in the field.

"Acetone Blank" Container. Measure acetone in this container either volumentrically or gravimetrically. Transfer the acetone to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE: At the option of the tester, the contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

4.4 Quality Control Procedures. The following quality control procedures are suggested to check the volume metering system calibration values at the field test site prior to sample collection. These procedures are optional for the tester.

4.4.1 Meter Orifice Check. Using the calibration data obtained during the calibration procedure described in Section 5.3, determine the $\Delta H_@$ for the metering system orifice. The $\Delta H_@$ is the orifice pressure differential in units of in. H_2O that correlates to 0.75 cfm of air at 528°R and 29.92 in. Hg. The $\Delta H_@$ is calculated as follows:

$$\Delta H_@ = 0.0319\ \Delta H \frac{T_m}{P_{bar}} \frac{\Theta^2}{Y^2 V_m^2}$$

Eq. 5-9

Where:

ΔH = Average pressure differential across the orifice meter, in. H_2O.

T_m = Absolute average dry gas meter temperature, °R.

P_{bar} = Barometric pressure, in. Hg.

Θ = Total sampling time, min.

Y = Dry gas meter calibration factor, dimensionless.

V_m = Volume of gas sample as measured by dry gas meter, dcf.

$0.0319 = (0.0567\ \text{in. Hg/°R}) \times (0.75\ \text{cfm})^2$

Before beginning the field test (a set of three runs usually constitutes a field test), operate the metering system (i.e., pump, volume meter, and orifice) at the $\Delta H_@$ pressure differential for 10 minutes. Record the volume collected, the dry gas meter temperature, and the barometric pressure. Calculate a dry gas meter calibration check value, Y_c, as follows:

$$Y_c = \frac{10}{V_m} \left[\frac{0.0319\ T_m}{P_{bar}} \right]^{1/2}$$

Eq. 5-10

Where:

Y_c = Dry gas meter calibration check value, dimensionless.

10 = 10 minutes of run time.

Compare the Y_c value with the dry gas meter calibration factor Y to determine that:

$0.97Y < Y_c < 1.03Y$

If the Y_c value is not within this range, the volume metering system should be investigated before beginning the test.

4.4.2 Calibration Critical Orifice. A calibrated critical orifice, calibrated against a wet test meter or spirometer and designed to be inserted at the inlet of the sampling meter box, may be used as a quality control check by following the procedure of Section 7.2.

5. *Calibration*

Maintain a laboratory log of all calibrations.

5.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the inside diameter of the nozzle to the nearest 01.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

5.2 Pitot Tube. The Type S pitot tube assembly shall be calibrated according to the procedure outlined in Section 4 of Method 2.

5.3 Metering System. Before its initial use in the field, the metering system shall be calibrated according to the procedure outlined in APTD-0576. Instead of physically adjusting the dry gas meter dial readings to correspond to the wet test meter readings, calibration factors may be used to mathematically correct the gas meter dial readings to the proper values. Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump, for these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.0057 m^3/min (0.02 cfm); at the end of the run, take the difference of the measured wet test meter and dry gas meter volumes; divide the difference by 10, to get the leak rate. The leak rate should not exceed 0.00057 m^3/min (0.02 cfm).

After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test). With the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the calibration factor. If the calibration has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as outlined in APTD-0576.

Alternative procedures, e.g., using the orifice meter coefficients, maybe used, subject to the approval of the Administrator.

NOTE: If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.3.1 Calibration Prior to Use. Before its initial use in the field, the metering system shall be calibrated as follows: Connect the metering system inlet to the outlet of a wet test meter that is accurate to within 1 percent. Refer to Figure 5.5. The wet test meter should have a capacity of 30 liters/rev (1 ft^3/rev). A spirometer of 400 liters (14 ft^3) or more capacity, or equivalent, may be used for this calibration, although a wet test meter is usually more practical. The wet test meter should be periodically calibrated with a spirometer or a liquid displacement meter to ensure the accuracy of the wet test meter. Spirometers or wet test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained. Run the metering system pump for about 15 minutes with the orifice manometer indicating a median reading as expected in field use to allow the pump to warm up and to permit the interior surface of the wet test meter to be thoroughly wetted. Then, at each of a minimum of three orifice manometer settings, pass an exact quantity of gas through the wet test meter and note the gas volume indicated by the dry gas meter. Also note the barometric pressure, and the temperatures of the wet test meter, the inlet of the dry gas meter, and the outlet of the dry gas meter. Select the highest and lowest orifice settings to bracket the expected field operating range of the orifice. Use a minimum volume of 0.15 m^3 (5 cf) at all orifice settings. Record all the data on a form similar to Figure 5.6, and calculate Y, the dry gas meter calibration factor, and $\Delta H@$, the orifice calibration factor, at each orifice setting as shown on Figure 5.6. Allowable tolerances for individual Y and $\Delta H@$, values are given in Figure 5.6. Use the average of the Y values in the calculations in Section 6.

Note that when two or more trains are used, separate analyses of the front-half and (if applicable) impinger catches from each train shall be performed, unless identical nozzle sizes were used on all trains, in which case, the front-half catches from the individual trains may be combined (as may the impinger catches) and one analysis of front-half catch and one analysis of impinger catch may be performed. Consult with the Administrator for details concerning the calculation of results when two or more trains are used.

At the end of the sample run, turn off the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 4.1.4.3. Also, leak-check the pitot lines as described in Method 2, Section 3.1; the lines must pass this leak-check, in order to validate the velocity head data.

4.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Calculations, Section 6) to determine whether the run was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

4.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe is removed from the stack at the end of the sampling period. Allow the probe to cool.

When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, thus drawing water from the impingers into the filter holder.

Before moving the sample train to the cleanup site, remove the probe from the sample train, wipe off the silicone grease, and cap the open outlet of the probe. Be careful not to lose any condensate that might be present. Wipe off the silicone grease from the filter inlet where the probe was fastened and cap it. Remove the umbilical cord from the last impinger and cap the impinger. If a flexible line is used between the first impinger or condenser and the filter holder, disconnect the line at the filter holder and let any condensed water or liquid drain into the impingers or condenser. After wiping off the silicone grease, cap off the filter holder outlet and impinger inlet. Either ground-glass stoppers, plastic caps, or serum caps may be used to close these openings.

Transfer the probe and filter-impinger assembly to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the acetone used for cleanup as a blank. Take 200 ml of this acetone directly from the wash bottle being used and place it in a glass sample container labeled "acetone blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry Nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator; in these cases, save a water blank and follow the Administrator's directions on analysis. Perform the acetone rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with acetone from a wash bottle and brushing with a Nylon bristle brush. Brush until the acetone rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

Brush and rinse the inside parts of the Swagelok fitting with acetone in a similar way until no visible particles remain.

Rinse the probe liner with acetone by tilting and rotating the probe while squirting acetone into its upper end so that all inside surfaces will be wetted with acetone. Let the acetone drain from the lower end into the sample container. A funnel (glass or polyethylene) may be used to aid on transferring liquid washes to the container. Follow the acetone rinse with a probe brush. Hold the probe in an inclined position, squirt acetone into the upper end as the probe brush is being pushed with a twisting action through the probe; hold a sample container underneath the lower end of the probe, and catch any acetone and particulate matter which is brushed from the probe. Run the brush through the probe three times or more until no visible particulate matter is carried out with the acetone or until none remains in the probe liner on visual inspection. With stainless steel or other metal probes, run the brush through in the above prescribed manner at least six times since metal probes have small crevices in which particulate matter can be entrapped. Rinse the brush with acetone, and quantitatively collect these washings in the sample container. After the brushing, make a final acetone rinse of the probe as described above.

It is recommended that two people be used to clean the probe to minimize sample losses. Between sampling runs, keep brushes clean and protected from contaminations.

After ensuring that all joints have been wiped clean of silicone grease, clean the inside of the front half of the filter holder by rubbing the surfaces with a Nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make a final rinse of the brush and filter holder. Carefully rinse out the glass cyclone, also (if applicable). After all acetone washings and particulate matter have been collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether or not leakage occured during transport. Label the container to clearly identify its contents.

Container No. 3. Note the color of the indicating silica gel to determine if it has been completely spent and make a notation of its condition. Transfer the silica gel from the fourth impinger to its original container and seal. A funnel may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the impinger wall and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for container No. 3 in Section 4.3.

Impinger Water. Treat the impingers as follows; Make a notation of any color or film in the liquid catch. Measure the liquid which is in the first three impingers to within ±1 ml by using a graduated cylinder or by weighing it to within ±0.5 g by using a balance (if one is available). Record the volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas.

Discard the liquid after measuring and recording the volume or weight, unless analysis of the impinger catch is required (see Note, Section 2.1.7).

If a different type of condenser is used, measure the amount of moisture condensed either volumetrically or gravimetrically.

Whenever possible, containers should be shipped in such a way that they remain upright at all times.

4.3 Analysis. Record the data required on a sheet such as the one shown in Figure 5-3. Handle each sample container as follows:

FIGURE 5-3—ANALYTICAL DATA

Plant _____
Date _____
Run No. _____
Filter No. _____
Amount liquid lost during transport _____
Acetone blank volume, ml _____
Acetone wash volume, ml _____
Acetone blank concentration, mg/mg (equation 5-4) _____
Acetone wash blank, mg (equation 5-5) _____

Container number	Weight of particulate collected, mg		
	Final weight	Tare weight	Weight gain
1			
2			
Total			
Less acetone blank			
Weight of particulate matter			

	Volume of liquid water collected	
	Impinger volume, ml	Silica gel weight, g
Final		
Initial		
Liquid collected		
Total volume collected		g* ml

*Convert weight of water to volume by dividing total weight increase by density of water (1 g/ml).

$$\frac{\text{Increase, g}}{\text{(1 g/ml)}} = \text{Volume water, ml}$$

if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 4.1.4.1 above shall be used.

4.1.4.3 Post-test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leakcheck shall be done in accordance with the procedures outlined in Section 4.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered.

If, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

4.1.5 Particulate Train Operation. During the sampling run, maintain an isokinetic sampling rate (within 10 percent of true isokinetic unless otherwise specified by the Administrator) and a temperature around the filter of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator.

For each run, record the data required on a data sheet such as the one shown in Figure 5-2. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak-check, and when sampling is halted. Take other readings required by Figure 5-2 at least once at each sample point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling deposited material. To begin sampling, remove the nozzle cap, verify that the filter and probe heating systems are up to temperature, and that the pitot tube and probe are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment of the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient is 0.85±0.02, and the stack gas equivalent density (dry molecular weight) is equal to 29±4. APTD-0576 details the procedure for using the nomographs. If C_s and M_d are outside the above stated ranges do not use the nomographs unless appropriate steps (see Citation 7 in Bibliography) are taken to compensate for the deviations.

When the stack is under significant negative pressure (height of impinger stem), take care to close the coarse adjust valve before inserting the probe into the stack to prevent water from backing into the filter holder. If necessary, the pump may be turned on with the coarse adjust valve closed.

When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

Traverse the stack cross-section, as required by Method 1 or as specified by the Administrator, being careful not to bump the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes; this minimizes the chance of extracting deposited material.

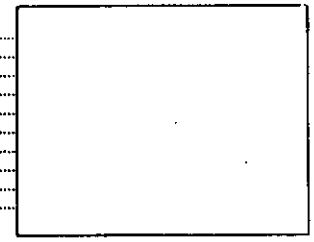
During the test run, make periodic adjustments to keep the temperature around the filter holder at the proper level; add more ice and, if necessary, salt to maintain a temperature of less than 20° C (68° F) at the condenser/silica gel outlet. Also, periodically check the level and zero of the manometer.

If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of a sample run. It is recommended that another complete filter assembly be used rather than attempting to change the filter itself. Before a new filter assembly is installed, conduct a leak-check (see Section 4.1.4.2). The total particulate weight shall include the summation of all filter assembly catches.

A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or, in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator.

FIGURE 5-2—PARTICULATE FIELD DATA

Plant .....
Location .....
Operator .....
Date .....
Run No .....
Sample box No .....
Meter box No .....
Meter ΔH@ .....
C factor .....
Pitot tube coefficient, Cp .....



Ambient temperature .....
Barometric pressure .....
Assumed moisture, % .....
Probe length, m. (ft.) .....
Nozzle identification No. .....
Average calibrated nozzle diameter, cm (in.) .....
Probe heater setting .....
Leak rate, m³/min, (cfm) .....
Probe liner material .....
Static pressure, mm. Hg (in. Hg) .....
Filter No. .....

SCHEMATIC OF STACK CROSS SECTION

Traverse point number	Sampling time (e), min.	Vacuum mm Hg (in. Hg)	Stack temperature (T_s), °C (° F)	Velocity head (ΔP_s), mm (in.) H_2O	Pressure differential across orifice meter mm H_2O (in. H_2O)	Gas sample volume m³ (ft³)	Gas sample temperature at dry gas meter: Inlet °C (° F)	Gas sample temperature at dry gas meter: Outlet ° C (° F)	Filter holder temperature ° C (° F)	Temperature of gas leaving condenser or last impinger ° C (° F)
Total							Avg.	Avg.		
Average							Avg.			

3.2 Sample Recovery. Acetone-reagent grade, <0.001 percent residue, in glass bottles—is required. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers; thus, acetone blanks shall be run prior to field use and only acetone with low blank values (<0.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

3.3 Analysis. Two reagents are required for the analysis:

3.3.1 Acetone. Same as 3.2.

3.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

4. *Procedure*

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. It is suggested that sampling equipment be maintained according to the procedures described in APTD-0576.

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in the impinger or sampling holder just prior to train assembly.

Check filters visually against light for irregularities and flaws or pinhole leaks. Label filters of the proper diameter on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

Desiccate the filters at 20±5.6° C (68±10° F) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., 0.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105° C (220° F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

4.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, Section 3.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particulate sample run.

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Ensure that the proper differental pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a suitable probe liner and probe length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time greater than or equal to the minimum total sampling time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 min (or some greater time interval as specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors. The sampling time at each point shall be the same.

In some cirumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

4.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and weighed filter in the filter holder. Be sure that the filter is property centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Check the filter for tears after assembly is completed.

When glass liners are used, install the selected nozzle using a Viton A O-ring when stack temperatures are less than 260° C (500° F) and an asbestos string gasket when temperatures are higher. See APTD-0576 for details. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. When metal liners are used, install the nozzle as above or by a leak-free direct mechanical connection. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Set up the train as in Figure 5-1, using (if necessary) a very light coat of silicone grease on all ground glass joints, greasing only the outer portion (see APTD-0576) to avoid possibility of contamination by the silicone grease. Subject to the approval of the Administrator, a glass cyclone may be used between the probe and filter holder when the total particulate catch is expected to exceed 100 mg or when water droplets are present in the stack gas.

Place crushed ice around the impingers.

4.1.4 Leak-Check Procedures.

4.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, the following procedure shall be used.

After the sampling train has been assembled, turn on and set the filter and probe heating systems at the desired operating temperatures. Allow time for the temperatures to stabilize. If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak-check the train at the sampling site by plugging the nozzle and pulling a 380 mm Hg (15 in. Hg) vacuum.

NOTE: A lower vacuum may be used, provided that it is not exceeded during the test.

If an asbestos string is used, do not connect the probe to the train during the leak-check. Instead, leak-check the train by first plugging the inlet to the filter holder (cycone, if applicable) and pulling a 380 mm Hg (15 in. Hg) vacuum (see Note immediately above). Then connect the probe to the train and leak-check at about 25 mm Hg (1 in. Hg) vacuum; alternatively, the probe may be leak-checked with the rest of the sampling train, in one step, at 380 mm Hg (15 in. Hg) vacuum. Leakage rates in excess of 4 percent of the average sampling rate or 0.00057 m³/min (0.02 cfm), whichever is less, are unacceptable.

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with bypass valve fully open and coarse adjust valve, completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of bypass value; this will cause water to back up into the filter holder. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak-check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe, filter holder, or cyclone (if applicable) and immediately turn off the vacuum pump. This prevents the water in the impingers from being forced backward into the filter holder and silica get from being entrained backward into the third impinger.

4.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes unecessary, a leak-check shall be conducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 4.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered;

2.1.4 Differentia Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used or velocity head (Δp) readings, and the other, for orifice differentia pressure readings.

2.1.5 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other materials of construction (e.g., stainless steel, Teflon, Viton) may be used, subject to approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The holder shall be attached immediately at the outlet of the probe (or cyclone, it used).

2.1.6 Filter Heating System. Any heating system capable of maintaining a temperature around the filter holder during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. Alternatively, the tester may opt to operate the equipment at a temperature lower than that specified. A temperature gauge capable of measuring temperature to within 3° C (5.4° F) shall be installed so that the temperature around the filter holder can be regulated and monitored during sampling. Heating systems other than the one shown in APTD-0581 may be used.

2.1.7 Condenser. The following system shall be used to determine the stack gas moisture content: Four impingers connected in series with leak-free ground glass fittings or any similar leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with 1.3 cm (½ in.) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator. The first and second impingers shall contain known quantities of water (Section 4.1.3), the third shall be empty, and the fourth shall contain a known weight of silica gel, or equivalent desiccant. A thermometer, capable of measuring temperture to within 1° C (2° F) shall be placed at the outlet of the fourth impinger for monitoring purposes.

Alternatively, any system that cools the sample gas stream and allows measurement of the water condensed and moisture leaving the condenser, each to within 1 ml or 1 g may be used, subject to the approval of the Administrator. Acceptable means are to measure the condensed water either gravimetrically or volumetrically and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures; or (2) passing the sample has stream through a tared silica gel (or equivalent desiccant) trap with exit gases kept below 20° C (68° F) and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

NOTE: If a determination of the particulate matter collected in the impingers is desired in addition to moisture content, the impinger system described above shall be used, without modification. Individual States or control agencies requiring this information shall be contacted as to the sample recovery and analysis of the impinger contents.

2.1.8 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 5-1. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for higher flow rates than that decribed in APTD-0581 or APDT-0576 may be used provided that the specifications of this method are met.

2.1.9 Barometer. Mercury aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.10 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3. The temperature sensor shall, preferably, be permanently attached to the pitot tube or sampling probe in a fixed configuration, such that the tip of the sensor extends beyond the leading edge of the probe sheath and does not touch any metal. Alternatively, the sensor may be attached just prior to use in the field. Note, however, that if the temperature sensor is attached in the field, the sensor must be placed in an interference-free arrangement with respect to the Type S pitot tube openings (see Method 2, Figure 2-7). As a second alternative, if a difference of not more than 1 percent in the average velocity measurement is to be introduced, the temperature gauge need not be attached to the probe or pitot tube. (This alternative is subject to the approval of the Administrator.)

2.2 Sample Recovery. The following items are needed.

2.2.1 Probe-Liner and Probe-Nozzle Brushes. Nylon bristle brushes with stainless steel wire handles. The probe brush shall have extensions (at least as long as the probe) of stainless steel, Nylon, Teflon, or similarly inert material. The brushes shall be properly sized and shaped to brush out the probe liner and nozzle.

2.2.2 Wash Bottles—Two. Glass wash bottles are recommended; polyethylene wash bottles may be used at the option of the tester. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

2.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

2.2.4 Petri Dishes. For filter samples, glass or polyethylene, unless otherwise specified by the Administrator.

2.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 1 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. Any of these balances is suitable or use here and in Section 2.3.4.

2.2.6 Plastic Storage Containers. Airtight containers to store silica gel.

2.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not

2.2.8 Funnel. Glass or polyethylene, to aid in sample recovery.

2.2 Analysis. For analysis, the following equipment is needed.

2.3.1 Glass Weighing Dishes.

2.3.2 Desiccator.

2.3.3 Analytical Balance. To measure to within 0.1 mg.

2.3.4 Balance. To measure to within 0.5 g.

2.3.5 Beakers. 250 ml.

2.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

2.3.7 Temperature Gauge. To measure the temperature of the laboratory environment.

3. *Reagents*

3.1 Sampling. The reagents used in sampling are as follows:

3.1.1 Filters. Glass fiber filters, without organic binder, exhibiting at least 99.95 percent efficiency (<0.05 percent penetration) on 0.3-micron dioctyl phthalate smoke particles. The filter efficiency test shall be conducted in accordance with ASTM standard method D2986-71 (Reapproved 1978) (incorporated by reference—see § 60.17). Test data from the supplier's quality control program are sufficient for this purpose. In sources containing SO_2 or SO_3, the filter material must be of a type that is unreactive to SO_2 or SO_3. Citation 10 in Section 7 Bibliography, may be used to select the appropriate filter.

3.1.2 Silica Gel. Indicating type, 6 to 16 mesh. If previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

3.1.3 Water. When analysis of the material caught in the impingers is required, distilled water shall be used. Run blanks prior to field use to eliminate a high blank on test samples.

3.1.4 Crushed Ice.

3.1.5 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

METHOD 5—DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at a temperature in the range of 120±14° C (248±25° F) or such other temperature as specified by an applicable subpart of the standards or approved by Administrator, U.S. Environmental Protection Agency, for a particular application. The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method is applicable for the determination of particulate emissions from stationary sources.

2. *Apparatus*

2.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 5-1. Complete construction details are given in APTD-0581 (Citation 2 in Bibliography); commercial models of this train are also available. For changes from APTD-0581 and for allowable modifications of the train shown in Figure 5-1, see the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576 (Citation 3 in Bibliography). Since correct usage is important in obtaining valid results, all users should read APTD-0576 and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

2.1.1 Probe Nozzle. Stainless steel (316) or glass with sharp, tapered leading edge. The angle of taper shall be 30° and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing; other materials of construction may be used, subject to the approval of the Administrator.

A range of nozzle sizes suitable for isokinetic sampling should be available, e.g., 0.32 to 1.27 cm (⅛ to ½ in.)—or larger if higher volume sampling trains are used—inside diameter (ID) nozzles in increments of 0.16 cm (1/16 in.). Each nozzle shall be calibrated according to the procedures outlined in Section 5.

2.1.2 Probe Liner. Borosilicate or quartz glass tubing with a heating system capable of maintaining a gas temperature at the exit end during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. (The tester may opt to operate the equipment at a temperature lower than that specified.) Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the procedure outlined in APTD-0576) will be considered acceptable.

Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480° C (900° F) quartz liners shall be used for temperatures between 480 and 900° C (900 and 1,650° F). Both types of liners may be used at higher temperatures than specified for short periods of time, subject to the approval of the Administrator. The softening temperature for borosilicate is 820° C (1,508° F), and for quartz it is 1,500° C (2,732° F).

Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incoloy 825,[1] or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

2.1.3 Pitot Tube. Type S, as described in Section 2.1 of Method 2, or other device approved by the Administrator. The pitot tube shall be attached to the probe (as shown in Figure 5-1) to allow constant monitoring of the stack gas velocity. The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane (see Method 2, Figure 2-6b) during sampling. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in Section 4 of Method 2.

[1] Mention of trade names or specific product does not constitute endorsement by the Environmental Protection Agency.

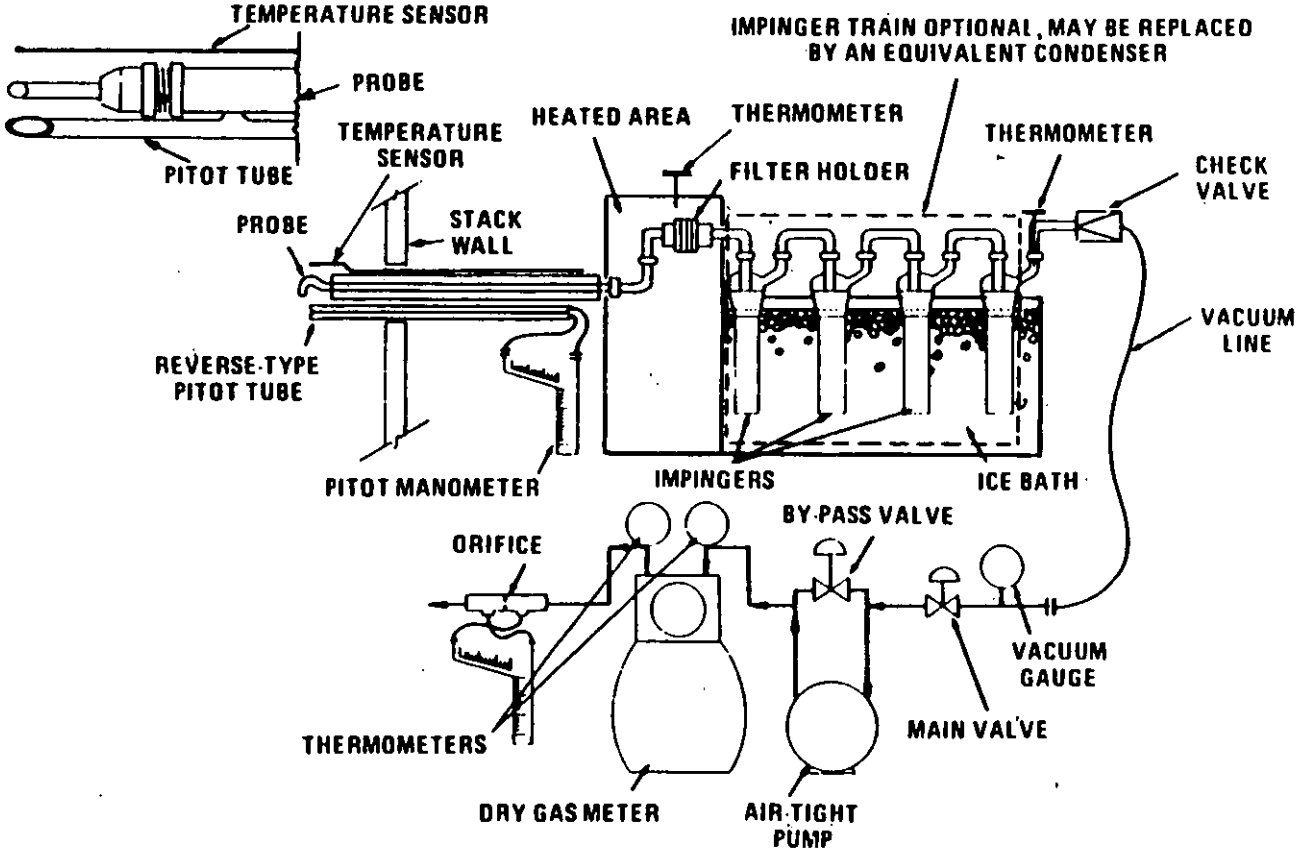


Figure 5-1. Particulate-sampling train.

NOTE: The above equation does not consider argon in air (about 0.9 percent, molecular weight of 37.7). A negative error of about 0.4 percent is introduced. The tester may opt to include argon in the analysis using procedures subject to approval of the Administrator.

7. *Bibliography*

1. Altshuller, A. P. Storage of Gases and Vapors in Plastic Bags. International Journal of Air and Water Pollution. *6*:75-81. 1963.

2. Conner, William D. and J. S. Nader. Air Sampling with Plastice Bags. Journal of the American Industrial Hygiene Association. *25*:291-297. 1964.

3. Burrell Manual for Gas Analysts. Seventh edition. Burrell Corporation, 2223 Fifth Avenue, Pittsburgh, Pa. 15219. 1951.

4. Mitchell, W. J. and M. R. Midgett. Field Reliability of the Orsat Analyzer. Journal of Air Pollution Control Association *26*:491-495. May 1976.

5. Shigehara, R. T., R. M. Neulicht, and W. S. Smith. Validating Orsat Analysis Data from Fossil Fuel-Fired Units. Stack Sampling News. *4*(2):21-26. August, 1976.

4.2.5 To insure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three of four) should be make between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.2.6 Repeat the analysis until the following criteria are met:

4.2.6.1 For percent CO_2, repeat the analytical procedure until the results of any three analyses differ by no more that (a) 0.3 percent by volume when CO_2 is greater than 4.0 percent or (b) 0.2 percent by volume when CO_2 is less than or equal to 4.0 percent. Average the three acceptable values of percent CO_2 and report the results to the nearest 0.1 percent.

4.2.6.2 For percent O_2, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when O_2 is less than 15.0 percent or (b) 0.2 percent by volume when O_2 is greater than or equal to 15.0 percent. Average the three acceptable values of percent O_2 and report the results to the nearest 0.1 percent.

4.2.6.3 For percent CO, repeat the analytical procedure until the results of any three analyses differ by no more than 0.3 percent. Average the three acceptable values of percent CO and report the results to the nearest 0.1 percent.

4.2.7 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before an after the analysis.

NOTE: Although in most instances only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.3 Multi-Point, Integrated Sampling and Analytical Procedure.

4.3.1 Both the minimum number of sampling points and the sampling point location shall be as specified in Section 3.3.1 of this method. The use of fewer points than specified is subject to the approval of the Administrator.

4.3.2 Follow the procedures outlined in Sections 4.2.2 through 4.2.7, except for the following: Traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

4.4 Quality Control Procedures.

4.4.1 Data Validation When Both CO_2 and O_2 Are Measured. Although in most instances, only CO_2 or O_2 measurement is required, it is recommended that both CO_2 and O_2 be measured to provide a check on the quality of the data. The following quality control procedure is suggested.

NOTE: Since the method for validating the CO_2 and O_2 analyses is based on combustion of organic and fossil fuels and dilution of the gas stream with air, this method does not apply to sources that (1) remove CO_2 or O_2 through processes other than combustion, (2) add O_2 (e.g., oxygen enrichment) and N_2 in proportions different from that of air, (3) add CO_2 (e.g., cement or lime kilns), or (4) have no fuel factor, F_o, values obtainable (e.g., extremely variable waste mixtures). This method validates the measured proportions of CO_2 and O_2 for the fuel type, but the method does not detect sample dilution resulting from leaks during or after sample collection. The method is applicable for samples collected downstream of most lime or limestone flue-gas desulfurization units as the CO_2 added or removed from the gas stream is not significant in relation to the total CO_2 concentration. The CO_2 concentrations from other types of scrubbers using only water or basic slurry can be significantly affected and would render the F_o check minimally useful.

4.4.1.1 Calculate a fuel factor, F_o, using the following equation:

$$F_o = \frac{20.9 - \%O_2}{\%CO_2}$$

Eq. 3-3

Where:
$\%O_2$ = Percent O_2 by volume (dry basis).
$\%CO_2$ = Percent CO_2 by volume (dry basis).
20.9 = Percent O_2 by volume in ambient air.

If CO is present in quantities measurable by this method, adjust the O_2 and CO_2 values before performing the calculation for F_o as follows:

$$\%CO_2(adj) = \%CO_2 + \%CO$$

$$\%O_2(adj) = \%O_2 - 0.5\ \%CO$$

Where: %CO = Percent CO by volume (dry basis).

4.4.1.2 Compare the calculated F_o factor with the expected F_o values. The following table may be used in establishing acceptable ranges for the expected F_o if the fuel being burned is known. When fuels are burned in combination, calculate the combined fuel F_d and F_c factors (as defined in Method 19) according to the procedure in Method 19 Section 5.2.3. Then calculate the F_o factor as follows:

$$F_o = \frac{0.209\ F_d}{F_c}$$

Eq. 3-4

Fuel type	F_o range
Coal:	
Anthracite and lignite	1.016–1.130
Bituminous	1.083–1.230
Oil:	
Distillate	1.260–1.413
Residual	1.210–1.370
Gas:	
Natural	1.600–1.836
Propane	1.434–1.586
Butane	1.405–1.553
Wood	1.000–1.120
Wood bark	1.003–1.130

Calculated F_o values beyond the acceptable ranges shown in this table should be investigated before accepting the test results. For example, the strength of the solutions in the gas analyzer and the analyzing technique should be checked by sampling and analyzing a known concentration, such as air; the fuel factor should be reviewed and verified. An acceptability range of ±12 percent is appropriate for the F_o factor of mixed fuels with variable fuel ratios. The level of the emission rate relative to the compliance level should be considered in determining if a retest is appropriate, i.e., if the measured emissions are much lower or much greater than the compliance limit, repetition of the test would not significantly change the compliance status of the source and would be unnecessarily time-consuming and costly.

5. *Leak-Check Procedure for Orsat Analyzers*

Moving an Orsat analyzer frequently causes it to leak. Therefore, an Orsat analyzer should be throughly leak-checked on site before the flue gas sample is introduced into it. The procedure for leak-checking an Orsat analyzer is:

5.1.1 Bring the liquid level in each pipette up to the reference mark on the capillary tubing and then close the pipette stopcock.

5.1.2 Raise the leveling bulb sufficiently to bring the confining liquid meniscus onto the graduated portion of the burette and then close the manifold stopcock.

5.1.3 Record the meniscus position.

5.1.4 Observe the menicus in the burette and the liquid level in the pipette for movement over the next 4 minutes.

5.1.5 For the Orsat analyzer to pass the leak-check, two conditions must be met.

5.1.5.1 The liquid level in each pipette must not fall below the bottom of the capillary tubing during this 4-minute interval.

5.1.5.2 The meniscus in the burette must not change by more than 0.2 ml during this 4-minute interval.

5.1.6 If the analyzer fails the leak-check procedure, all rubber connections and stopcocks should be checked until the cause of the leak is identified. Leaking stopcocks must be disassembled, cleaned, and regreased. Leaking rubber connections must be replaced. After the analyzer is reassembled, the leak-check procedure must be repeated.

6. *Calculations*

6.1 Nomenclature.

M_d = Dry molecular weight, g/g-mole (lb/lb-mole).
%EA = Percent excess air.
$\%CO_2$ = Percent CO_2 by volume (dry basis).
$\%O_2$ = Percent O_2 by volume (dry basis).
%CO = Percent CO by volume (dry basis).
$\%N_2$ = Percent N_2 by volume (dry basis).
0.264 = Ratio of O_2 to N_2 in air, v/v.
0.280 = Molecular weight of N_2 or CO, divided by 100.
0.320 = Molecular weight of O_2 divided by 100.
0.440 = Molecular weight of CO_2 divided by 100.

6.2 Percent Excess Air. Calculate the percent excess air (if applicable), by substituting the appropriate values of percent O_2, CO, and N_2 (obtained from Section 4.1.3 or 4.2.4) into Equation 3-1.

$$\%\ EA = \frac{\%O_2 - 0.5\%\ CO}{0.264\%\ N_2 - (\%O_2 - 0.5\ \%\ CO)} \times 100$$

Equation 3-1

NOTE: The equation above assumes that ambient air is used as the source of O_2 and that the fuel does not contain appreciable amounts of N_2 (as do coke oven or blast furnace gases). For those cases when appreciable amounts of N_2 are present (coal, oil, and natural gas do not contain appreciable amounts of N_2) or when oxygen enrichment is used, alternate methods, subject to approval of the Administrator, are required.

6.3 Dry Molecular Weight. Use Equation 3-2 to calculate the dry molecular weight of the stack gas

$$M_d = 0.440(\%CO_2) + 0.320(\%O_2) + 0.280(\%N_2 + \%CO)$$

Equation 3-2

2.3.1 Dry Molecular Weight Determination. An Orsat analyzer or Fyrite type combustion gas analyzer may be used.

2.3.2 Emission Rate Correction Factor or Excess Air Determination. An Orsat analyzer must be used. For low CO_2 (less than 4.0 percent) or high O_2 (greater that 15.0 percent) concentrations, the measuring burette of the Orsat must have at least 0.1 percent subdivisions.

3. *Dry Molecular Weight Determination*

Any of the three sampling and analytical procedures described below may be used for determining the dry molecular weight.

3.1 Single-Point, Grab Sampling and Analytical Procedure.

3.1.1 The sampling point in the duct shall either be at the centroid of the cross section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

3.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. If and Orsat analyzer is used, it is recommended that the analyzer be leaked-checked by following the procedure in Section 5; however, the leak-check is optional.

3.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer and immediately analyze it for percent CO_2 and percent O_2. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO_2 and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.1.4 Repeat the sampling, analysis, and calculation procedures, until the dry molecular weights of any three grab samples differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (lb/lb-mole).

3.2 Single-Point, Integrated Sampling and Analytical Procedure.

3.2.1 The sampling point in the duct shall be located as specified in Section 3.1.1.

3.2.2 Leak-check (optional) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (optional) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum should remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

3.2.3 Sample at a constant rate. The sampling run should be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collection of at least 30 liters (1.00 ft^3) of sample gas is recommended; however, smaller volumes may be collected, if desired.

3.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. Within 8 hours after the sample is taken, analyze it for percent CO_2 and percent O_2 using either an Orsat analyzer or a Fyrite-type combustion gas analyzer. If an Orsat analyzer is used, it is recommended that the Orsat leak-check described in Section 5 be performed before this determination; however, the check is optional. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO_2 and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.2.5 Repeat the analysis and calculation procedures until the individual dry molecular weights for any three analyses differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (0.1 lb/lb-mole).

3.3 Multi-Point, Integrated Sampling and Analytical Procedure.

3.3.1 Unless otherwise specified by the Administrator, a minimum of eight traverse points shall be used for circular stacks having diameters less than 0.61 m (24 in.), a minimum of nine shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in.), and a minimum of twelve traverse points shall be used for all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to approval of the Administrator.

3.3.2 Follow the procedures outlined in sections 3.2.2 throught 3.2.5, except for the following: traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

4. *Emission Rate Correction Factor or Excess Air Determination*

NOTE: A Fyrite-type combustion gas analyzer is not acceptable for excess air or emission rate correction factor determination, unless approved by the Administrator. If both percent CO_2 and percent O_2 are measured, the analytical results of any of the three procedures given below may also be used for calculating the dry molecular weight.

Each of the three procedures below shall be used only when specified in an applicable subpart of the standards. The use of these procedures for other purposes must have specific prior approval of the Administrator.

4.1 Single-Point, Grab Sampling and Analytical Procedure.

4.1.1 The sampling point in the duct shall either be at the centroid of the cross-section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

4.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. Leak-check the Orsat analyzer according to the procedure described in Section 5. This leak-check is mandatory.

FIGURE 3-3—SAMPLING RATE DATA

Time	Traverse pt.	Q lpm	% dev.*
Average.....			

*% Dev. = $(Q - Q_{avg})/Q_{avg} \times 100$ (Must be <10%)

4.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer. For emission rate correction factor determination, immediately analyze the sample, as outlined in Sections 4.1.4 and 4.1.5, for percent CO_2 or percent O_2. If excess air is desired, proceed as follows: (1) immediately analyze the sample, as in Sections 4.1.4 and 4.1.5, for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; and (3) calculate percent excess air as outlined in Section 6.2.

4.1.4 To insure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.1.5 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis.

NOTE: Since this single-point, grab sampling and analytical procedure in normally conducted in conjunction with a single-point, grab sampling and analytical procedure for a pollutant, only one analysis is ordinarily conducted. Therefore, great care must be taken to obtain a valid sample and analysis. Although in most cases only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Section 4.4 be used to validate the analytical data.

4.2 Single-Point, Integrated Sampling and Analytical Procedure.

4.2.1 The sampling point in the duct shall be located as specified in Section 4.1.1.

4.2.2 Leak-check (mandatory) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (mandatory) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of a least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum shall remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

4.2.3 Sample at a constant rate, or as specified by the Administrator. The sampling run must be simultaneous with, and for the same total lengh of time as, the pollutant emission rate determination. Collect at least 30 liters (1.00 ft^3) of sample gas. Smaller volumes may be collected, subject to approval of the Administrator.

4.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. For emission rate correction factor determination, analyze the sample within 4 hours after it is taken for percent CO_2 or percent O_2 (as outlined in Sections 4.2.5 through 4.2.7). The Orsat analyzer must be leak-check (see Section 5) before the analysis. If excess air is desired, proceed as follows: (1) within 4 hours after the sample is taken, analyze it (as in Sections 4.2.5 through 4.2.7) for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; (3) calculate percent excess air, as outlined in Section 6.2.

METHOD 3—GAS ANALYSIS FOR CARBON DIOXIDE, OXYGEN, EXCESS AIR, AND DRY MOLECULAR WEIGHT

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted from a stack, by one of the following methods: (1) single-point, grab sampling; (2) single-point, integrated sampling; or (3) multi-point, integrated sampling. The gas sample is analyzed for percent carbon dioxide (CO_2), percent oxygen (O_2), and, if necessary, percent carbon monoxide (CO). If a dry molecular weight determination is to be made, either an Orsat or a Fyrite [1] analyzer may be used for the analysis; for excess air or emission rate correction factor determination, an Orsat analyzer must be used.

1.2 Applicability. This method is applicable for determining CO_2 and O_2 concentrations, excess air, and dry molecular weight of a sample from a gas stream of a fossil-fuel combustion process. The method may also be applicable to other processes where it has been determined that compounds other than CO_2, O_2, CO, and nitrogen (n_2) are not present in concentrations sufficient to affect the results.

Other methods, as well as modifications to the procedure described herein, are also applicable for some or all of the above determinations. Examples of specific methods and modifications include: (1) a multi-point sampling method using an Orsat analyzer to analyze individual grab samples obtained at each point; (2) a method using CO_2 or O_2 and stoichiometric calculations to determine dry molecular weight and excess air; (3) assigning a value of 30.0 for dry molecular weight, in lieu of actual measurements, for processes burning natural gas, coal, or oil. These methods and modifications may be used, but are subject to the approval of the Administrator, U.S. Environmental Protection Agency.

2. *Apparatus*

As an alternative to the sampling apparatus and systems described herein, other sampling systems (e.g., liquid displacement) may be used provided such systems are capable of obtaining a representative sample and maintaining a constant sampling rate, and are otherwise capable of yielding acceptable results. Use of such systems is subject to the approval of the Administrator.

2.1 Grab Sampling (Figure 3-1).

2.1.1 Probe. The probe should be made of stainless steel or borosilicate glass tubing and should be equipped with an in-stack or out-stack filter to remove particulate matter (a plug of glass wool is satisfactory for this purpose). Any other materials inert to O_2, CO_2, CO, and N_2 and resistant to temperature at sampling conditions may be used for the probe; examples of such material are aluminum, copper, quartz glass and Teflon.

2.1.2 Pump. A one-way squeeze bulb, or equivalent, is used to transport the gas sample to the analyzer.

2.2 Integrated Sampling (Figure 3-2).

2.2.1 Probe. A probe such as that described in Section 2.1.1 is suitable.

2.2.2 Condenser. An air-cooled or water-cooled condenser, or other condenser that will not remove O_2, CO_2, CO, and N_2, may be used to remove excess moisture which would interfere with the operation of the pump and flow meter.

2.2.3 Valve. A needle valve is used to adjust sample gas flow rate.

2.2.4 Pump. A leak-free, diaphragm-type pump, or equivalent, is used to transport sample gas to the flexible bag. Install a small surge tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

2.2.5 Rate Meter. The rotameter, or equivalent rate meter, used should be capable of measuring flow rate to within ±2 percent of the selected flow rate. A flow rate range of 500 to 1000 cm^3/min is suggested.

2.2.6 Flexible Bag. Any leak-free plastic (e.g., Tedlar, Mylar, Teflon) or plastic-coated aluminum (e.g., aluminized Mylar) bag, or equivalent, having a capacity consistent with the selected flow rate and time length of the test run, may be used. A capacity in the range of 55 to 90 liters is suggested.

To leak-check the bag, connect it to a water manometer and pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O). Allow to stand for 10 minutes. Any displacement in the water manometer indicates a leak. An alternative leak-check method is to pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O) and allow to stand overnight. A deflated bag indicates a leak.

2.2.7 Pressure Gauge. A water-filled U-tube manometer, or equivalent, of about 28 cm (12 in.) is used for the flexible bag leak-check.

2.2.8 Vacuum Gauge. A mercury manometer, or equivalent, of at least 760 mm Hg (30 in. Hg) is used for the sampling train leak-check.

2.3 Analysis. For Orsat and Fyrite analyzer maintenance and operation procedures, follow the instructions recommended by the manufacturer, unless otherwise specified herein.

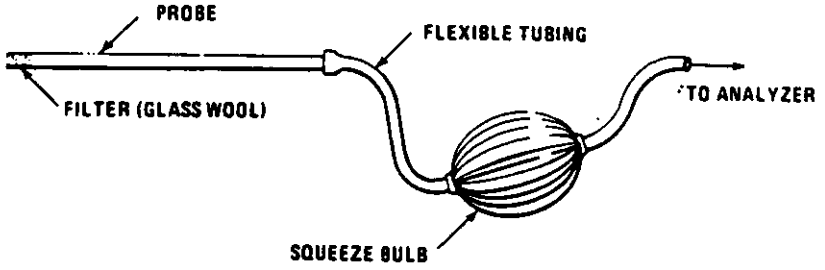


Figure 3-1. Grab-sampling train.

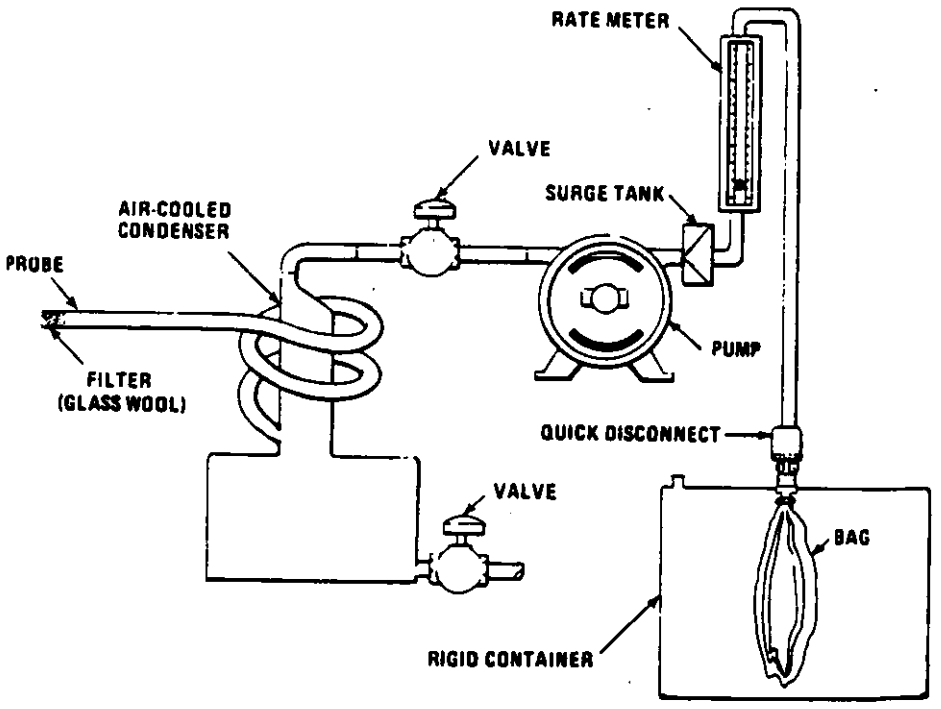


Figure 3-2. Integrated gas-sampling train.

[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

15. Smith, Marvin L. Velocity Calibration of EPA Type Source Sampling Probe. United Technologies Corporation, Pratt and Whitney Aircraft Division, East Hartford, Conn. 1975.

16. Vollaro, R. F. Recommended Procedure for Sample Traverses in Ducts Smaller than 12 Inches in Diameter. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park N.C. November 1976.

17. Ower, E. and R. C. Pankhurst. The Measurement of Air Flow, 4th Ed., London, Pergamon Press. 1966.

18. Vollaro, R. F. A Survey of Commercially Available Instrumentation for the Measurement of Low-Range Gas Velocities. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park N.C. November 1976. (Unpublished Paper)

19. Gnyp, A. W., C. C. St. Pierre, D. S. Smith, D. Mozzon, and J. Steiner. An Experimental Investigation of the Effect of Pitot Tube-Sampling Probe Configurations on the Magnitude of the S Type Pitot Tube Coefficient for Commercially Available Source Sampling Probes. Prepared by the University of Windsor for the Ministry of the Environment, Toronto, Canada. Februarv 1975.

Figure 2-10. Projected-area models for typical pitot tube assemblies.

4.1.6 Field Use and Recalibration.

4.1.6.1 Field Use.

4.1.6.1.1 When a Type S pitot tube (isolated tube or assembly) is used in the field, the appropriate coefficient value (whether assigned or obtained by calibration) shall be used to perform velocity calculations. For calibrated Type S pitot tubes, the A side coefficient shall be used when the A side of the tube faces the flow, and the B side coefficient shall be used when the B side faces the flow; alternatively, the arithmetic average of the A and B side coefficient values may be used, irrespective of which side faces the flow.

4.1.6.1.2 When a probe assembly is used to sample a small duct (12 to 36 in. in diameter), the probe sheath sometimes blocks a significant part of the duct cross-section, causing a reduction in the effective value of $C_{p(s)}$. Consult Citation 9 in Section 6 for details. Conventional pitot-sampling probe assemblies are not recommended for use in ducts having inside diameters smaller than 12 inches (Citation 16 in Section 6).

4.1.6.2 Recalibration.

4.1.6.2.1 Isolated Pitot Tubes. After each field use, the pitot tube shall be carefully reexamined in top, side, and end views. If the pitot face openings are still aligned within the specifications illustrated in Figure 2-2 or 2-3, it can be assumed that the baseline coefficient of the pitot tube has not changed. If, however, the tube has been damanged to the extent that it no longer meets the specifications of Figure 2-2 or 2-3, the damage shall either be repaired to restore proper alignment of the face openings or the tube shall be discarded.

4.1.6.2.2 Pitot Tube Assemblies. After each field use, check the face opening alignment of the pitot tube, as in Section 4.1.6.2.1; also, remeasure the intercomponent spacings of the assembly. If the intercomponent spacings have not changed and the face opening alignment is acceptable, it can be assumed that the coefficient of the assembly has not changed. If the face opening alignment is no longer within the specifications of Figures 2-2 or 2-3, either repair the damage or replace the pitot tube (calibrating the new assembly, if necessary). If the intercomponent spacings have changed, restore the original spacings or recalibrate the assembly.

4.2 Standard pitot tube (if applicable). If a standard pitot tube is used for the velocity traverse, the tube shall be constructed according to the criteria of Section 2.7 and shall be assigned a baseline coefficient value of 0.99. If the standard pitot tube is used as part of an assembly, the tube shall be in an interference-free arrangement (subject to the approval of the Administrator).

4.3 Temperature Gauges. After each field use, calibrate dial thermometers, liquid-filled bulb thermometers, thermocouple-potentiometer systems, and other gauges at a temperature within 10 percent of the average absolute stack temperature. For temperatures up to 405° C (761° F), use an ASTM mercury-in-glass reference thermometer, or equivalent, as a reference; alternatively, either a reference thermocouple and potentiometer (calibrated by NBS) or thermometric fixed points, e.g., ice bath and boiling water (corrected for barometric pressure) may be used. For temperatures above 405° C (761° F), use an NBS-calibrated reference thermocouple-potentiometer system or an alternate reference, subject to the approval of the Administrator.

If, during calibration, the absolute temperatures measured with the gauge being calibrated and the reference gauge agree within 1.5 percent, the temperature data taken in the field shall be considered valid. Otherwise, the pollutant emission test shall either be considered invalid or adjustments (if appropriate) of the test results shall be made, subject to the approval of the Administrator.

4.4 Barometer. Calibrate the barometer used against a mercury barometer.

5. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

5.1 Nomenclature.

A = Cross-sectional area of stack, m^2 (ft^2).

B_{ws} = Water vapor in the gas stream (from Method 5 or Reference Method 4), proportion by volume.

C_p = Pitot tube coefficient, dimensionless.

K_p = Pitot tube constant,

$$34.97 \frac{m}{sec}\left[\frac{(g/g\text{-mole})(mm\ Hg)}{(°K)(mm\ H_2O)}\right]^{1/2}$$

for the metric system and

$$85.49 \frac{ft}{sec}\left[\frac{(lb/lb\text{-mole})(in.\ Hg)}{(°R)(in.\ H_2O)}\right]^{1/2}$$

for the English system.

M_d = Molecular weight of stack gas, dry basis (see Section 3.6) g/g-mole (lb/lb-mole).

M_s = Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole).

$= M_d(1-B_{ws}) + 18.0\ B_{ws}$

Equation 2-5

P_{bar} = Barometric pressure at measurement site, mm Hg (in. Hg).

P_g = Stack static pressure, mm Hg (in. Hg).

P_s = Absolute stack gas pressure, mm Hg (in. Hg).

$= P_{bar} + P_g$

Equation 2-6

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

Q_{sd} = Dry volumetric stack gas flow rate corrected to standard conditions, dscm/hr (dscf/hr).

t_s = Stack temperature, °C (°F).

T_s = Absolute stack temperature, °K, (°R).

$= 273 + t_s$ for metric

Equation 2-7

$= 460 + t_s$ for English

Equation 2-8

T_{std} = Standard absolute temperature, 293 °K (528° R)

v_s = Average stack gas velocity, m/sec (ft/sec).

Δ_p = Velocity head of stack gas, mm H_2O (in. H_2O).

3,600 = Conversion factor, sec/hr.

18.0 = Molecular weight of water, g/g-mole (lb/lb-mole).

5.2 Average stack gas velocity.

$$v_s = K_p C_p (\sqrt{\Delta p})_{ave} \sqrt{\frac{T_{s(ave)}}{P_s M_s}}$$

Equation 2-9

5.3 Average stack gas dry volumetric flow rate.

$$Q_{sd} = 3{,}600(1-B_{ws}) v_s A \left(\frac{T_{std}}{T_{s\ (ave)}}\right)\left(\frac{P_s}{P_{std}}\right)$$

Equation 2-10

6. *Bibliography*

1. Mark, L. S. Mechanical Engineers' Handbook. New York, McGraw-Hill Book Co., Inc. 1951.

2. Perry, J. H. Chemical Engineers' Handbook. New York. McGraw-Hill Book Co., Inc. 1960.

3. Shigehara, R. T., W. F. Todd, and W. S. Smith. Significance of Errors in Stack Sampling Measurements. U.S. Environmental Protection Agency, Research Triangle Park, N.C. (Presented at the Annual Meeting of the Air Pollution Control Association, St. Louis, Mo., June 14-19, 1970.)

4. Standard Method for Sampling Stacks for Particulate Matter. In: 1971 Book of ASTM Standards, Part 23. Philadelphia, Pa. 1971. ASTM Designation D-2928-71.

5. Vennard, J. K. Elementary Fluid Mechanics. New York. John Wiley and Sons, Inc. 1947.

6. Fluid Meters—Their Theory and Application. American Society of Mechanical Engineers, New York, N.Y. 1959.

7. ASHRAE Handbook of Fundamentals. 1972. p. 208.

8. Annual Book of ASTM Standards, Part 26. 1974. p. 648.

9. Vollaro, R. F. Guidelines for Type S Pitot Tube Calibration. U.S. Environmental Protection Agency. Research Triangle Park, N.C. (Presented at 1st Annual Meeting, Source Evaluation Society, Dayton, Ohio, September 18, 1975.)

10. Vollaro, R. F. A Type S Pitot Tube Calibration Study. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. July 1974.

11. Vollaro, R. F. The Effects of Impact Opening Misalignment on the Value of the Type S Pitot Tube Coefficient. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. October 1976.

12. Vollaro, R. F. Establishment of a Basline Coefficient Value for Properly Constructed Type S Pitot Tubes. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park N.C. November 1976.

13. Vollaro, R. F. An Evaluation of Single-Velocity Calibration Technique as a Means of Determining Type S Pitot Tubes Coefficient. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park N.C. August 1975.

14. Vollaro, R. F. The Use of Type S Pitot Tubes for the Measurement of Low Velocities. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park N.C. November 1976.

$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$$

Equation 2-2

where:

$C_{p(s)}$ = Type S pitot tube coefficient

$C_{p(std)}$ = Standard pitot tube coefficient; use 0.99 if the coefficient is unknown and the tube is designed according to the criteria of Sections 2.7.1 to 2.7.5 of this method.

Δp_{std} = Velocity head measured by the standard pitot tube, cm H_2O (in. H_2O)

Δp_s = Velocity head measured by the Type S pitot tube, cm H_2O (in H_2O)

4.1.4.2 Calculate C_p (side A), the mean A-side coefficient, and C_p (side B), the mean B-side coefficient; calculate the difference between these two average values.

4.1.4.3 Calculate the deviation of each of the three A-side values of $C_{p(s)}$ from C_p (side A), and the deviation of each B-side value of $C_{p(s)}$ from C_p (side B). Use the following equation:

$$\text{Deviation} = C_{p(s)} - \overline{C}_p(\text{A or B})$$

Equation 2-3

4.1.4.4 Calculate δ, the average deviation from the mean, for both the A and B sides of the pitot tube. Use the following equation:

$$\sigma\ (\text{side A or B}) = \frac{\sum_{1}^{3} |C_{p(s)} - \overline{C}_p(A \text{ or } B)|}{3}$$

Equation 2-4

4.1.4.5 Use the Type S pitot tube only if the values of δ (side A) and δ (side B) are less than or equal to 0.01 and if the absolute value of the difference between C_p (A) and C_p (B) is 0.01 or less.

4.1.5 Special considerations.

4.1.5.1 Selection of calibration point.

4.1.5.1.1 When an isolated Type S pitot tube is calibrated, select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The Type S pitot coefficients so obtained, i.e., C_p (side A) and C_p (side B), will be valid, so long as either: (1) the isolated pitot tube is used; or (2) the pitot tube is used with other components (nozzle, thermocouple, sample probe) in an arrangement that is free from aerodynamic interference effects (see Figures 2-6 through 2-8).

4.1.5.1.2 For Type S pitot tube-thermocouple combinations (without sample probe), select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The coefficients so obtained will be valid so long as the pitot tube-thermocouple combination is used by itself or with other components in an interference-free arrangement (Figures 2-6, and 2-8).

4.1.5.1.3 For assemblies with sample probes, the calibration point should be located at or near the center of the duct; however, insertion of a probe sheath into a small duct may cause significant cross-sectional area blockage and yield incorrect coefficient values (Citation 9 in Section 6). Therefore, to minimize the blockage effect, the calibration point may be a few inches off-center if necessary. The actual blockage effect will be negligible when the theoretical blockage, as determined by a projected-area model of the probe sheath, is 2 percent or less of the duct cross-sectional area for assemblies without external sheaths (Figure 2-10a), and 3 percent or less for assemblies with external sheaths (Figure 2-10b).

4.1.5.2 For those probe assemblies in which pitot tube-nozzle interference is a factor (i.e., those in which the pitot-nozzle separation distance fails to meet the specification illustrated in Figure 2-6a), the value of $C_{p(s)}$ depends upon the amount of free-space between the tube and nozzle, and therefore is a function of nozzle size. In these instances, separate calibrations shall be performed with each of the commonly used nozzle sizes in place. Note that the single-velocity calibration technique is acceptable for this purpose, even though the larger nozzle sizes (>0.635 cm or ¼ in.) are not ordinarily used for isokinetic sampling at velocities around 915 m/min (3,000 ft/min), which is the calibration velocity; note also that it is not necessary to draw an isokinetic sample during calibration (see Citation 19 in Section 6).

4.1.5.3 For a probe assembly constructed such that its pitot tube is always used in the same orientation, only one side of the pitot tube need be calibrated (the side which will face the flow). The pitot tube must still meet the alignment specifications of Figure 2-2 or 2-3, however, and must have an average deviation (δ) value of 0.01 or less (see Section 4.1.4.4).

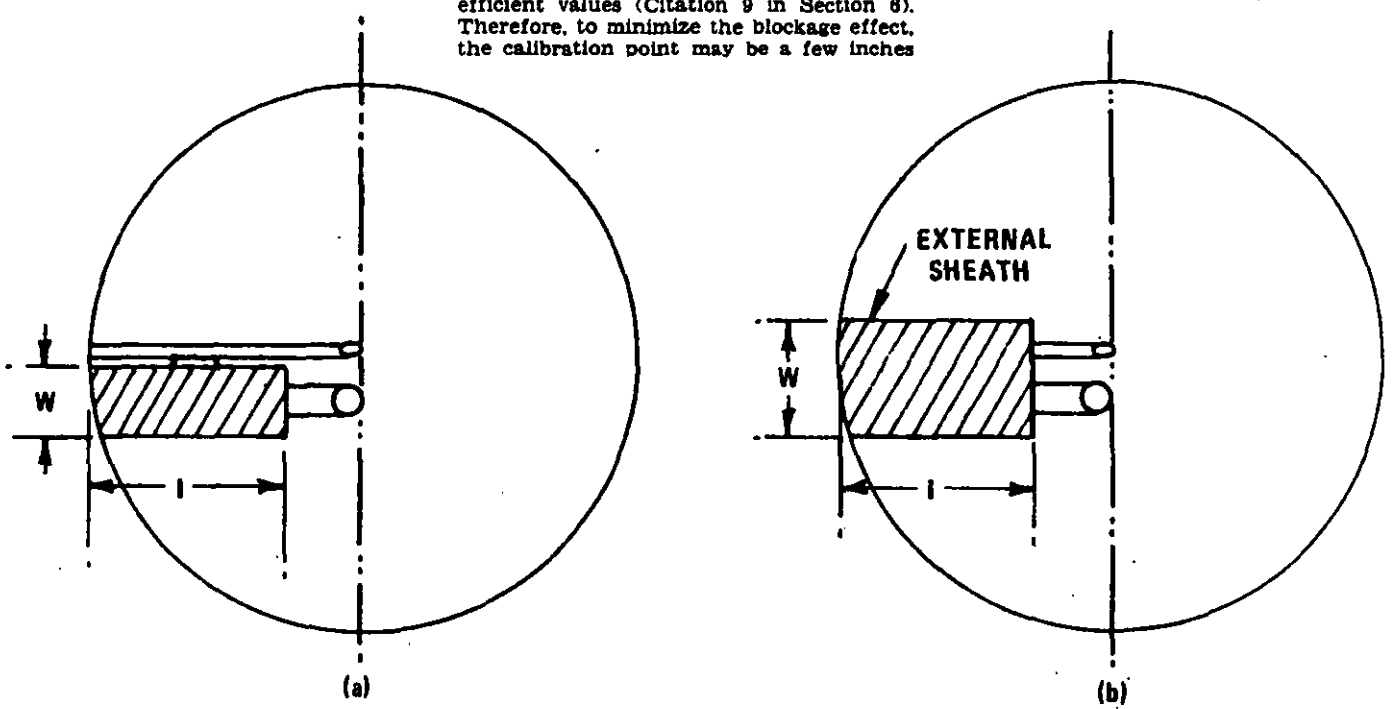


Figure 2-10. Projected-area models for typical pitot tube assemblies.

4.1.2.1 The flowing gas stream must be confined to a duct of definite cross-sectional area, either circular or rectangular. For circular cross-sections, the minimum duct diameter shall be 30.5 cm (12 in.); for rectangular cross-sections, the width (shorter side) shall be at least 25.4 cm (10 in.).

4.1.2.2 The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross-section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters:

$$D = \frac{2LW}{(L+W)}$$

Equation 2-1

where:
D = Equivalent diameter
L = Length
W = Width

To ensure the presence of stable, fully developed flow patterns at the calibration site, or "test section," the site must be located at least eight diameters downstream and two diameters upstream from the nearest disturbances.

NOTE: The eight- and two-diameter criteria are not absolute; other test section locations may be used (subject to approval of the Administrator), provided that the flow at the test site is stable and demonstrably parallel to the duct axis.

4.1.2.3 The flow system shall have the capacity to generate a test-section velocity around 915 m/min (3,000 ft/min). This velocity must be constant with time to guarantee steady flow during calibration. Note that Type S pitot tube coefficients obtained by single-velocity calibration at 915 m/min (3,000 ft/min) will generally be valid to within ±3 percent for the measurement of velocities above 305 m/min (1,000 ft/min) and to within ±5 to 6 percent for the measurement of velocities between 180 and 305 m/min (600 and 1,000 ft/min). If a more precise correlation between C_p and velocity is desired, the flow system shall have the capacity to generate at least four distinct, time-invariant test-section velocities covering the velocity range from 180 to 1,525 m/min (600 to 5,000 ft/min), and calibration data shall be taken at regular velocity intervals over this range (see Citations 9 and 14 in Section 6 for details).

4.1.2.4 Two entry ports, one each for the standard and Type S pitot tubes, shall be cut in the test section; the standard pitot entry port shall be located slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. To facilitate alignment of the pitot tubes during calibration, it is advisable that the test section be constructed of plexiglas or some other transparent material.

4.1.3 Calibration Procedure. Note that this procedure is a general one and must not be used without first referring to the special considerations presented in Section 4.1.5. Note also that this procedure applies only to single-velocity calibration. To obtain calibration data for the A and B sides of the Type S pitot tube, proceed as follows:

4.1.3.1 Make sure that the manometer is properly filled and that the oil is free from contamination and is of the proper density. Inspect and leak-check all pitot lines; repair or replace if necessary.

PITOT TUBE IDENTIFICATION NUMBER: _____ DATE: _____

CALIBRATED BY: _____

"A" SIDE CALIBRATION				
RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_{p(A)}$
1				
2				
3				
		$\bar{C}_p$ (SIDE A)		

"B" SIDE CALIBRATION				
RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_{p(B)}$
1				
2				
3				
		$\bar{C}_p$ (SIDE B)		

$$\text{AVERAGE DEVIATION} = \sigma\,(\text{A OR B}) = \frac{\sum_{1}^{3} \left| C_{p(s)} - \bar{C}_{p(\text{A OR B})} \right|}{3} \quad \leftarrow \text{MUST BE} \leq 0.01$$

$$\left| \bar{C}_p\,(\text{SIDE A}) - \bar{C}_p\,(\text{SIDE B}) \right| \leftarrow \text{MUST BE} \leq 0.01$$

Figure 2-9. Pitot tube calibration data.

4.1.3.2 Level and zero the manometer. Turn on the fan and allow the flow to stabilize. Seal the Type S entry port.

4.1.3.3 Ensure that the manometer is level and zeroed. Position the standard pitot tube at the calibration point (determined as outlined in Section 4.1.5.1), and align the tube so that its tip is pointed directly into the flow. Particular car should be taken in aligning the tube to avoid yaw and pitch angles. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.4 Read Δp_{std} and record its value in a data table similar to the one shown in Figure 2-9. Remove the standard pitot tube from the duct and disconnect it from the manometer. Seal the standard entry port.

4.1.3.5 Connect the Type S pitot tube to the manometer. Open the Type S entry port. Check the manometer level and zero. Insert and align the Type S pitot tube so that its A side impact opening is at the same point as was the standard pitot tube and is pointed directly into the flow. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.6 Read Δp_s and enter its value in the data table. Remove the Type S pitot tube from the duct and disconnect it from the manometer.

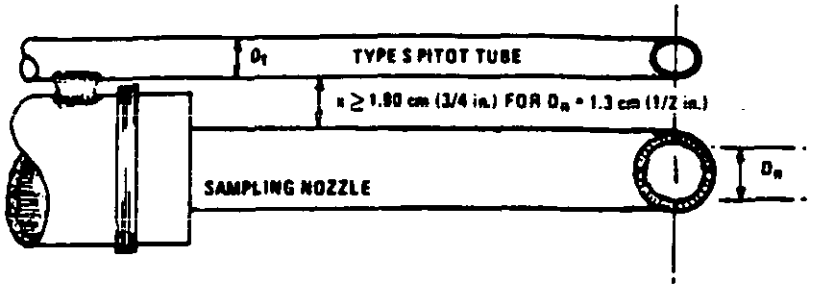
4.1.3.7 Repeat steps 4.1.3.3 through 4.1.3.6 above until three pairs of Δp readings have been obtained.

4.1.3.8 Repeat steps 4.1.3.3 through 4.1.3.7 above for the B side of the Type S pitot tube.

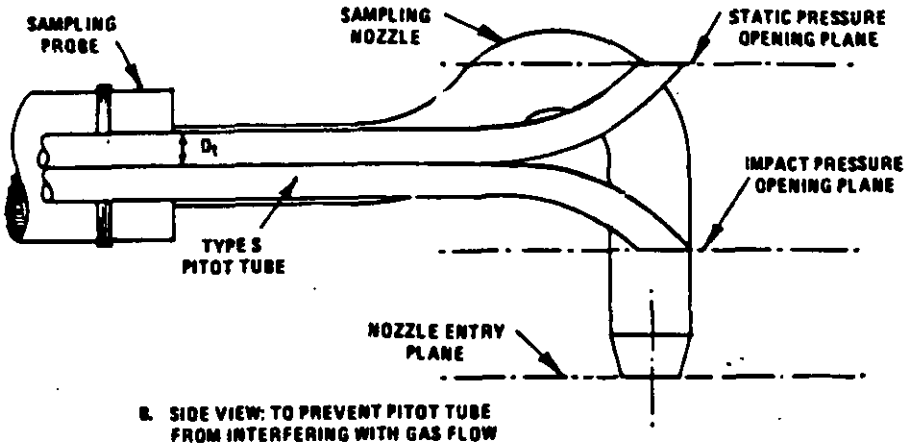
4.1.3.9 Perform calculations, as described in Section 4.1.4 below.

4.1.4 Calculations.

4.1.4.1 For each of the six pairs of Δp readings (i.e., three from side A and three from side B) obtained in Section 4.1.3 above, calculate the value of the Type S pitot tube coeffficient as follows:



A. BOTTOM VIEW: SHOWING MINIMUM PITOT-NOZZLE SEPARATION.



B. SIDE VIEW: TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.

4.1.1 Type S Pitot Tube Assemblies. During sample and velocity traverses, the isolated Type S pitot tube is not always used; in many instances, the pitot tube is used in combination with other source-sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly." The presence of other sampling components can sometimes affect the baseline value of the Type S pitot tube coefficient (Citation 9 in Section 6); therefore an assigned (or otherwise known) baseline coefficient value may or may not be valid for a given assembly. The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such that aerodynamic interference effects are eliminated. Figures 2-6 through 2-8 illustrate interference-free component arrangements for Type S pitot tubes having external tubing diameters between 0.48 and 0.95 cm (3/16 and 3/8 in.). Type S pitot tube assemblies that fail to meet any or all of the specifications of Figures 2-6 through 2-8 shall be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, and prior to calibration, the values of the intercomponent spacings (pitot-nozzle, pitot-thermocouple, pitot-probe sheath) shall be measured and recorded.

NOTE: Do not use any Type S pitot tube assembly which is constructed such that the impact pressure opening plane of the pitot tube is below the entry plane of the nozzle (see Figure 2-6b).

4.1.2 Calibration Setup. If the Type S pitot tube is to be calibrated, one leg of the tube shall be permanently marked A, and the other, B. Calibration shall be done in a flow system having the following essential design features:

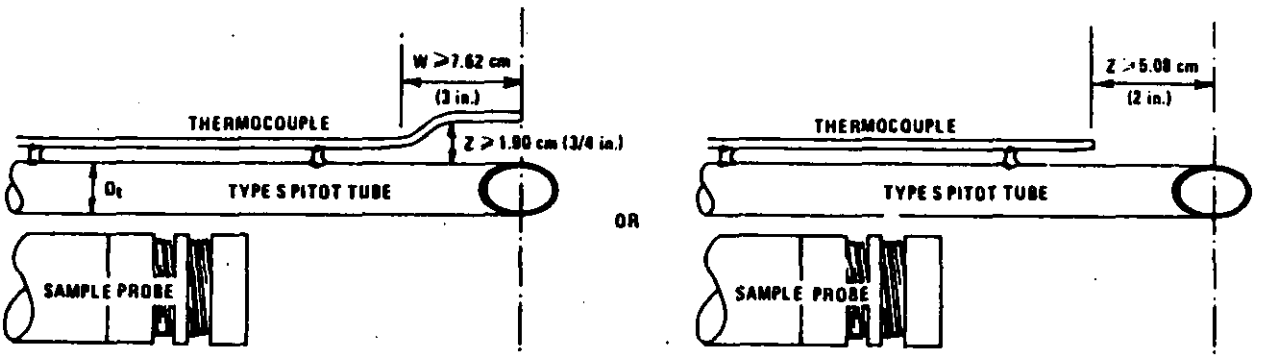


Figure 2-7. Proper thermocouple placement to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

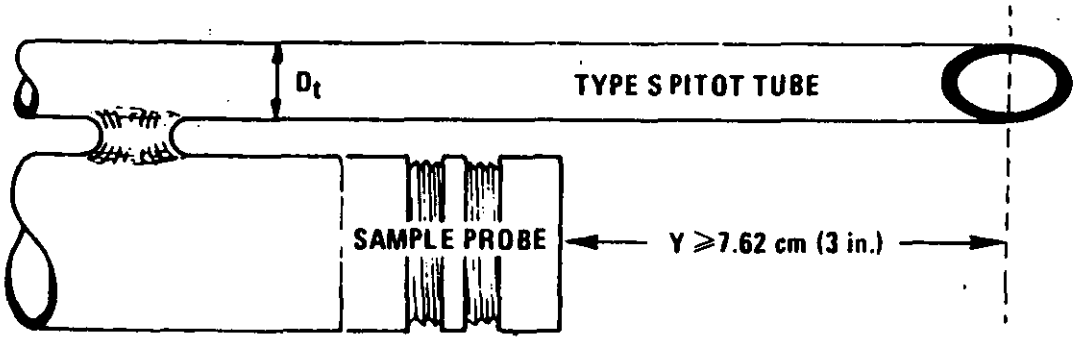


Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

PLANT ______________________

DATE ____________ RUN NO. ____________

STACK DIAMETER OR DIMENSIONS, m(in.) ____________

BAROMETRIC PRESSURE, mm Hg (in. Hg) ____________

CROSS SECTIONAL AREA, m^2(ft^2) ____________

OPERATORS ____________

PITOT TUBE I.D. NO. ____________

AVG. COEFFICIENT, C_p = ____________

LAST DATE CALIBRATED ____________

SCHEMATIC OF STACK CROSS SECTION

Traverse Pt. No.	Vel. Hd., Δp mm (in.) H_2O	Stack Temperature		P_g mm Hg (in.Hg)	$\sqrt{\Delta p}$
		t_s, °C (°F)	T_s, °K (°R)		
		Average			

Figure 2-5. Velocity traverse data.

3.6 Determine the stack gas dry molecular weight. For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use Method 3. For processes emitting essentially air, an analysis need not be conducted; use a dry molecular weight of 29.0. For other processes, other methods, subject to the approval of the Administrator, must be used.

3.7 Obtain the moisture content from Reference Method 4 (or equivalent) or from Method 5.

3.8 Determine the cross-sectional area of the stack or duct at the sampling location. Whenever possible, physically measure the stack dimensions rather than using blueprints.

4. *Calibration*

4.1 Type S Pitot Tube. Before its initial use, carefully examine the Type S pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in Figure 2-2 or 2-3. The pitot tube shall not be used if it fails to meet these alignment specifications.

After verifying the face opening alignment, measure and record the following dimensions of the pitot tube: (a) the external tubing diameter (dimension D_t, Figure 2-2b); and (b) the base-to-opening plane distances (dimensions P_A and P_B, Figure 2-2b). If D_t is between 0.48 and 0.95 cm (3/16 and 3/8 in.) and if P_A and P_B are equal and between 1.05 and 1.50 D_t, there are two possible options: (1) the pitot tube may be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, or (2) a baseline (isolated tube) coefficient value of 0.84 may be assigned to the pitot tube. Note, however, that if the pitot tube is part of an assembly, calibration may still be required, despite knowledge of the baseline coefficient value (see Section 4.1.1).

If D_t, P_A, and P_B are outside the specified limits, the pitot tube must be calibrated as outlined in 4.1.2 through 4.1.5 below.

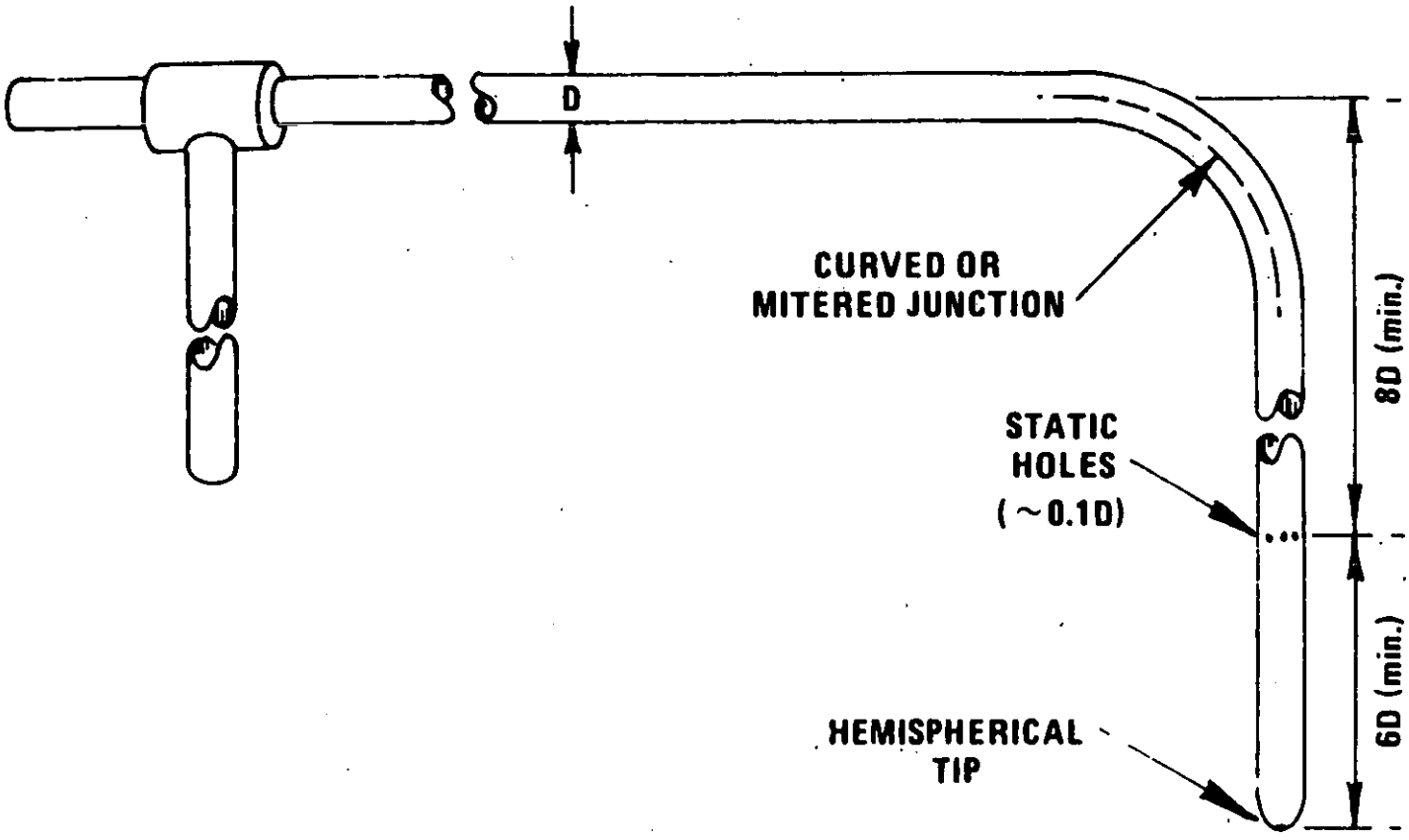


Figure 2-4. Standard pitot tube design specifications.

3. *Procedure*

3.1 Set up the apparatus as shown in Figure 2-1. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen Δp fluctuations. It is recommended, but not required, that a pretest leak-check be conducted, as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3 in.) H_2O velocity pressure registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3 in.) H_2O. Other leak-check procedures, subject to the approval of the Administrator may be used.

3.2 Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record all necessary data as shown in the example data sheet (Figure 2-5).

3.3 Measure the velocity head and temperature at the traverse points specified by Method 1. Ensure that the proper differential pressure gauge is being used for the range of Δp values encountered (see Section 2.2). If it is necessary to change to a more sensitive gauge, do so, and remeasure the Δp and temperature readings at each traverse point. Conduct a post-test leak-check (mandatory), as described in Section 3.1 above, to validate the traverse run.

3.4 Measure the static pressure in the stack. One reading is usually adequate.

3.5 Determine the atmospheric pressure.

taken, as above, for the last two back purges at which suitably high Δp readings are observed.

2.2 Differential Pressure Gauge. An inclined manometer or equivalent device is used. Most sampling trains are equipped with a 10-in. (water column) inclined-vertical manometer, having 0.01-in. H_2O divisions on the 0-to 1-in. inclined scale, and 0.1-in. H_2O divisions on the 1- to 10-in. vertical scale. This type of manometer (or other gauge of equivalent sensitivity) is satisfactory for the measurement of Δp values as low as 1.3 mm (0.05 in.) H_2O. However, a differential pressure gauge of greater sensitivity shall be used (subject to the approval of the Administrator), if any of the following is found to be true: (1) the arithmetic average of all Δp readings at the traverse points in the stack is less than 1.3 mm (0.05 in.) H_2O; (2) for traverses of 12 or more points, more than 10 percent of the individual Δp readings are below 1.3 mm (0.05 in.) H_2O; (3) for traverses of fewer than 12 points, more than one Δp reading is below 1.3 mm (0.05 in.) H_2O. Citation 18 in Section 6 describes commercially available instrumentation for the measurement of low-range gas velocities.

As an alternative to criteria (1) through (3) above, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$T = \frac{\sum_{i=1}^{n} \sqrt{\Delta p_i + K}}{\sum_{i=1}^{n} \sqrt{\Delta p_i}}$$

where:

Δp_i = Individual velocity head reading at a traverse point, mm H_2O (in. H_2O).

n = Total number of traverse points.

K = 0.13 mm H_2O when metric units are used and 0.005 in H_2O when English units are used.

If T is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gauge must be used.

NOTE: If differential pressure gauges other than inclined manometers are used (e.g., magnehelic gauges), their calibration must be checked after each test series. To check the calibration of a differential pressure gauge, compare Δp readings of the gauge with those of a gauge-oil manometer at a minimum of three points, approximately representing the range of Δp values in the stack. If, at each point, the values of Δp as read by the differential pressure gauge and gauge-oil manometer agree to within 5 percent, the differential pressure gauge shall be considered to be in proper calibration. Otherwise, the test series shall either be voided, or procedures to adjust the measured Δp values and final results shall be used subject to the approval of the Administrator.

2.3 Temperature Gauge. A thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge, capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature shall be used. The temperature gauge shall be attached to the pitot tube such that the sensor tip does not touch any metal; the gauge shall be in an interference-free arrangement with respect to the pitot tube face openings (see Figure 2-1 and also Figure 2-7 in Section 4). Alternate positions may be used if the pitot tube-temperature gauge system is calibrated according to the procedure of Section 4. Provided that a difference of not more than 1 percent in the average velocity measurement is introduced, the temperature gauge need not be attached to the pitot tube; this alternative is subject to the approval of the Administrator.

2.4 Pressure Probe and Gauge. A piezometer tube and mercury- or water-filled U-tube manometer capable of measuring stack pressure to within 2.5 mm (0.1 in.) Hg is used. The static tap of a standard type pitot tube or one leg of a Type S pitot tube with the face opening planes positioned parallel to the gas flow may also be used as the pressure probe.

2.5 Barometer. A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm (0.1 in.) Hg per 30-meter (100 foot) elevation increase or vice-versa for elevation decrease.

2.6 Gas Density Determination Equipment. Method 3 equipment, if needed (see Section 3.6), to determine the stack gas dry molecular weight, and Reference Method 4 or Method 5 equipment for moisture content determination; other methods may be used subject to approval of the Administrator.

2.7 Calibration Pilot Tube. When calibration of the Type S pitot tube is necessary (see Section 4), a standard pitot tube is used as a reference. The standard pitot tube shall, preferably, have a known coefficient, obtained either (1) directly from the National Bureau of Standards, Route 270, Quince Orchard Road, Gaithersburg, Maryland, or (2) by calibration against another standard pitot tube with an NBS-traceable coefficient. Alternatively, a standard pitot tube designed according to the criteria given in 2.7.1 through 2.7.5 below and illustrated in Figure 2-4 (see also Citations 7, 8, and 17 in Section 6) may be used. Pitot tubes designed according to these specifications will have baseline coefficients of about 0.99 ± 0.01.

2.7.1 Hemispherical (shown in Figure 2-4), ellipsoidal, or conical tip.

2.7.2 A minimum of six diameters straight run (based upon D, the external diameter of the tube) between the tip and the static pressure holes.

2.7.3 A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90 degree bend.

2.7.4 Static pressure holes of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration.

2.7.5 Ninety degree bend, with curved or mitered junction.

2.8 Differential Pressure Gauge for Type S Pitot Tube Calibration. An inclined manometer or equivalent is used. If the single-velocity calibration technique is employed (see Section 4.1.2.3), the calibration differential pressure gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in. H_2O). For multivelocity calibrations, the gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in H_2O) for Δp values between 1.3 and 25 mm H_2O (0.05 and 1.0 in. H_2O), and to the nearest 1.3 mm H_2O (0.05 in. H_2O) for Δp values above 25 mm H_2O (1.0 in. H_2O). A special, more sensitive gauge will be required to read Δp values below 1.3 mm H_2O [0.05 in. H_2O] (see Citation 18 in Section 6).

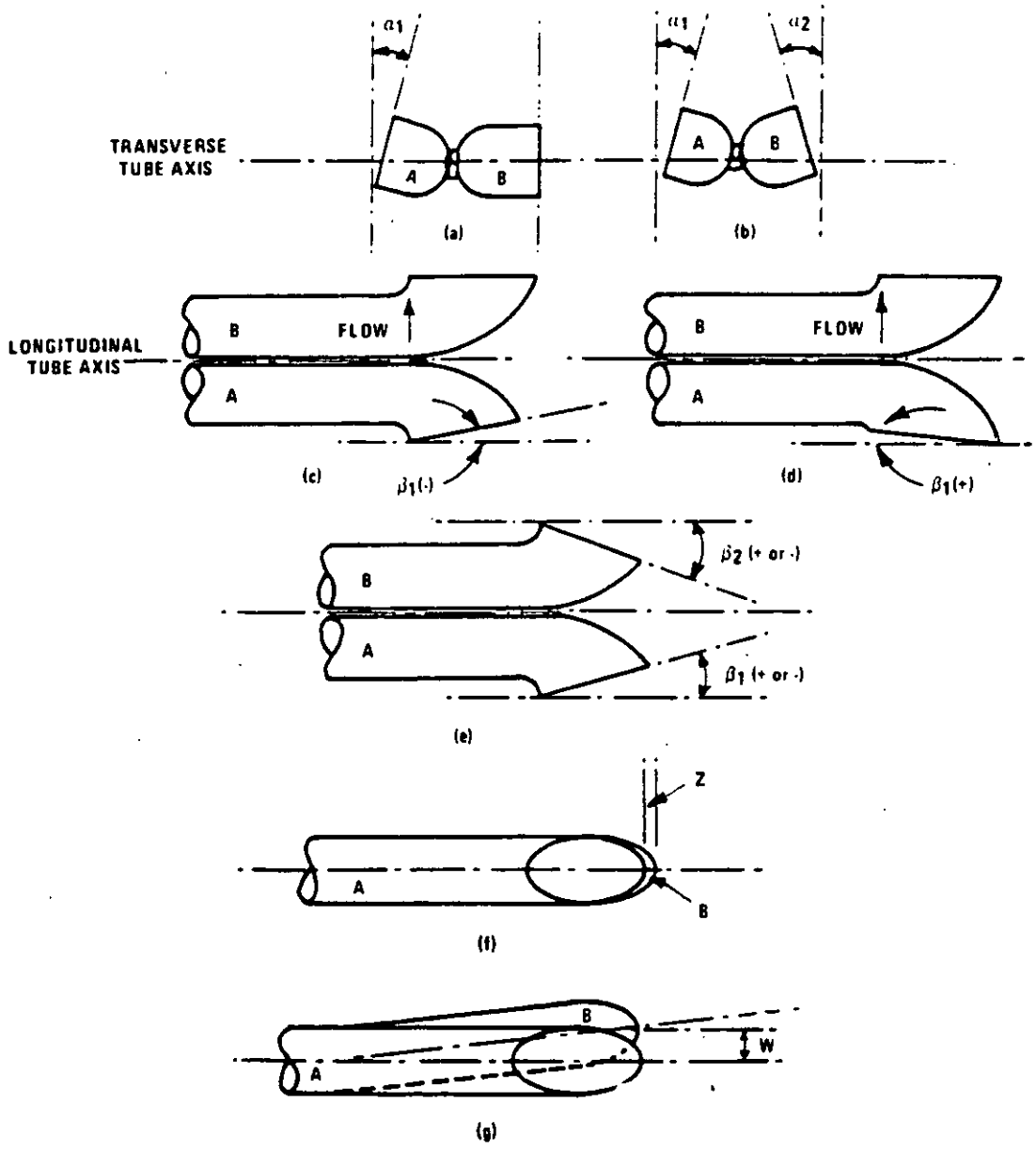


Figure 2-3. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect the baseline value of Cp(s) so long as $\alpha 1$ and $\alpha 2$ 10°, $\beta 1$ and $\beta 2$ 5°, z 0.32 cm (1/8 in.) and w 0.08 cm (1/32 in.) (citation 11 in Section 6).

A standard pitot tube may be used instead of a Type S, provided that it meets the specifications of Sections 2.7 and 4.2; note, however, that the static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden gas streams. Therefore, whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the pitot tube have not plugged up during the traverse period; this can be done by taking a velocity head (Δp) reading at the final traverse point, cleaning out the impact and static holes of the standard pitot tube by "back-purging" with pressurized air, and then taking another Δp reading. If the Δp readings made before and after the air purge are the same (±5 percent), the traverse is acceptable. Otherwise, reject the run. Note that if Δp at the final traverse point is unsuitably low, another point may be selected. If "back-purging" at regular intervals is part of the procedure, then comparative Δp readings shall be

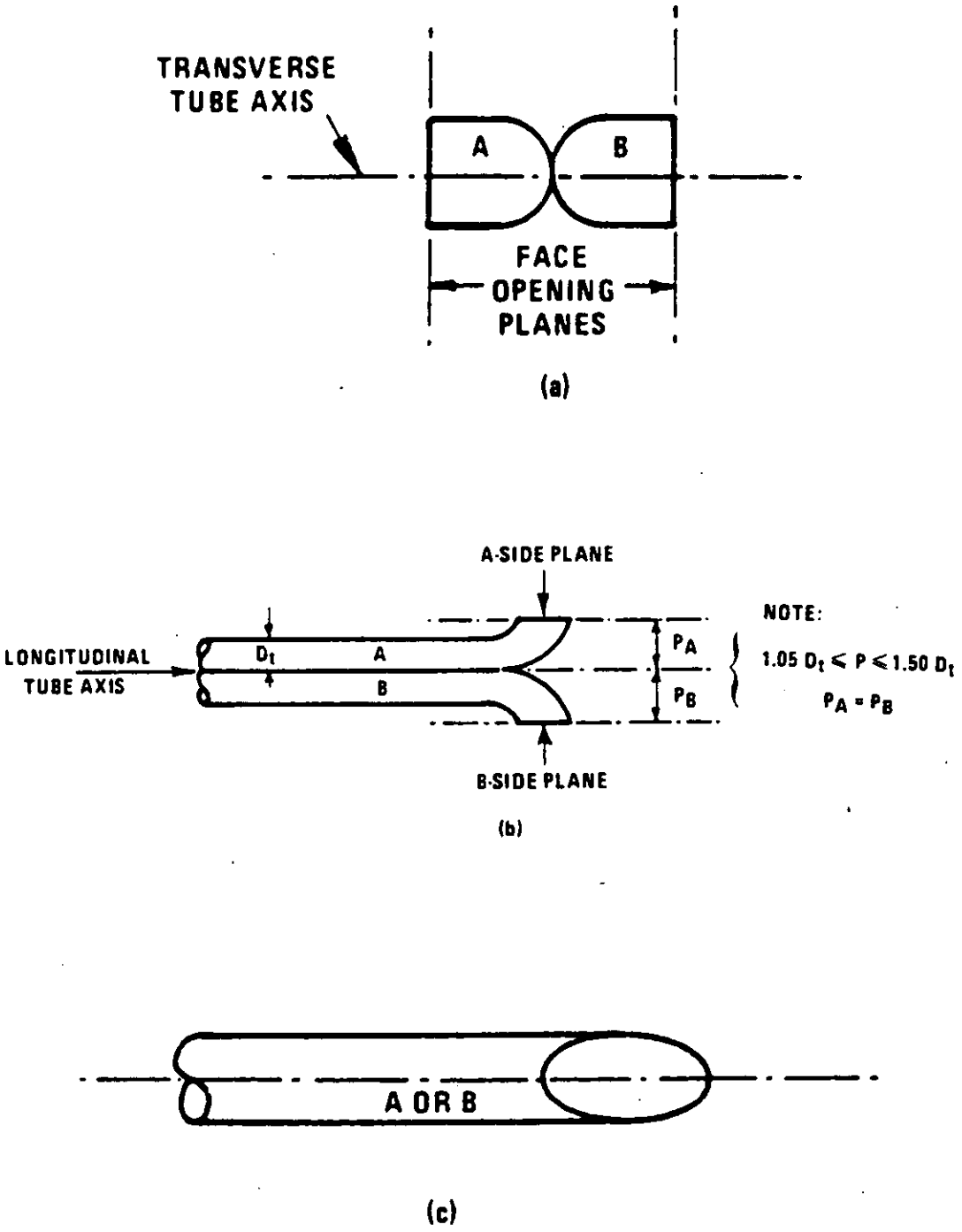


Figure 2-2. Properly constructed Type S pitot tube, shown in: (a) end view; face opening planes perpendicular to transverse axis; (b) top view; face opening planes parallel to longitudinal axis; (c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way.

METHOD 2—DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)

1. *Principle and Applicability*

1.1 Principle. The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube.

1.2 Applicability. This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow.

This procedure is not applicable at measurement sites which fail to meet the criteria of Method 1, Section 2.1. Also, the method cannot be used for direct measurement in cyclonic or swirling gas streams; Section 2.4 of Method 1 shows how to determine cyclonic or swirling flow conditions. When unacceptable conditions exist, alternative procedures, subject to the approval of the Administrator, U.S. Environmental Protection Agency, must be employed to make accurate flow rate determinations; examples of such alternative procedures are: (1) to install straightening vanes; (2) to calculate the total volumetric flow rate stoichiometrically, or (3) to move to another measurement site at which the flow is acceptable.

2. *Apparatus*

Specifications for the apparatus are given below. Any other apparatus that has been demonstrated (subject to approval of the Administrator) to be capable of meeting the specifications will be considered acceptable.

2.1 Type S Pitot Tube. The Type S pitot tube (Figure 2-1) shall be made of metal tubing (e.g. stainless steel). It is recommended that the external tubing diameter (dimension D_t, Figure 2-2b) be between 0.48 and 0.95 centimeters (3/16 and 3/8 inch). There shall be an equal distance from the base of each leg of the pitot tube to its face-opening plane (dimensions P_A and P_B, Figure 2-2b); it is recommended that this distance be between 1.05 and 1.50 times the external tubing diameter. The face openings of the pitot tube shall, preferably, be aligned as shown in Figure 2-2; however, slight misalignments of the openings are permissible (see Figure 2-3).

The Type S pitot tube shall have a known coefficient, determined as outlined in Section 4, an identification number shall be assigned to the pitot tube; this number shall be permanently marked or engraved on the body of the tube.

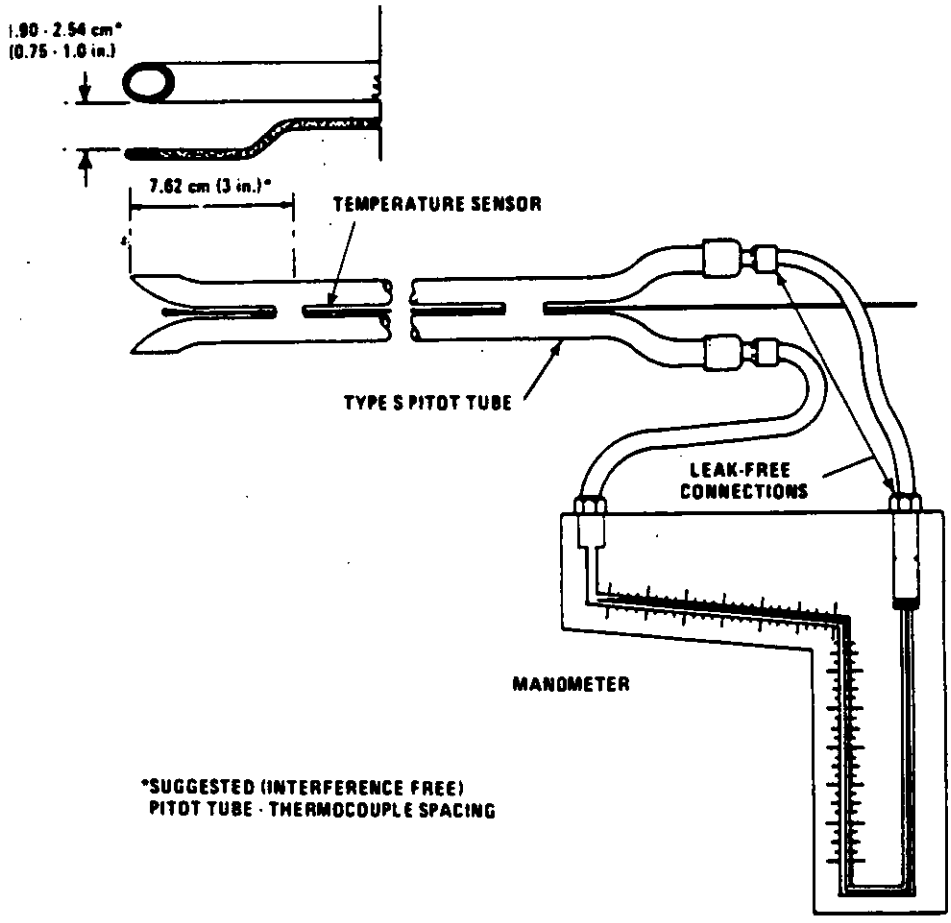


Figure 2-1. Type S pitot tube manometer assembly.

2.5.4.1 Calculate the resultant angle at each traverse point:

R_i = arc cosine [(cosine Y_i)(cosine P_i)] Eq. 1-2

Where:

R_i = Resultant angle at traverse point i, degree.

Y_i = Yaw angle at traverse point i, degree.

P_i = Pitch angle at traverse point i, degree.

2.5.4.2 Calculate the average resultant for the measurements:

$$\bar{R} = \frac{\Sigma R_i}{n} \qquad \text{Eq. 1-3}$$

where:

$\bar{R}$ = Average resultant angle, degree.

n = Total number of traverse points.

2.5.4.3 Calculate the standard deviations:

$$S_d = \sqrt{\frac{\sum_{i=1}^{n} (R_i - \bar{R})^2}{(n-1)}} \qquad \text{Eq. 1-4}$$

Where:

S_d = Standard deviation, degree.

2.5.5 The measurement location is acceptable if $\bar{R} < 20°$ and $S_d < 10°$.

2.5.6 Calibration. Use a flow system as described in Sections 4.1.2.1 and 4.1.2.2 of Method 2. In addition, the flow system shall have the capacity to generate two test-section velocities: one between 365 and 730 m/min (1200 and 2400 ft/min) and one between 730 and 1100 m/min (2400 and 3600 ft/min).

2.5.6.1 Cut two entry ports in the test section. The axes through the entry ports shall be perpendicular to each other and intersect in the centroid of the test section. The ports should be elongated slots parallel to the axis of the test section and of sufficient length to allow measurement of pitch angles while maintaining the pitot head position at the test-section centroid. To facilitate alignment of the directional probe during calibration, the test section should be constructed of plexiglass or some other transparent material. All calibration measurements should be made at the same point in the test section, preferably at the centroid of the test-section.

2.5.6.2 To ensure that the gas flow is parallel to the central axis of the test section, follow the procedure in Section 2.4 for cyclonic flow determination to measure the gas flow angles at the centroid of the test section from two test ports located 90° apart. The gas flow angle measured in each port must be ± 2° of 0°. Straightening vanes should be installed, if necessary, to meet this criterion.

2.5.6.3 Pitch Angle Calibration. Perform a calibration traverse according to the manufacturer's recommended protocol in 5° increments for angles from −60° to +60° at one velocity in each of the two ranges specified above. Average the pressure ratio values obtained for each angle in the two flow ranges, and plot a calibration curve with the average values of the pressure ratio (or other suitable measurement factor as recommended by the manufacturer) versus the pitch angle. Draw a smooth line through the data points. Plot also the data values for each traverse point. Determine the differences between the measured data values and the angle from the calibration curve at the same pressure ratio. The difference at each comparison must be within 2° for angles between 0° and 40° and within 3° for angles between 40° and 60°.

2.5.6.4 Yaw Angle Calibration. Mark the three-dimensional probe to allow the determination of the yaw position of the probe. This is usually a line extending the length of the probe and aligned with the impact opening. To determine the accuracy of measurements of the yaw angle, only the zero or null position need be calilbrated as follows. Place the directional probe in the test section, and rotate the probe until the zero position is found. With a protractor or other angle measuring device, measure the angle indicated by the yaw angle indicator on the three-demensional probe. This should be within 2° of 0°. Repeat this measurement for any other points along the length of the pitot where yaw angle measurements could be read in order to account for variations in the pitot markings used to indicate pitot head positions.

3. *Bibliography*

1. Determining Dust Concentration in a Gas Stream, ASME. Performance Test Code No. 27. New York, 1957.

2. Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District. Los Angeles, CA. November 1963.

3. Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co. Los Angeles, CA. Bulletin WP-50. 1968.

4. Standard Method for Sampling Stacks for Particulate Matter. In: 1971 Book of ASTM Standards, Part 23. ASTM Designation D-2928-71. Philadelphia, Pa. 1971.

5. Hanson, H. A., et al. Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow. USEPA, ORD, ESRL, Research Triangle Park, N.C. EPA-600/2-76-170, June 1976.

6. Entropy Environmentalists, Inc. Determination of the Optimum Number of Sampling Points: An Analysis of Method 1 Criteria. Environmental Protection Agency, Research Triangle Park, N.C. EPA Contract No. 68-01-3172, Task 7.

7. Hanson, H.A., R.J. Davini, J.K. Morgan, and A.A. Iversen. Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-600/2-76-170. June 1976. 350 p.

8. Brooks, E.F., and R.L. Williams. Flow and Gas Sampling Manual. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-600/2-76-203. July 1976. 93 p.

9. Entropy Environmentalists, Inc. Traverse Point Study. EPA Contract No. 68-02-3172. June 1977. 19 p.

10. Brown, J. and K. Yu. Test Report: Particulate Sampling Strategy in Circular Ducts. Emission Measurement Branch, Emission Standards and Engineering Division. U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711. July 31, 1980. 12 p.

11. Hawksley, P.G.W., S. Badzioch, and J.H. Blackett. Measurement of Solids in Flue Gases. Leatherhead, England, The British Coal Utilisation Research Association, 1961. p. 129-133.

12. Knapp, K.T. The Number of Sampling Points Needed for Representative Source Sampling. In: Proceedings of the Fourth National Conference on Energy and the Environment, Theodore, L., et al. (ed.). Dayton,

13. Smith, W.S. and D.J. Grove. A Proposed Extension of EPA Method 1 Criteria. "Pollution Engineering." *XV*(8):36-37. August 1983.

14. Gerhart, P.M. and M.J. Dorsey. Investigation of Field Test Procedures for Large Fans. University of Akron. Akron, Ohio. (EPRI Contract CS-1651). Final Report (RP-1649-5) December 1980.

15. Smith, W.S. and D.J. Grove. A New Look at Isokinetic Sampling—Theory and Applications. "Source Evaluation Society Newsletter." *VIII*(3):19-24. August 1983.

2.3.1.2 Stacks With Diameters Equal to or Less Than 0.61 m (24 in.). Follow the procedure in Section 2.3.1.1, noting only that any "adjusted" points should be relocated away from the stack walls to: (1) a distance of 1.3 cm (0.50 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger.

2.3.2 Rectangular Stacks. Determine the number of traverse points as explained in Sections 2.1 and 2.2 of this method. From Table 1-1, determine the grid configuration. Divide the stack cross-section into as many equal rectangular elemental areas as traverse points, and then locate a traverse point at the centroid of each equal area according to the example in Figure 1-4.

If the tester desires to use more than the minimum number of traverse points, expand the "minimum number of traverse points" matrix (see Table 1-1) by adding the extra traverse points along one or the other or both legs of the matrix; the final matrix need not be balanced. For example, if a 4x3 "minimum number of points; matrix were expanded to 36 points, the final matrix could be 9x4 or 12x3, and would not necessarily have to be 6x6. After constructing the final matrix, divide the stack cross-section into as many equal rectangular, elemental areas as traverse points, and locate a traverse point at the centroid of each equal area.

The situation of traverse points being too close to the stack walls is not expected to arise with rectangular stacks. If this problem should ever arise, the Administrator must be contacted for resolution of the matter.

2.4 Verification of Absence of Cyclonic Flow. In most stationary sources, the direction of stack gas flow is essentially parallel to the stack walls. However, cyclonic flow may exist (1) after such devices as cyclones and inertial demisters following venturi scrubbers, or (2) in stacks having tangential inlets or other duct configurations which tend to induce swirling; in these instances, the presence or absence of cyclonic flow at the sampling location must be determined. The following techniques are acceptable for this determination.

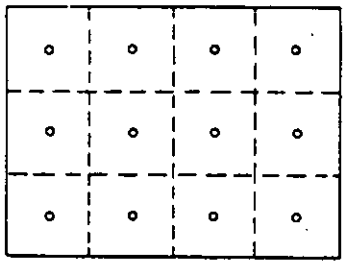


Figure 1-4. Example showing rectangular stack cross section divided into 12 equal areas, with a traverse point at centroid of each area.

Level and zero the manometer. Connect a Type S pitot tube to the manometer. Position the Type S pitot tube at each traverse point, in succession, so that the planes of the face openings of the pitot tube are perpendicular to the stack cross-sectional plane; when the Type S pitot tube is in this position, it is at "0° reference." Note the differential pressure (Δp) reading at each traverse point. If a null (zero) pitot reading is obtained at 0° reference at a given traverse point, an acceptable flow condition exists at that point. If the pitot reading is not zero at 0° reference, rotate the pitot tube (up to ±90° yaw angle), until a null reading is obtained. Carefully determine and record the value of the rotation angle (α) to the nearest degree. After the null technique has been applied at each traverse point, calculate the average of the absolute values of α; assign α values of 0° to those points for which no rotation was required, and include these in the overall average. If the average value of α is greater than 20°, the overall flow condition in the stack is unacceptable and alternative methodology, subject to the approval of the Administrator, must be used to perform accurate sample and velocity traverses.

The alternative procedure described in Section 2.5 may be used to determine the rotation angles in lieu of the procedure described above. The limit of acceptability for the average value of α would remain 20°.

2.5 Alternative Measurement Site Selection Procedure. This alternative applies to sources where measurement locations are less than 2 equivalent stack or duct diameters downstream or less than ½ duct diameter upstream from a flow disturbance. The alternative should be limited to ducts larger than 24 in. in diameter where blockage and wall effects are minimal. A directional flow-sensing probe is used to measure pitch and yaw angles of the gas flow at 40 or more traverse points; the resultant angle is calculated and compared with acceptable criteria for mean and standard deviation.

Note.—Both the pitch and yaw angles are measured from a line passing through the traverse point and parallel to the stack axis. The pitch angle is the angle of the gas flow component in the plane that INCLUDES the traverse line and is parallel to the stack axis. The yaw angle is the angle of the gas flow component in the plane PERPENDICULAR to the traverse line at the traverse point and is measured from the line passing through the traverse point and parallel to the stack axis.

2.5.1 Apparatus.

2.5.1.1 Directional Probe. Any directional probe, such as United Sensor Type DA Three-Dimensional Directional Probe, capable of measuring both the pitch and yaw angles of gas flows is acceptable. [Note: Mention of trade name or specific products does not constitute endorsement by the U.S. Environmental Protection Agency.] Assign an identification number to the directional probe, and permanently mark or engrave the number on the body of the probe. The pressure holes of directional probes are susceptible to plugging when used in particulate-laden gas streams. Therefore, a system for cleaning the pressure holes by "back-purging" with pressurized air is required.

2.5.1.2 Differential Pressure Gauges. Inclined manometers, U-tube manometers, or other differential pressure gauges (e.g., magnehelic gauges) that meet the specifications described in Method 2, § 2.2.

Note.—If the differential pressure gauge produces both negative and positive readings, then both negative and positive pressure readings shall be calibrated at a minimum of three points as specified in Method 2, § 2.2.

2.5.2 Traverse Points. Use a minimum of 40 traverse points for circular ducts and 42 points for rectangular ducts for the gas flow angle determinations. Follow § 2.3 and Table 1-1 or 1-2 for the location and layout of the traverse points. If the measurement location is determined to be acceptable according to the criteria in this alternative procedure, use the same traverse point number and locations for sampling and velocity measurements.

2.5.3 Measurement Procedure.

2.5.3.1 Prepare the directional probe and differential pressure gauges as recommended by the manufacturer. Capillary tubing or surge tanks may be used to dampen pressure fluctuations. It is recommended, but not required, that a pretest leak check be conducted. To perform a leak check, pressurize or use suction on the impact opening until a reading of at least 7.6 cm (3 in.) H_2O registers on the differential pressure gauge, then plug the impact opening. The pressure of a leak-free system will remain stable for at least 15 seconds.

2.5.3.2 Level and zero the manometers. Since the manometer level and zero may drift because of vibrations and temperature changes, periodically check the level and zero during the traverse.

2.5.3.3 Position the probe at the appropriate locations in the gas stream, and rotate until zero deflection is indicated for the yaw angle pressure gauge. Determine and record the yaw angle. Record the pressure gauge readings for the pitch angle, and determine the pitch angle from the calibration curve. Repeat this procedure for each traverse point. Complete a "back-purge" of the pressure lines and the impact openings prior to measurements of each traverse point.

A post-test check as described in § 2.5.3.1 is required. If the criteria for a leak-free system are not met, repair the equipment, and repeat the flow angle measurements.

2.5.4 Calculate the resultant angle at each traverse point, the average resultant angle, and the standard deviation using the following equations. Complete the calculations retaining at least one extra significant figure beyond that of the acquired data. Round the values after the final calculations.

2.2.2 Velocity (Non-Particulate) Traverses. When velocity or volumetric flow rate is to be determined (but not particulate matter), the same procedure as that for particulate traverses (Section 2.2.1) is followed, except that Figure 1-2 may be used instead of Figure 1-1.

2.3 Cross-sectional Layout and Location of Traverse Points.

2.3.1 Circular Stacks. Locate the traverse points on two perpendicular diameters according to Table 1-2 and the example shown in Figure 1-3. Any equation (for examples, see Citations 2 and 3 in the Bibliography) that gives the same values as those in Table 1-2 may be used in lieu of Table 1-2.

For particulate traverses, one of the diameters must be in a plane containing the greatest expected concentration variation, e.g., after bends, one diameter shall be in the plane of the bend. This requirement becomes less critical as the distance from the disturbance increases; therefore, other diameter locations may be used, subject to approval of the Administrator.

In addition for stacks having diameters greater than 0.61 m (24 in.) no traverse points shall be located within 2.5 centimeters (1.00 in.) of the stack walls; and for stack diameters equal to or less than 0.61 m (24 in.), no traverse points shall be located within 1.3 cm (0.50 in.) of the stack walls.

To meet these criteria, observe the procedures given below.

2.3.1.1 Stacks With Diameters Greater Than 0.61 m (24 in.). When any of the traverse points as located in Section 2.3.1 fall within 2.5 cm (1.00 in.) of the stack walls, relocate them away from the stack walls to: (1) a distance of 2.5 cm (1.00 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be the "adjusted" traverse points.

Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points, both in the sampling (or velocity measurement) procedure, and in recording the data.

TRAVERSE POINT	DISTANCE, % of diameter
1	4.4
2	14.7
3	29.5
4	70 5
5	85.3
6	95.6

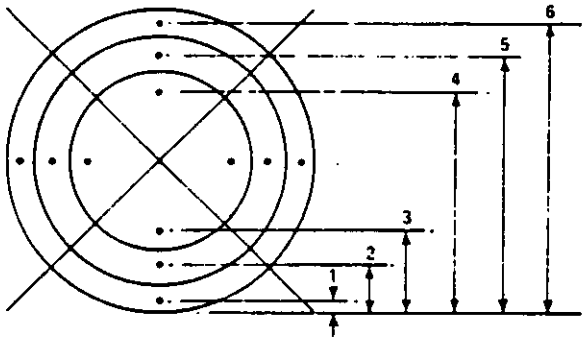


Figure 1-3. Example showing circular stack cross section divided into 12 equal areas, with location of traverse points indicated.

TABLE 1-2. LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

[Percent of stack diameter from inside wall to traverse point]

Traverse point number on a diameter	Number of traverse points on a diameter—											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8				96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10					97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.8	67.7
15								95.1	89.1	83.5	78.2	72.6
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

METHOD 1—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. To aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source, a measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas.

1.2 Applicability. This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when: (1) flow is cyclonic or swirling (see Section 2.4), (2) a stack is smaller than about 0.30 meter (12 in.) in diameter, or 0.071 m^2 (113 $in.^2$) cross-sectional area, or (3) the measurement site is less than two stack or duct diameters downstream or less than a half diameter upstream from a flow disturbance.

The requirements of this method must be considered before construction of a new facility from which emissions will be measured; failure to do so may require subsequent alterations to the stack or deviation from the standard procedure. Cases involving variants are subject to approval by the Administrator, U.S. Environmental Protection Agency.

2. *Procedure*

2.1 Selection of Measurement Site. Sampling or velocity measurement is performed at a site located at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, or from a visible flame. If necessary, an alternative location may be selected, at a position at least two stack or duct diameters downstream and a half diameter upstream from any flow disturbance. For a rectangular cross section, an equivalent diameter (D_e) shall be calculated from the following equation, to determine the upstream and downstream distances:

$$D_e = \frac{2LW}{(L+W)}$$

where L=length and W=width.

An alternative procedure is available for determining the acceptability of a measurement location not meeting the criteria above. This precedure, determination of gas flow angles at the sampling points and comparing the results with acceptability criteria, is described in Section 2.5.

2.2 Determining the Number of Traverse Points.

2.2.1 Particulate Traverses. When the eight- and two-diameter criterion can be met, the minimum number of traverse points shall be: (1) twelve, for circular or rectangular stacks with diameters (or equivalent diameters) greater than 0.61 meter (24 in.); (2) eight, for circular stacks with diameters between 0.30 and 0.61 meter (12-24 in.); (3) nine, for rectangular stacks with equivalent diameters between 0.30 and 0.61 meter (12-24 in.).

When the eight- and two-diameter criterion cannot be met, the minimum number of traverse points is determined from Figure 1-1. Before referring to the figure, however, determine the distances from the chosen measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. Then, determine from Figure 1-1 the minimum number of traverse points that corresponds: (1) to the number of duct diameters upstream; and (2) to the number of diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value, so that for circular stacks the number is a multiple of 4, and for rectangular stacks, the number is one of those shown in Table 1-1.

TABLE 1-1. CROSS-SECTION LAYOUT FOR RECTANGULAR STACKS

Number of traverse points	Matrix layout
8	3x3
12	4x3
16	4x4
20	5x4
25	5x5
30	6x5
36	6x6
42	7x6
49	7x7

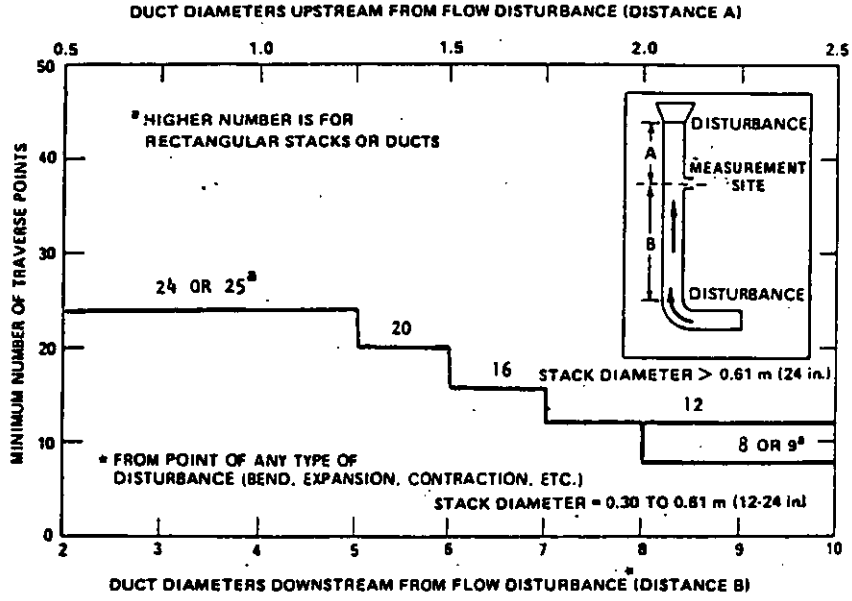


Figure 1-1. Minimum number of traverse points for particulate traverses.

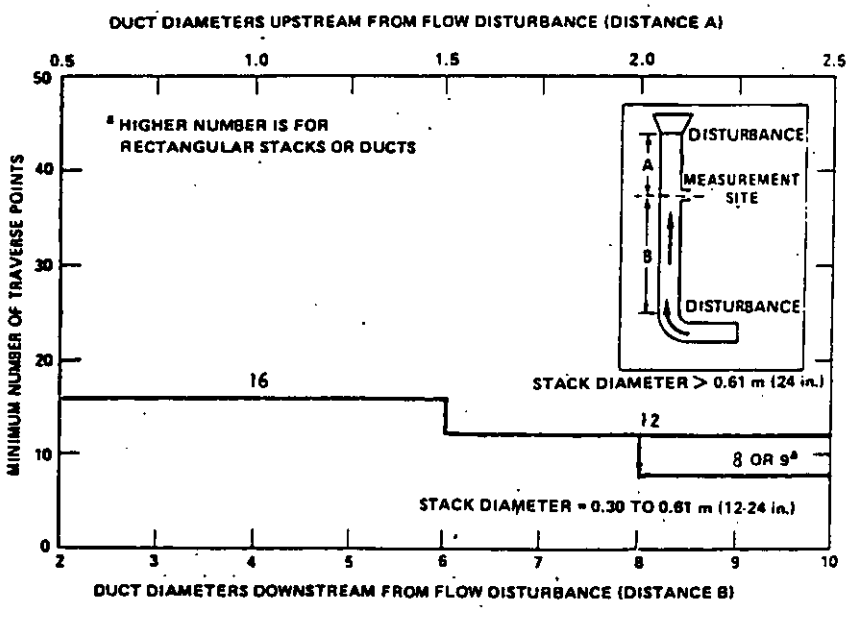


Figure 1-2. Minimum number of traverse points for velocity (nonparticulate) traverses.

Owens-Corning Fiberglass
October 8 & 9, 1991
Huntingdon Borough, Huntingdon County

INTRODUCTION

Particulate and ammonia compliance sampling was performed on the Drying Drum exhaust from the #2 Conductive Roving line at the Owens-Corning Fiberglas Huntingdon Plant on October 8 and 9, 1991. The testing was performed per conditions for the renewal of permit number 31-309-005a.

The particulate testing was performed according to U.S. E.P.A. Methods 5 and Pennsylvania DER method 5.

The particulate and ammonia testing was performed by Leroy F. Owens, Advanced Environmental Specialist , Paul Detterline, Environmental Engineer, and Donald C. Jenne, Environmental Technician , of Owens-Corning Fiberglas', Environmental Affairs Department.

The particulate analysis was performed by Owens-Corning Fiberglas' Environmental Affairs Laboratory. The Ammonia analysis was performed by Clayton Environmental Consultants, Novi, Michigan 48375.

DISCUSSION

Samples were obtained according to the test procedures outlined in the section titled, "Sampling and Laboratory Procedures". All the tests were performed to prescribed methods with no known errors occurring.

The average particulate emission rate calculated from the three particulate tests was 0.06 lbs/hr. The highest concentration measured was 0.0043 gr/dscf This is well below the allowable of 0.04 gr/dscf.
The average ammonia emission rate calculated from the three ammonia tests was 0.026 lbs/hr.

SUMMARY OF RESULTS

Ammonia

	TEST#1	TEST#2	TEST#3
Average effluent velocity (FPS)	33.12	32.96	33.58
Area of Stack	0.994	0.994	0.994
Effluent Density (kg/m3)	1.169	1.150	1.135
Percent Moisture	1.1	1.0	1.0
Volumetric Flow (dscfm)	1910	1872	1836
Average sampling rate (CFM)	0.588	0.599	0.593
Corrected Sample Volume (dscf)	71.236	69.679	67.080
Weight Collected (gms)	7.4	6.3	8.7
Effluent Concentration (ppm)	5.2	4.5	6.5
Emission Rate (lbs/hr)	0.026	0.022	0.032
% Isokinetic	98.4	98.2	96.4

SUMMARY OF RESULTS

PARTICULATE

	TEST#1	TEST#2	TEST#3
Average effluent velocity (FPS)	33.58	33.33	33.42
Area of Stack	0.994	0.994	0.994
Effluent Density (kg/m3)	1.167	1.161	1.346
Percent Moisture	0.9	1.1	1.2
Volumetric Flow (dscfm)	1939	1888	1852
Average sampling rate (CFM)	0.584	0.598	0.623
Corrected Sample Volume (dscf)	70.904	68.983	69.396
Weight Collected (gms)	15.4	19.1	16.4
Effluent Concentration (gr/dscf)	0.0034	0.0043	0.0036
Emission Rate (lbs/hr)	0.056	0.069	0.058
% Isokinetic	96.5	96.4	98.9

PROCESS DESCRIPTION

AND

FLOW DIAGRAM

See Confidental Supplement

PROCESS DATA

SEE CONFIDENTIAL SUPPLEMENT

AMMONIA TEST

This method involves the use of a Method 5 train with a glass probe, no filter, and 0.1 N H_2SO_4 in the impingers in instead of distilled water. Isokinetic sampling the same as described in EPA Method 5 utilizing sample points as determined by EPA Method 1 is required with a minimum sample volume of 50 dry standard cubic feet.

Sample recovery containers:
{Use leak-free glass sample bottles.}

1.) The entire front half 0.1 N H_2SO_4 washings.
2.) The contents of all of the impingers {except the silica gel impinger} along with the washings of these impingers and the rest of the back half.
3.) Silica gel from the silica gel impinger.
4.) 0.01 N H_2SO_4 blank.

For sample analysis, use ion chromatography and filter the samples through a prewashed 0.22 um filter prior to analysis to avoid fouling or clogging the resin columns as per the ion chromatograph manufacturer's instructions. Adjust the samples to a pH of 2 or less during recovery and analyze the samples as soon as possible after collection.

Ion chromatographic analysis is required of the entire train. Utilize the ion chromatograph in accordance with the manufacturer's instructions. The analyte used by the ion chromatograph is the ammonium ion (NH_4^+). If ion chromatography is unavailable, the Nessler reagent colorimetric method may be used for analysis.

SUMMARY OF WEIGHTS

	TEST #1 MG	TEST #2 MG	TEST #3 MG
FRONT HALF			
SOLUBLE	14.7	18.6	15.6
INSOLUBLE	0	0	0
TOTAL	14.7	18.6	15.6
BACK HALF			
SOLUBLE	66.9	31.4	24.6
INSOLUBLE	0.7	0.5	0.8

NAIMA
NORTH AMERICAN INSULATION
MANUFACTURERS ASSOCIATION

February 4, 1992

Ron Myers
Emission Inventory Branch (MD-14)
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Subject: Request For Information - AP-42

Dear Ron:

The NAIMA Environmental Affairs Committee appreciates the extension of the deadline until March 15, 1992 for the above referenced subject. We are looking forward to working with you on AP-42.

Best regards,

George R. Phelps
NAIMA

44 CANAL CENTER PLAZA ■ SUITE 310 ■ ALEXANDRIA, VA 22314 ■ TEL 703/684-0084 ■ FAX 703/684-0427

NAIMA
NORTH AMERICAN INSULATION MANUFACTURERS ASSOCIATION

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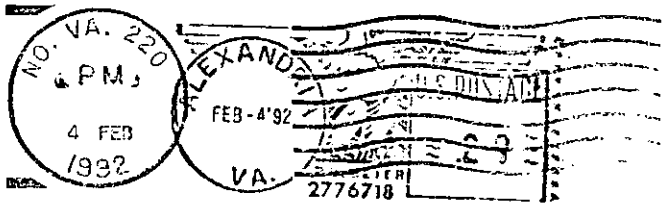


Ron Myers
Emission Inventory Branch (MD-14)
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Region 10
1200 Sixth Avenue
Seattle WA 98101

Alaska
Idaho
Oregon
Washington

HRP5#025

March 29, 1990

Reply To
Attn Of: AT-082

4-17-90

MEMORANDUM

Subject: Washington Styrene Emissions Study Draft Report

From: Elizabeth Waddell, Air Toxics Coordinator
Air Programs Development Section, Region 10

To: Charles H. Darvin, Co-Chair
Control Technology Center

Attached is the draft report from the University of Washington of the styrene emissions study conducted last summer. This report is for your information. However, we would welcome your comments and recommendations. We will incorporate all comments received by April 18th into the final report.

Attachment

cc: Dave Painter, MD-15
Dave Kircher, APDS

Styrene Emissions

by

Stacia Dugan and Michael Pilat

Department of Civil Engineering
University of Washington
Seattle, Washington 98105

to

Teddy Le
Project Engineer
Air Quality Program
State of Washington
Department of Ecology PV-11
Olympia, WA 98504-8711

January 1990

Table of Contents

Styrene Emissions Study

I. Introduction

A. Research Objectives

The objectives of this research project are, in general, to determine the magnitude of the styrene air pollutant emissions at the Western Recreational Vehicles, Inc. plant (Yakima) and possible adverse health effects caused by these styrene emissions.

B. Research Significance

The proposed research has significance to the issue of human health effects related to the emissions of styrene air pollutants from fiberglass fabrication plants in the State of Washington. These styrene emissions have caused complaints by citizens living near the plants. The complaints include objectionable odors and various health distresses.

II. Approach

The research approach will be to measure the styrene emission rates (concentration and volumetric air flowrates) from the plants. Also, the ambient air styrene concentration will be estimated using a screening model. The research approach will include a literature search to acquire information on the manufacturing process which generates the styrene emissions and the emission control systems presently available to control these emissions. The health impact of styrene on the neighborings residents will be estimated with the assistance for the Washington State Department of Social and Health Services. The results of this research project will be presented in a report which will also be the thesis for the degree of Master of Science in Civil Engineering at the University of Washington.

II. Sampling Sites

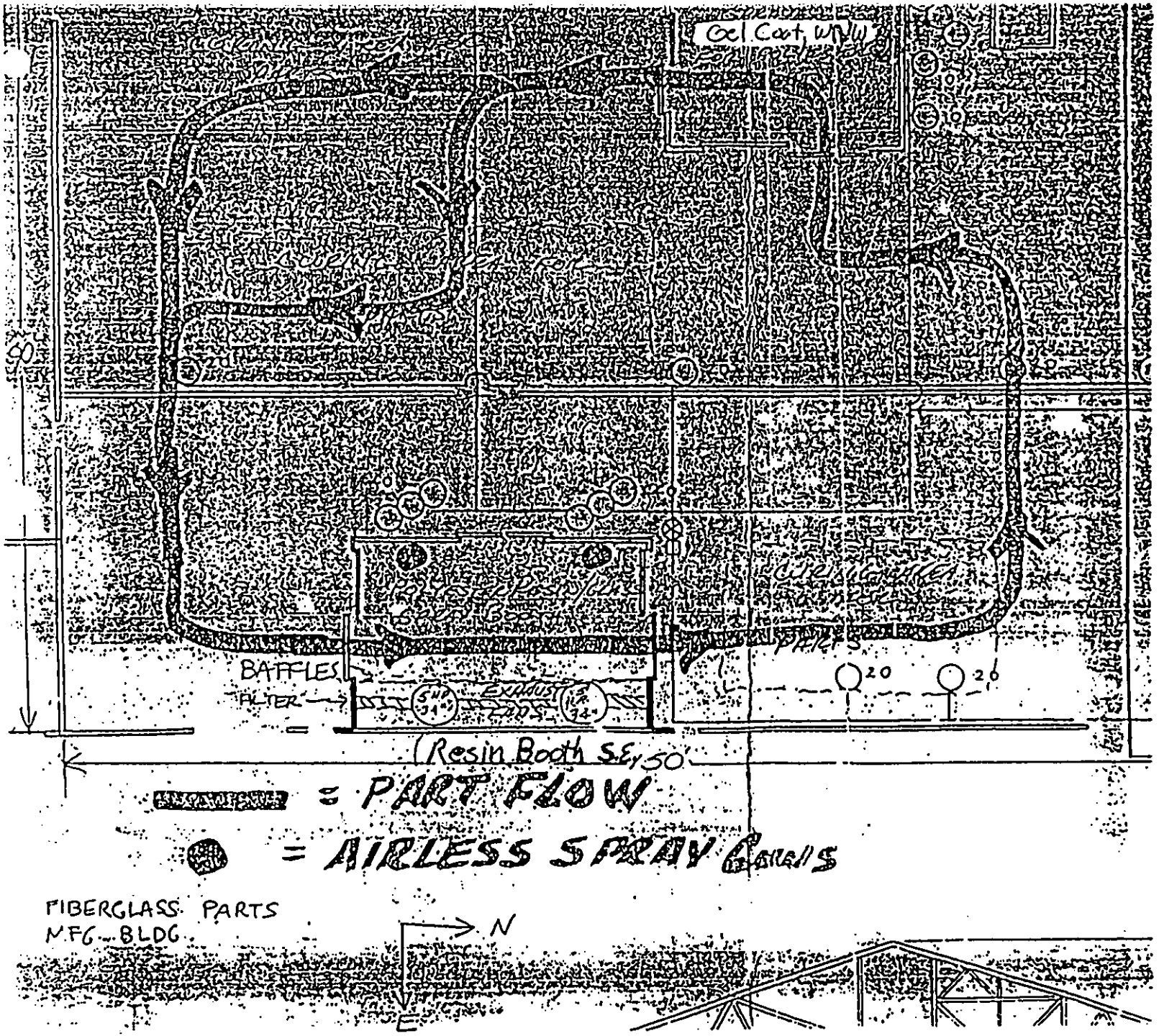
A. Western Recreational Vehicles - Yakima, Wa.

The plant manufactures recreational vehicles. The manufacturing process starts with welding the steel chassis and ends with a recreational vehicle ready for sale. The showers, tubs, and fiberglass roofs for the over the cab berth section of the RVs are made of fiberglass. The fiberglass facility is designed with 2 enclosed booths in a warehouse. Each booth has 2 ventilation ducts located behind wall size filters. The ventilation system draws the air and styrene vapor from the booth through the filter, which catches the large particulate, and expels the air out into the environment.

The booth located in the North East side of the warehouse is the gel coat booth. Here, the gel coat is applied to the mold. Only one of the two ventilation ducts was running during the sampling period. The sampling identification for this duct is WNW which stands for Western Recreational Vehicles, North-East Duct.

The booth located in the South East section of the warehouse is were the suppressed styrene resin and the chopped fiberglass strands are applied to the gel coat layer previously applied to the mold. Western Recreational Vehicle (WRV) uses a suppressed resin, which is suppose to release less styrene vapor than typical styrene resins. The ventilation system is the same as the one in the gel coat booth, a wall filter before the 34" ventilation ducts. Only one of the 2 ducts was operational during the sampling period, WSE, (Western Recreation Vehicle, South East Duct).

The parts are allowed to set inside the warehouse and the emission leave the building threw the ventilation ducts, and by way of cracks and vents in the building.


Gel Coat, W/W
BAFFLES
FILTER
EXHAUST FANS
Resin Booth S.E. 50'
= PART FLOW
= AIRLESS SPRAY GUNS
FIBERGLASS PARTS
MFG. BLDG.
N
E

II. Sampling Sites

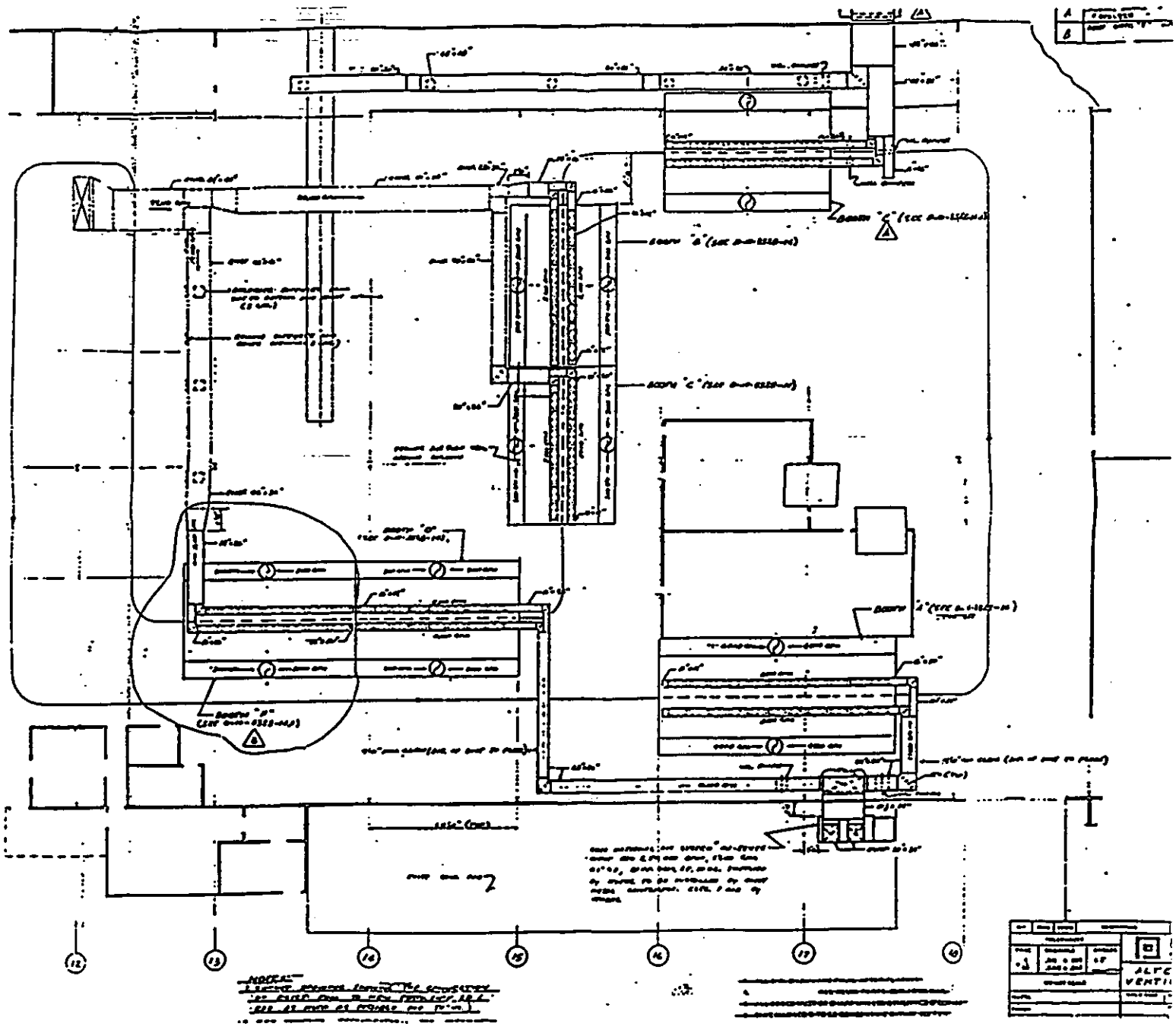
B. Hytech - Yelm, Wa.

The plant manufactures fiberglass hot tubs and showers. The fabrication process is on an assembly line through 5 booths or hoods. The booths can be identified by a production step.

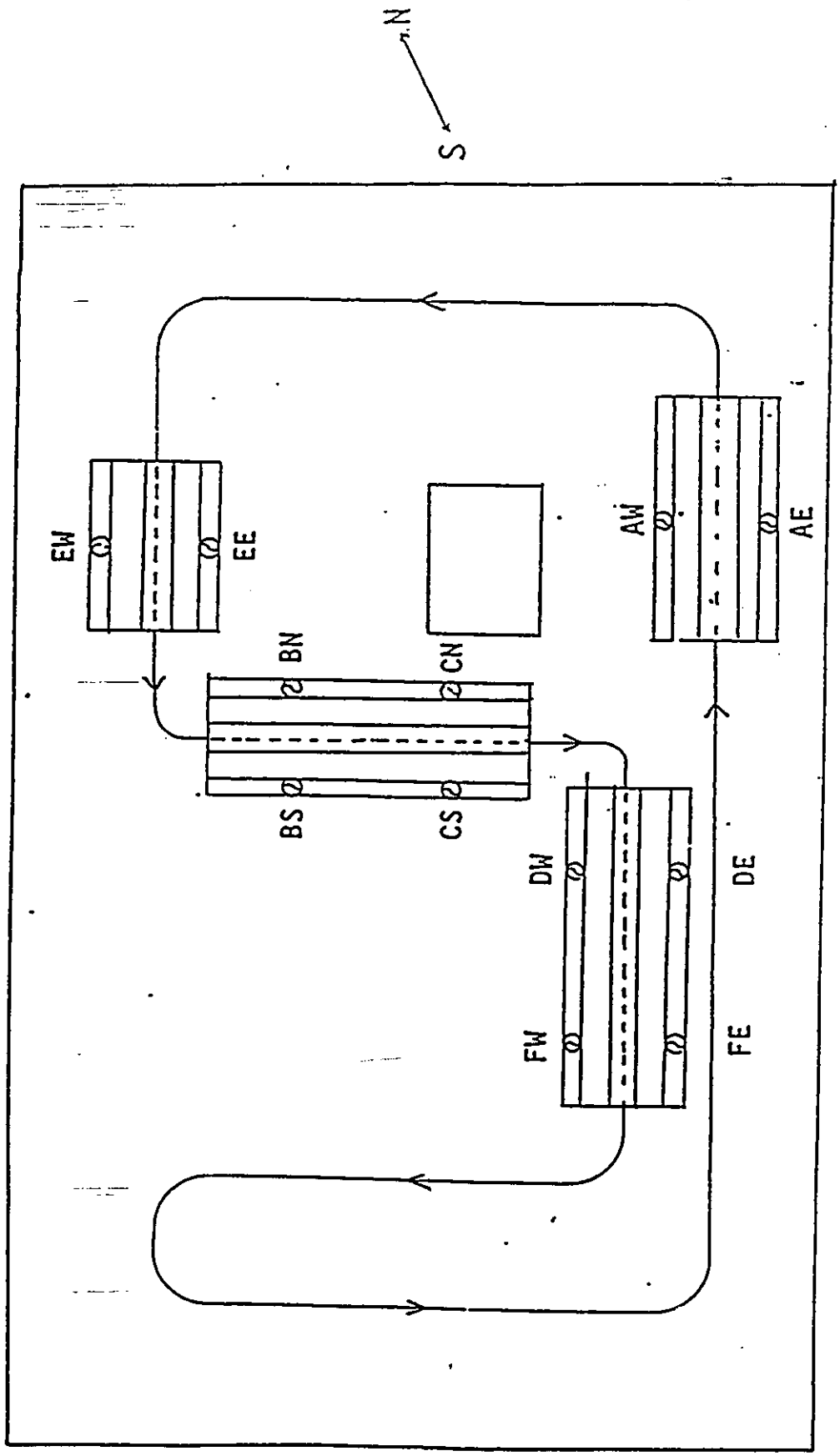
Step #1	Booth A:	Application of gel coat to the mold.
Step #2	Booth E:	Application of barrier coat to the gel coat.
Step #3	Booths B, D, and E:	Application of fiberglass resin layer to the gel coat and barrier coat already on the mold.

Two ducts are located on the roof above each booth. Duct identification is by three letters; i.e. HAE. The first letter H, stand for Hytech. The second letter, A, is the booth identification for the gel coat booth. The third letter is the direction of the duct relative to the booth; N-North, S-South, E-East, and W-West. The ten ducts rise approximately 4 to 5 feet above the roof and are 34 inches in diameter. Access to the roof is via a ladder.

If necessary, electrical outlets are available inside the plant and accessible with extension cords. Care must be taken to avoid sparks, as styrene is flammable.



FIBERGLASS FABRICATION PROCESS



III. Measurement Methods

A. Gas Velocity

Duct gas velocity and volumetric flow rate are determined using Environmental Protection Agency Method 2-Determination of Stack Gas Velocity and volumetric Flow Rate. (40 CFR Ch.1, 7-1-88 Edition, Pt. 60, App. A, Meth. 2)

The ducts at the 2 fiberglass fabrication plants have no ports. A few have configurations that do not allow for the installation of usable ports. Therefore when necessary, velocity is measured at the ducts outlet to the atmosphere (across top of duct). Ports were cut in Hytech duct BN (booth-B, North-N). A velocity traverse was made across the top of duct BN and using the ports. The difference in the measured velocity for these two locations is less than 5%.

Gas Velocity results are in the appendix.

III. Measurement Methods

B. Sampling Method

NIOSH Method 1500 to sample Styrene at the fiberglass fabrication facilities. The methods uses charcoal tubes for sampling and a gas chromatography for analysis. The methods are outlined below.

Equipment:

1. 100/50 mg or 350/350/350 mg charcoal tubes. The charcoal tubes are from SKC West of Fulleron, California, The 100/50 glass tube consists of a glass wool plug at the inlet followed by 100 mg of charcoal, a foam plug, and 50 mg of charcoal. the 350/350/350 charcoal tubes have a similar design
2. Personal sampling pumps, 0.01 to 0.2 L/min. Flow rates form 20-80 ml/min for 8hr sampling periods.
3. Tubing to connect pump and charcoal tube.
4. Gas chromatography (g.c.) for analysis.
5. Vials for desorbtion of tubes-amber with septum caps.
6. Syringe, 10 ul, for g.c. injections.
7. Pipettes, volumetric flasks for preparing standards & desorbing samples.
8. Carbon disulfide for desorbing samples.
9. Styrene for standards.
10. Helium, hydrogen, and air for g.c.

III. Measurement Methods

B. Sampling Method (continued)

Presampling

1. Calibrate each personal sampling pump at the sampling flow rate with a representative charcoal sampling tube in line. A bubble meter will be used for calibration.

Sampling

1. Assemble sampling train on site. Break ends of tube immediately before sampling. Attach tube to pump with flexible tubing. Suspend charcoal tube into duct.
2. Record time and initial digital reading on pump. Start pump.
3. Sample at the pumps calibrated flow rate for a total sampling size of approx. 25 L.
4. Record time and temperature throughout the sampling day.
5. At the end of the sampling period, turn off pump, record time and final digital reading.
6. Cap tubes with plastic caps, tape sealed and ship to lab.

Post Sampling

1. Recalibrate each personal sampling pump at the sampling flow rate with a representative charcoal sampling tube in line. A bubble meter will be used for calibration.

III. Measurement Methods

C. Chemical Analysis

Sample Preparation:

1. Place each charcoal section of the sampler tube in a separate vial. Discard the glass wool and foam plugs.
2. Add 1.5 ml of cs_2 to each vial. containing 350 mg charcoal, 0.5 ml to each vial containing 50 or 100 mg charcoal. Attach cap to vial.
3. Allow sample to stand (desorb) 30 min. with occasional agitation.

Calibration & Quality Control:

1. Calibrate Gas Chromatography daily with three to five working standards over the range 0.02 to 10 mg analyte per standard.
   a. Add known amounts of analyte to CS_2 in 50 ml flasks and dilute to mark.
   b. Analyze together with samples and blanks.
   c. Prepare calibration graph (peak area vs. mg analyte).
2. Determine desorbtion efficiency (DE) at least once for each batch of charcoal used for sampling in the calibration range.
   a. Inject a known amount of analyte directly onto front adsorbent section with a microliter syringe.
   b. Cap tube. Allow to stand overnight.
   c. Desorb and analyze together with working standards.
3. Analyze samples within 2 weeks of collection. Refrigerate samples during time between collection and analysis.

III. Measurement Methods

C. Chemical Analysis (continued)

Measurement:

1. Set g.c. operating parameters - proper attenuation, temperature, etc. Inject sample aliquot.
2. Record peak area for known standards and unknown samples.

Concentration Calculations:

1. Determine, from the standard graphs, the mass, mg (corrected for DE) of analyte found in the sample front, 100 mg (Wf) and black, 50 mg (Wb) adsorbent sections, and in the average media blank front (Bf) and black (Bb) adsorbent sections.
2. Calculate concentration, c, of analyte in the air volume sampled, V:

$$C = \frac{(Wf+Wb-Bf-Bb)x1000}{V} = mg/m^3$$

Emission Rates From a Fiberglass Fabrication Industry (Western Recreational Vehicles)
Calculations performed: Dugan & Apostol

Duct ID	Area of Duct (ft^2)	Air Velocity in Duct (ft/~~min~~ sec)	Date of	Volumetric Flow Rate (ft^3/min.)	Date measured	Styrene Concentration mg styrene / m	grams / sec	(lb/hr)	(lb/day)
WNW	12.11	21.92	11/28	15,927	11/28	120.40	0.9050	7.1834	61.06
					11/29	84.071	0.6319	5.0159	42.64
					11/30	54.66	0.4109	3.2612	27.72
					12/1	64.73	0.4866	3.0620	32.83
WSE	6.0305	39.96	11/28	14,459	11/29	101.91	0.6954	5.5198	46.92
					11/30	90.625	0.6184	4.9086	41.72
					12/1	93.56	0.6385	5.0675	43.07

Emission Rates From a Fiberglass Fabrication Industry (Hytech)
Calculations performed: Dugan & Apostol

Duct ID	Area of Duct (ft^2)	Air Velocity in Duct (ft/sec.)	Date of	Volumetric Flow Rate (ft^3/min.)	Date measured	Styrene Concentration mg styrene / m^3	grams / sec	(lb/hr)	(lb/day)
AE	6.305	42.34	8/23	16,017	10/6	276.01	2.0865	16.56	132.49
AW	6.305	36.55	8/23	13,829	10/6	292.67	1.9102	15.161	121.29
BN	6.305	29.88	8/23	11,302	10/6	240.86	1.2847	10.197	81.576
BS	6.305	33.48	8/23	12,667	10/6	274.43	1.6407	13.022	104.176
DE	6.305	27.055	12/12	10,235	10/6	108.31	0.52317	4.152	33.22
DW	6.305	35.767	12/12	13,531	10/6	281.60	1.7983	14.274	114.192
EE	6.305	43.72	8/23	16,539	10/6	119.30	0.9313	7.392	59.134
EW	6.305	45.80	8/23	17,327	10/6	120.63	0.98645	7.830	62.64
FE	6.305	37.722	12/12	14,270	10/6	325.03	2.1890	17.375	139
FW	6.305	34.598	12/12	13,088	10/6	226.47	1.40	11.103	88.82

Emission Rates From a Fiberglass Fabrication Industry (Hytech)
Calculations performed: Dugan & Apostol

Duct ID	Area of Duct (ft^2)	Air Velocity in Duct (ft/sec)	Date of	Volumetric Flow Rate (ft^3/min.)	Date measured	Styrene Concentration mg styrene / m^3	grams / sec	(lb/hr)	(lb/day)
AE	6.305	42.34	3/23	16,017	11/1	367.1687	2.724	22.03	187.25
AW	6.305	36.55	8/23	13,829	11/1	308.0032	2.0102	15.956	135.63
BN	6.305	29.88	8/23	11,302	11/1	333,5556	1.7792	14.122	120.04
BS	6.305	33.48	8/23	12,667	11/1	478.65467	2.8615	22.712	193.05
DE	6.305	27.055	12/12	10,235	11/1	242.06902	1.1693	9.281	78.89
DW	6.305	35.767	12/12	13,531	11/1	344.4685	2.1998	17.460	148.41
EE	6.305	43.72	8/23	16,539	11/1	164,8912.	1.2871	10.216	86.84
EW	6.305	45.80	8/23	17,327	11/1	171.3661	1.4014	11.123	94.55
FE	6.305	37.722	12/12	14,270	11/1	358.2205	2.4125	19.149	162.77
FW	6.305	34.598	12/12	13,088	10/31-11/	266.5380	1.6464	13.068	111.08

V. Appendices

Gas Velocity Data Sheet (EPA Method 2)

Plant: Western Recreational Vehicles, Yakima Date: 11/28/89

Location in Plant: NW duct, a/c coat booth.

Location in Duct: across top of duct, drive end Duct Dimensions: 52" outer, 22" inner

Atm. Barometric Press: 29.235 - 9.24" Duct Static Press: —

Dry Gas Mol. Wt. 28.84 % Water Vapor: 12H = 8.1%

Date of EPA Mth 3 Orsat Test: — Date of EPA Mth 4 Moisture Test:

Pitot Tube Cp: 0.84 Pitot Tube ID No. Type S-Flex Cr #6

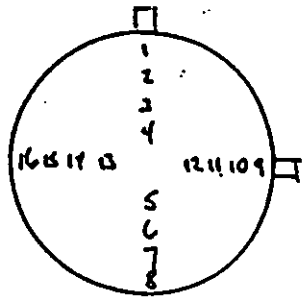
Time of Vel. Traverse Measurements: 13:05 Operators: Dugan

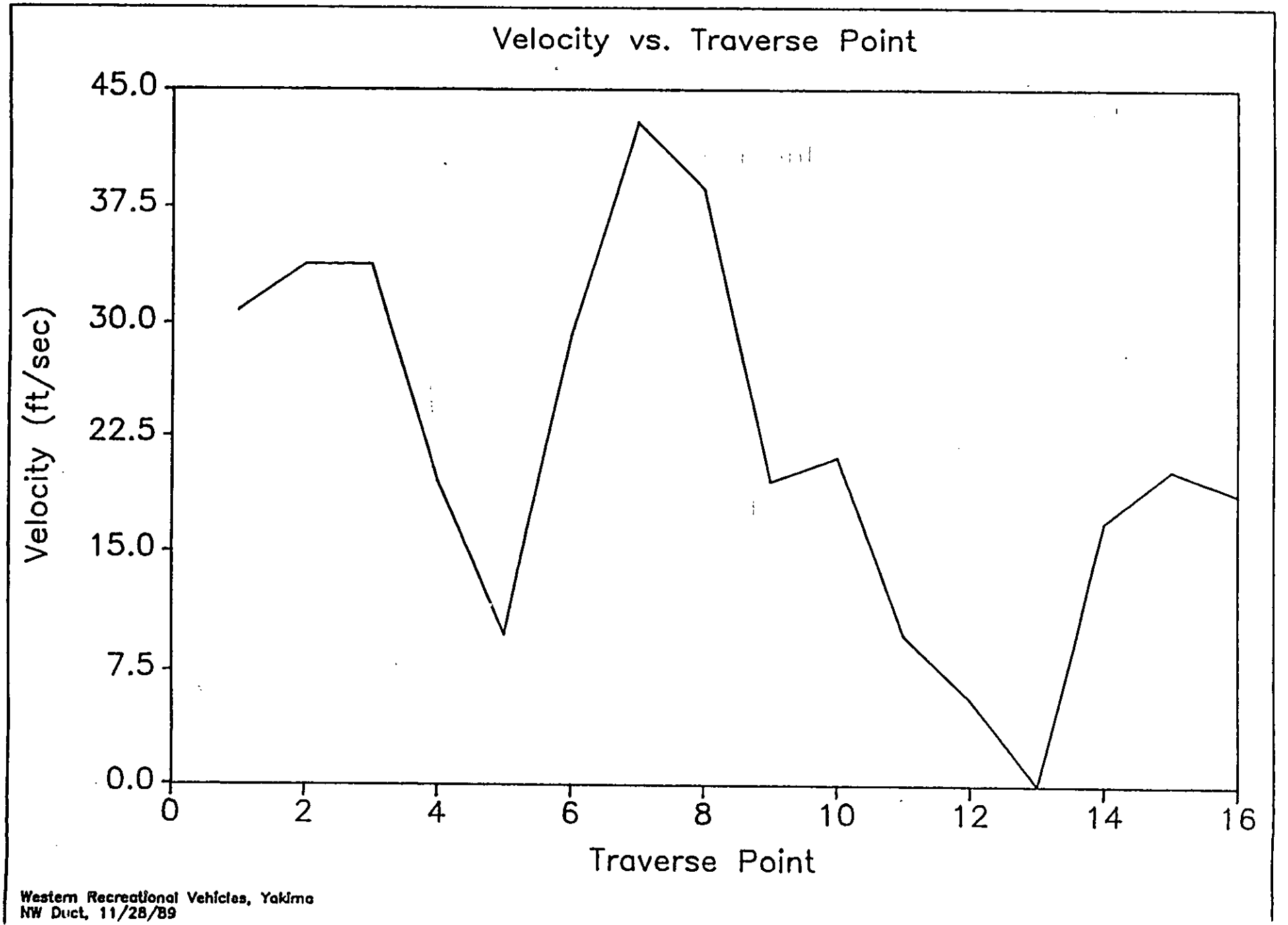
Sampling Location ID: WNW

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1.37" ; 1 3/8	0.3	15C, 59F	30.89	
2	4.35" ; 4 3/8	0.36		33.83	
3	7.86" ; 7 7/8	0.36		33.83	
4	12.20" ; 12 3/16	0.12		19.53	
5	18.37"	0.03		9.77	
6	4.37"	0.27		29.30	
7	9.86"	0.52		42.95	
8	12.20"	0.47		38.66	
9	1.37"	0.12		19.53	
10	4.37"	0.14		21.10	
11	7.86"	0.03		9.77	
12	12.20"	0.01		5.64	
13	1.37"	0		0	
14	4.35"	0.09		16.92	
15	7.86"	0.13		20.33	
16	12.20"	0.11		18.70	Avg = 21.90

$\sqrt{\Delta P}_{avg} = 0.3286$

$V_{avg} = 21.92$




Velocity vs. Traverse Point
45.0
37.5
30.0
22.5
15.0
7.5
0.0
Velocity (ft/sec)
0
2
4
6
8
10
12
14
16
Traverse Point
Western Recreational Vehicles, Yakima
NW Duct, 11/28/89

Gas Velocity Data Sheet (EPA Method 2)

Plant: Western Precipitation Industries Date: 11/28/89

Location in Plant: SE Duct, Laminar Leg

Location in Duct: East or "Sample port" Duct Dimensions: 24"

Atm. Barometric Press: 29.24 "Hg Duct Static Press: —

Dry Gas Mol. Wt. (mass) 29.84 % Water Vapor: 6.1 - 8.1%

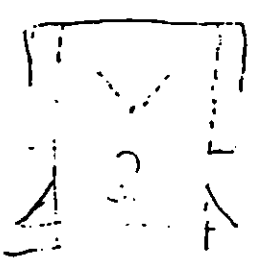
Date of EPA Mth 3 Orsat Test: — Date of EPA Mth 4 Moisture Test: —

Pitot Tube Cp: Standard 1.99 N.K. Pitot Tube ID No. 5/16" Standard

Time of Vel. Traverse Measurements: 14:30 Operators: Duncan

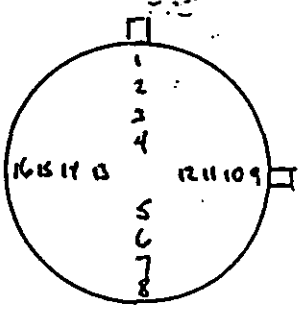
Sampling Location ID: WSE Ambient Air temp = 60°C

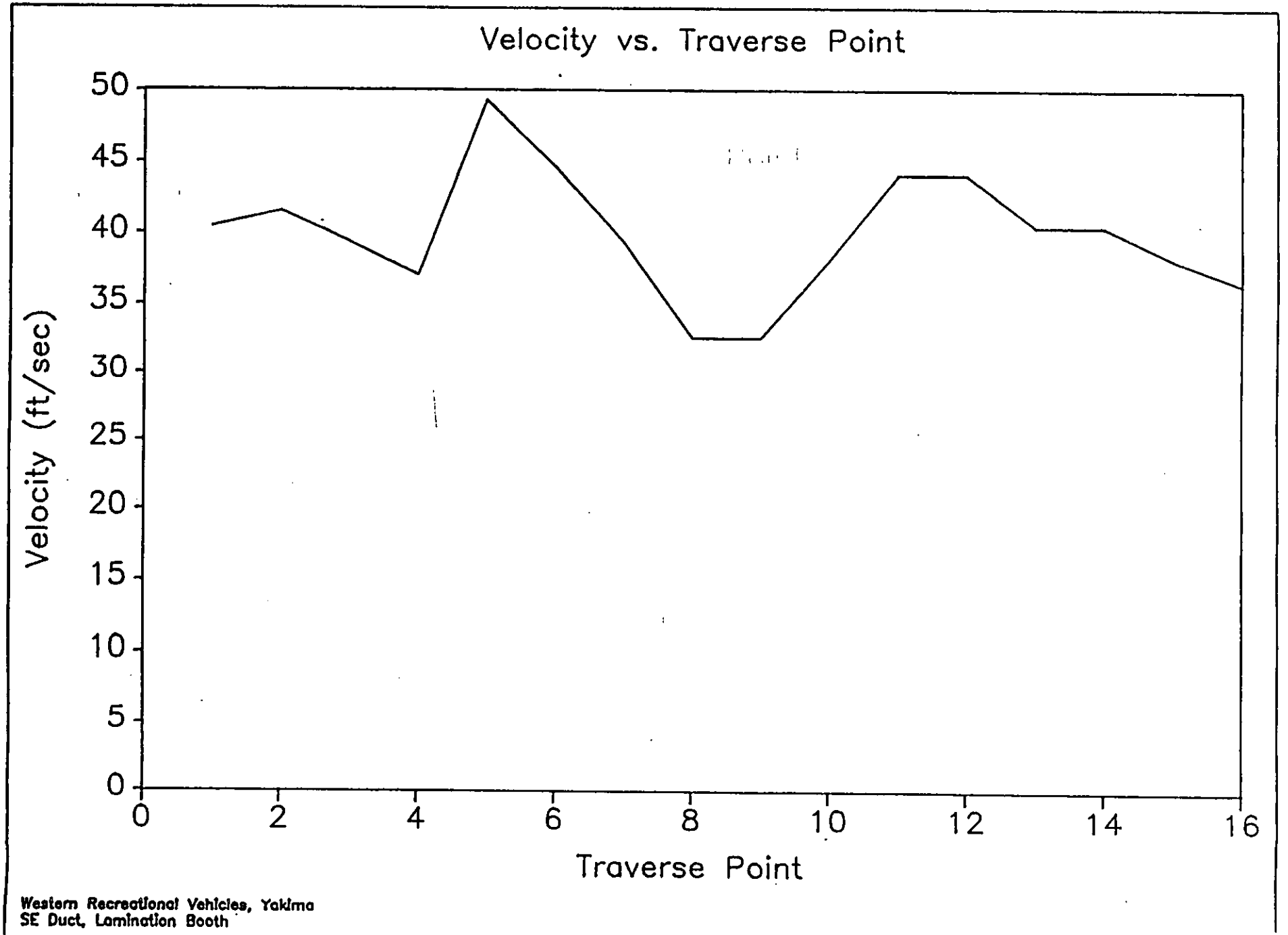
Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1.09	0.29	16°C	40.49	
2	3.59	0.34	60.8° F	41.57	
3	6.60	0.30		39.38	
4	10.98	0.31		37.06	
5	23.02	0.50		49.37	
6	27.40	0.55		44.66	
7	30.43	0.30		39.38	
8	32.91	0.21		32.61	
9	1.09	0.21		32.61	
10	3.59	0.28		38.24	
11	6.60	0.34		44.16	
12	10.98	0.34		44.16	
13	23.02	0.29		40.49	
14	27.40	0.29		40.49	
15	30.43	0.28		38.24	
16	32.91	0.25		36.46	Av 39.96



Area Duct 0.600 sf

39.96





Western Recreational Vehicles, Yakima
SE Duct, Lamination Booth

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hytech Date: 8/23/89

Location in Plant: Booth AE

Location in Duct: ACROSS duct Duct Dimensions: 34"

Atm. Barometric Press: 30.07 Duct Static Press: ~~0.30 in. H2O~~

Dry Gas Mol. Wt. ~~29 g/mole~~ 28.84 g/mole % Water Vapor: R.H. = 60%

Date of EPA Mth 3 Orsat Test: ——— Date of EPA Mth 4 Moisture Test: ———

Pitot Tube Cp: 0.84 Pitot Tube ID No. ODE #2

Time of Vel. Traverse Measurements: 11:50/19°C Operators: Dugan & Hall

Sampling Location ID: AAE

$V_{s(AVE)}$ = 40.7639 fps

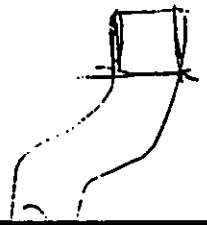
Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1.09	0.27	66°C	28.8114	
2	3.57	0.31	78.8°F	30.9719	
3	6.60	042	"	35.9342	
4	10.98	0.26	"	29.3401	
5	23.02	0.59	"	34.6271	
6	27.04	0.83	"	50.5152	
7	30.43	0.88	"	52.0145	
8	32.91	0.89	"	52.3092	
9	1.09	0.54	"	40.7455	
10	3.37	0.59	"	42.59015	
11	6.60	0.52	"	39.4939	
12	10.98	0.48	"	38.4153	
13	23.02	0.35	"	32.2033	
14	27.04	0.65	"	44.7033	
15	30.43	0.77	"	43.6551	
16	32.91	0.81	"	44.9029	

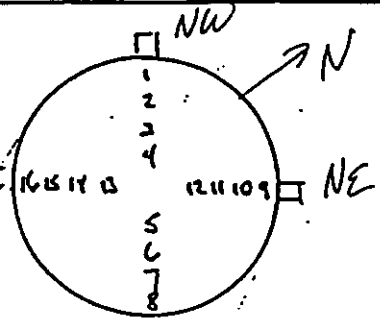
$C_{P_{AVG}}$ = 0.57375

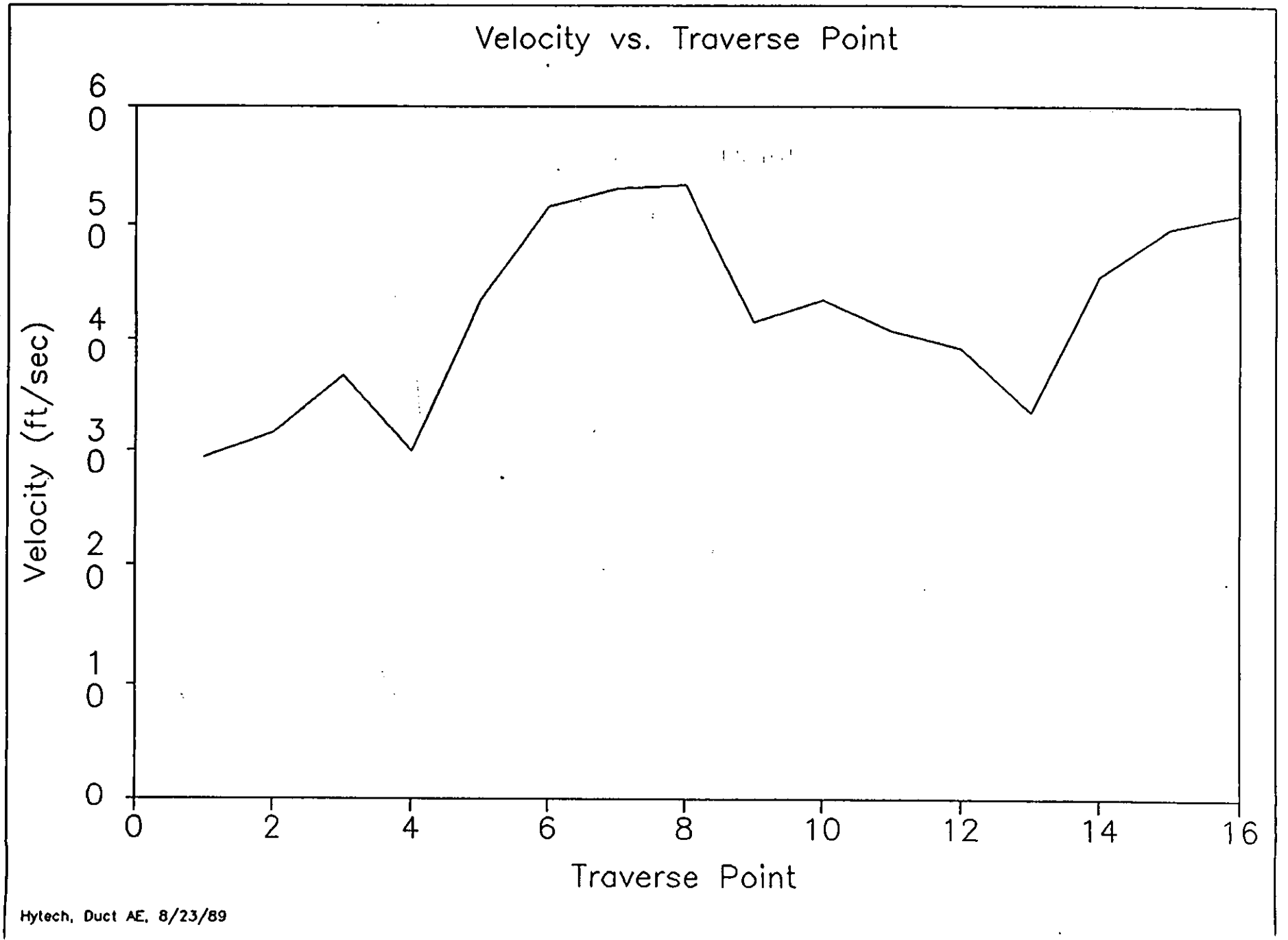
V_S = 42.34 ft/sec

Q_a = 94.2063 ft³/sec

A = 2.225 ft²






Velocity vs. Traverse Point
Velocity (ft/sec)
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
Traverse Point
Hytech, Duct AE, 8/23/89

HAW 823

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hytech Date: 8-22-89

Location in Plant: South A. W.

Location in Duct: — Duct Dimensions: 34" dia

Atm. Barometric Press: 30.07 Duct Static Press: 0.30

Dry Gas Mol. Wt. 28.84 lb/lb-mole % Water Vapor: —

Date of EPA Mth 3 Orsat Test: — Date of EPA Mth 4 Moisture Test: —

Pitot Tube Cp: 0.84 Pitot Tube ID No. Type S, Crtd

Time of Vel. Traverse Measurements: 1120 am / 19°C Operators: Dycus & Hall

Sampling Location ID: AW

Duct Temp 28°C

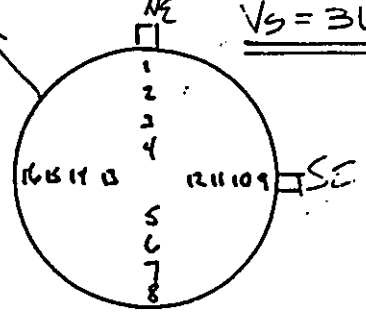
Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1.09	0.27	28°C	23.4075	
2	3.57	0.30	82.4	30.4712	
3	6.60	0.36		33.3796	
4	10.98	0.39		34.7425	
5	22.02	0.35		32.9127	
6	27.04	0.58		42.3685	
7	30.43	0.63		44.1570	
8	32.91	0.63		44.1570	
9		0.60		43.0928	
10		0.70		46.5456	
11		0.62		43.8051	
12		0.50		39.3382	
13		0.16		22.2530	
14		0.45		37.3195	
15		0.39		34.7425	
16		0.23		26.6905	

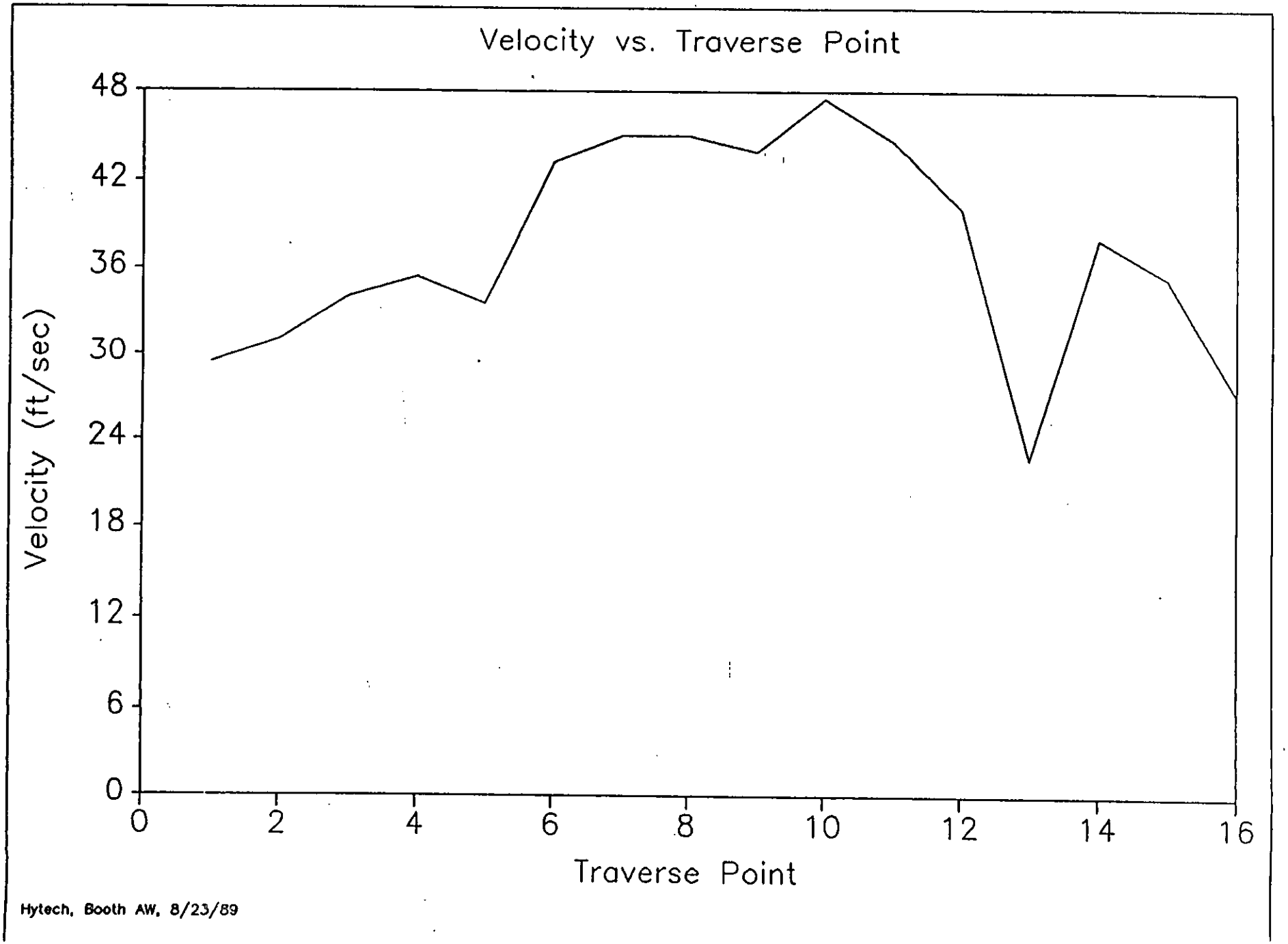
velocity of duct [illegible] (1120) [illegible]

$\Delta P_{AVG} = 0.44875$

$V_S = 36.1162$

$V_S = 36.55400$ fps




Velocity vs. Traverse Point
Velocity (ft/sec)
48
42
36
30
24
18
12
6
0
0
2
4
6
8
10
12
14
16
Traverse Point
Hytech, Booth AW, 8/23/89

VHBN823

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hytec - Yelm, WA Date: 8-22-02

Location in Plant: Roof. Duct BN (South-E, North duct)

Location in Duct: 8/8 diameters Duct Dimensions: 24"

Atm. Barometric Press: 30.07" Duct Static Press: ~~0.14~~

Dry Gas Mol. Wt. 29.0 ... 28.84 % Water Vapor:

Date of EPA Mth 3 Orsat Test: -- Date of EPA Mth 4 Moisture Test: -

Pitot Tube Cp: 8:45 (.84) Pitot Tube ID No. [illegible]

Time of Vel. Traverse Measurements: 8:45 Operators: [illegible]

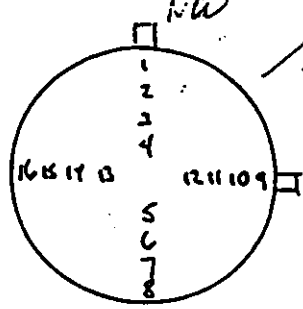
Sampling Location ID: BN

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1.09 (1 1/8)	0.15	74.5°F	23.5158	
2	3.57 (3 5/8)	0.20	76.1°F	24.7878	
3	6.60 (6 7/8)	0.21		25.4000	
4	10.95 (11 1/16)	0.23		26.5820	
5	23.03 (23.0)	0.23		26.5820	
6	27.04 (27 1/16)	0.29		29.8485	
7	30.42 (30 7/16)	0.345		32.7912	
8	32.91 (32 15/16)	0.33		31.5406	
9	1.09	0.33		31.5406	
10	3.57	0.37		33.7151	
11	6.60	0.38		34.1677	
12	10.95	0.30		30.3588	
13	23.0	0.21		25.4000	
14	27.04	0.29		29.8485	
15	30.42	0.34		32.3194	
16	32.91	0.39		34.6143	

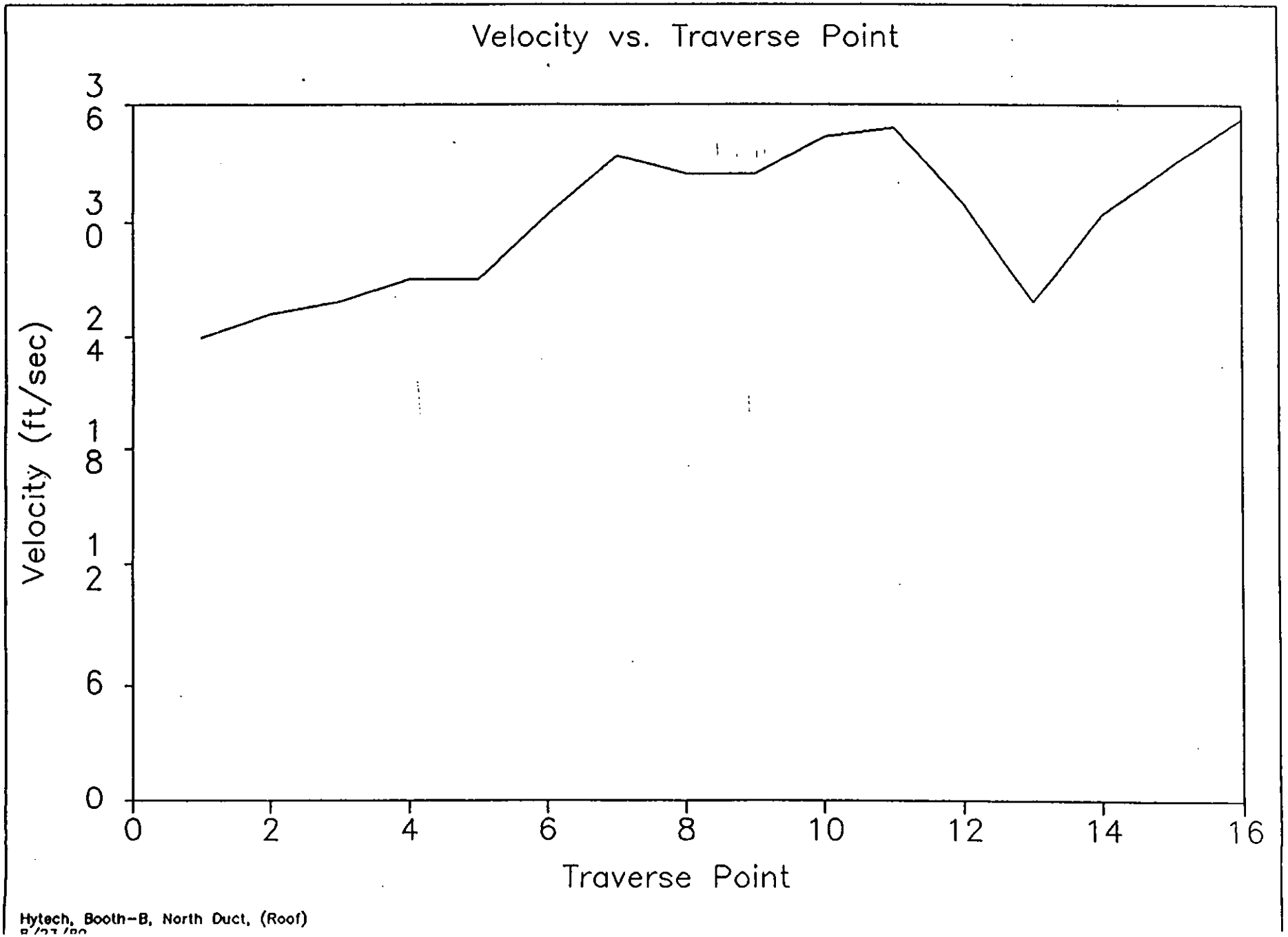
Barometer - West. Precip — Boilers on

$\Delta P_{avg} = 0.2894$

$V_s = 29.4686$



$V_s = 29.6008$ fps



Hytech, Booth-B, North Duct, (Roof)

GRAPHITE

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hydro [illegible] Date: 8-22-89

Location in Plant: [illegible] BN

Location in Duct: [illegible] Top Duct Dimensions: 34"

Atm. Barometric Press: 30.00 Duct Static Press: 0.15

Dry Gas Mol. Wt. 28.84 % Water Vapor: —

Date of EPA Mth 3 Orsat Test: — Date of EPA Mth 4 Moisture Test: —

Pitot Tube Cp: .84 Pitot Tube ID No. Type S, Cr^{+6}

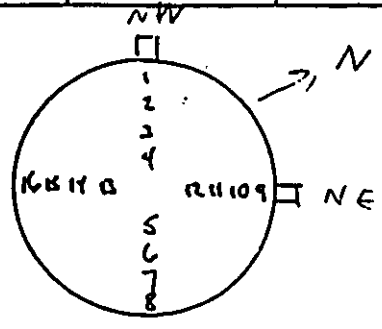
Time of Vel. Traverse Measurements: — Operators: —

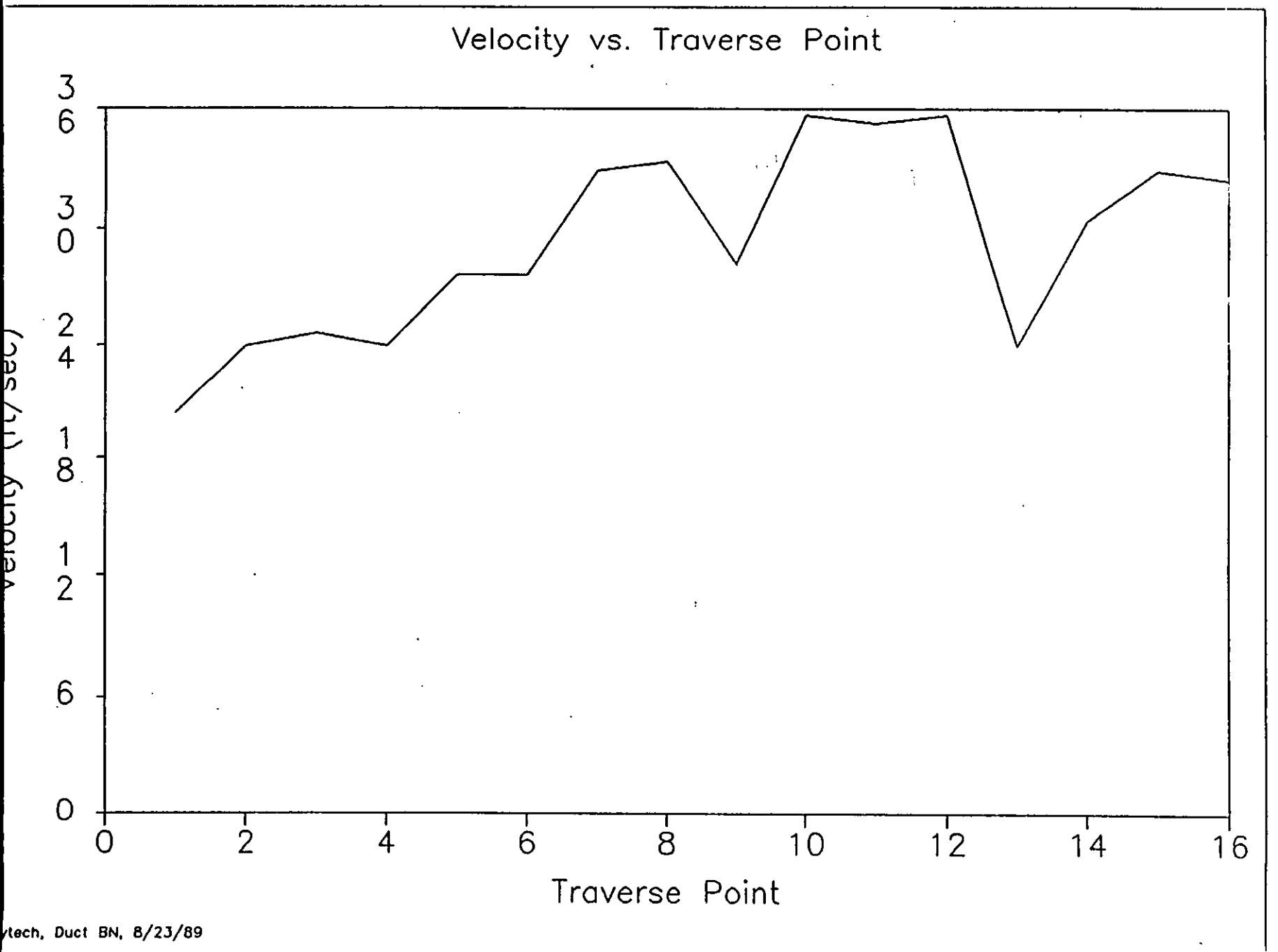
Sampling Location ID: BN

V_s = 28.7848 fps

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1 1/5	0.13	76	19.9546	
2	3 5/8	0.18	76.1°F	23.5158	
3	6 5/8	0.19		24.1602	
4	11 1/16	0.18		23.5158	
5	23	0.24		27.1537	
6	27 7/16	0.24		27.1537	
7	30 7/16	0.34		32.3194	
8	32 15/16	0.35		32.7912	
9	1 1/8	0.25		27.7137	
10	3 5/8	0.40		35.0553	
11	6 5/8	0.39		34.6143	
12	11 1/16	[illegible]		35.0553	
13	23	[illegible]		23.5158	
14	27 7/16	[illegible]		29.5465	
15	30 7/16	[illegible]		32.3194	
16	32 15/16	[illegible]		31.9406	

C_f/AC = 0.2719





ytech, Duct BN, 8/23/89

HB58'c

Gas Velocity Data Sheet (EPA Method 2)

Plant: HyTech Date: 5/23/[illegible]

Location in Plant: Duct B5, [illegible]

Location in Duct: across 4" Duct Diameter: 24"

Atm. Barometric Press: 30.07 Duct Static Press: 0.18

Dry Gas Mol. Wt. 29.9 (assumed) % Water: ~

Date of EPA Mth 3 Orsat Test: — Date of EPA Mth 4 Moisture Test: [illegible]

Pitot Tube Cp: 0.842 Pitot Tube ID No. [illegible]

Time of Vel. Traverse Measurements: 9:20 a.m. Operator: [illegible]

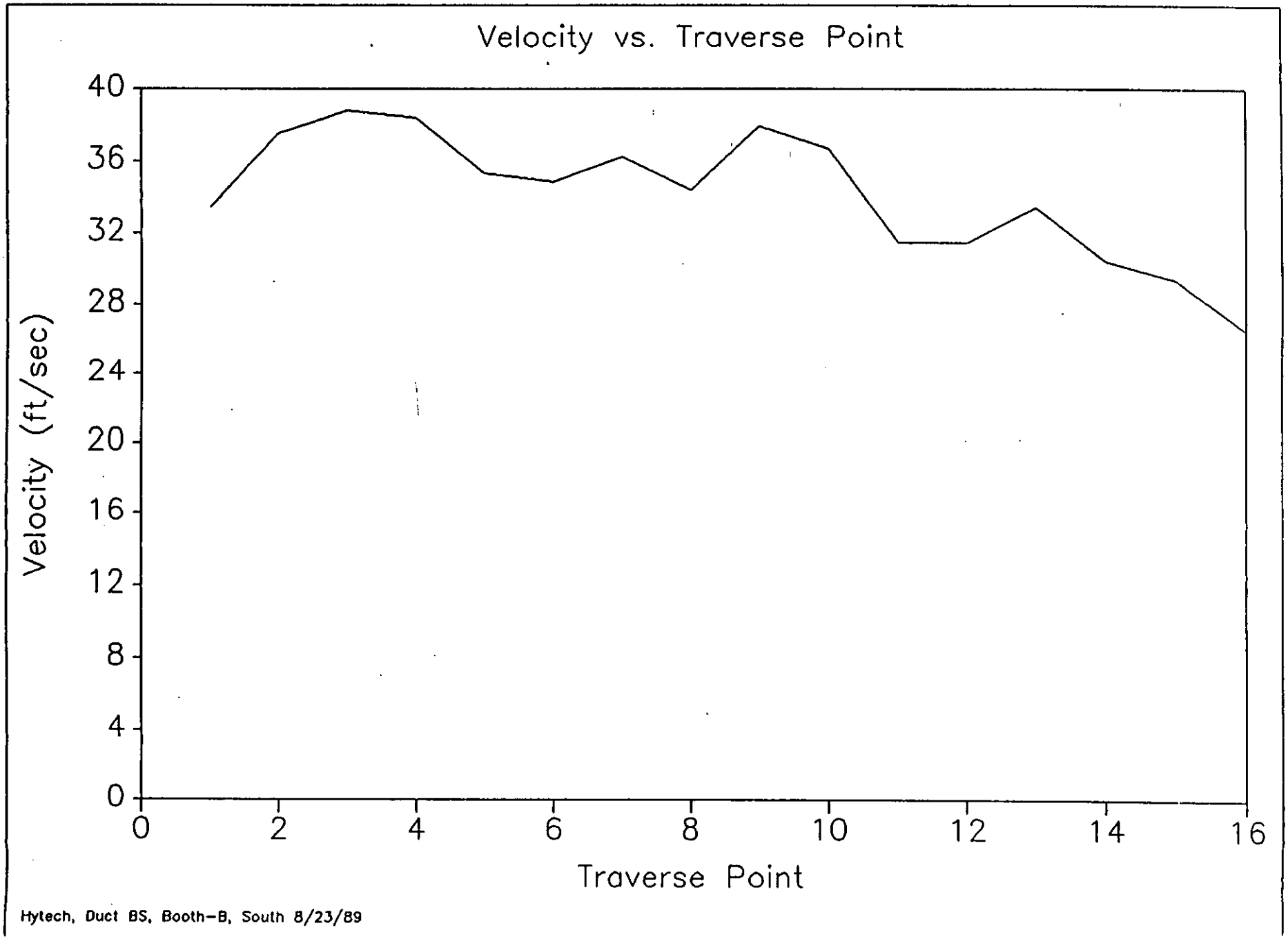
Sampling Location ID: B5

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F) °C	Gas Vel. (ft/sec)
1		0.35	25°C	32.8133
2		0.44	78.8°F	36.7911
3		0.49		38.2246
4		0.46		37.61796
5		0.39		34.6377
6		0.36		34.1907
7		0.41		35.5147
8		0.37		33.7378
9		0.45		37.2068
10		0.40		35.9452
11		0.31		30.3314
12		0.31		30.9314
13		0.45		32.8133
14		0.[illegible]		29.9656
15		0.[illegible]		25.9703
16		0.[illegible]		24.0152

[illegible] 0.[illegible]

$V_{s(AVE)}$ = 33.45

[illegible]


Velocity vs. Traverse Point
Velocity (ft/sec)
0
4
8
12
16
20
24
28
32
36
40
0
2
4
6
8
10
12
14
16
Traverse Point
Hytech, Duct BS, Booth-B, South 8/23/89

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hytech. Velm Date: 12/12/89

Location in Plant: Duct DE

Location in Duct: across top Duct Dimensions: 34"

Atm. Barometric Press: 30.38 Duct Static Press: 0.0

Dry Gas Mol. Wt. 28.84 % Water Vapor: NA

Date of EPA Mth 3 Orsat Test: N.A Date of EPA Mth 4 Moisture Test:

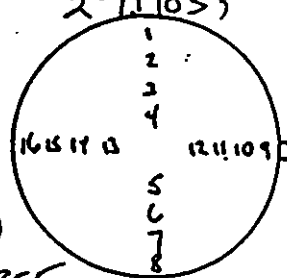
Pitot Tube Cp: .99 Pitot Tube ID No.

Time of Vel. Traverse Measurements: 12:57 Operators: Duane

Sampling Location ID: HDE

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)		Temp (°F)	Gas Vel. (ft/sec)	
1		.21	.16	26°C	26.548	
2		.25	.17	78.8°F	27.365	
3		.28	.18		28.158	
4		.29	.16		26.548	
5		.39	.18		28.158	
6		.39	.18		28.158	
7		.35	.16		26.548	
8		.33	.15		25.965	
9		.20	.17		27.365	
10		.23	.16		26.548	
11		.27	.18		28.158	
12		.28	.18		28.158	
13		.33	.17		27.365	
14		.33	.16		26.548	
15		.32	.17		27.365	
16		.30	.15		23.930	

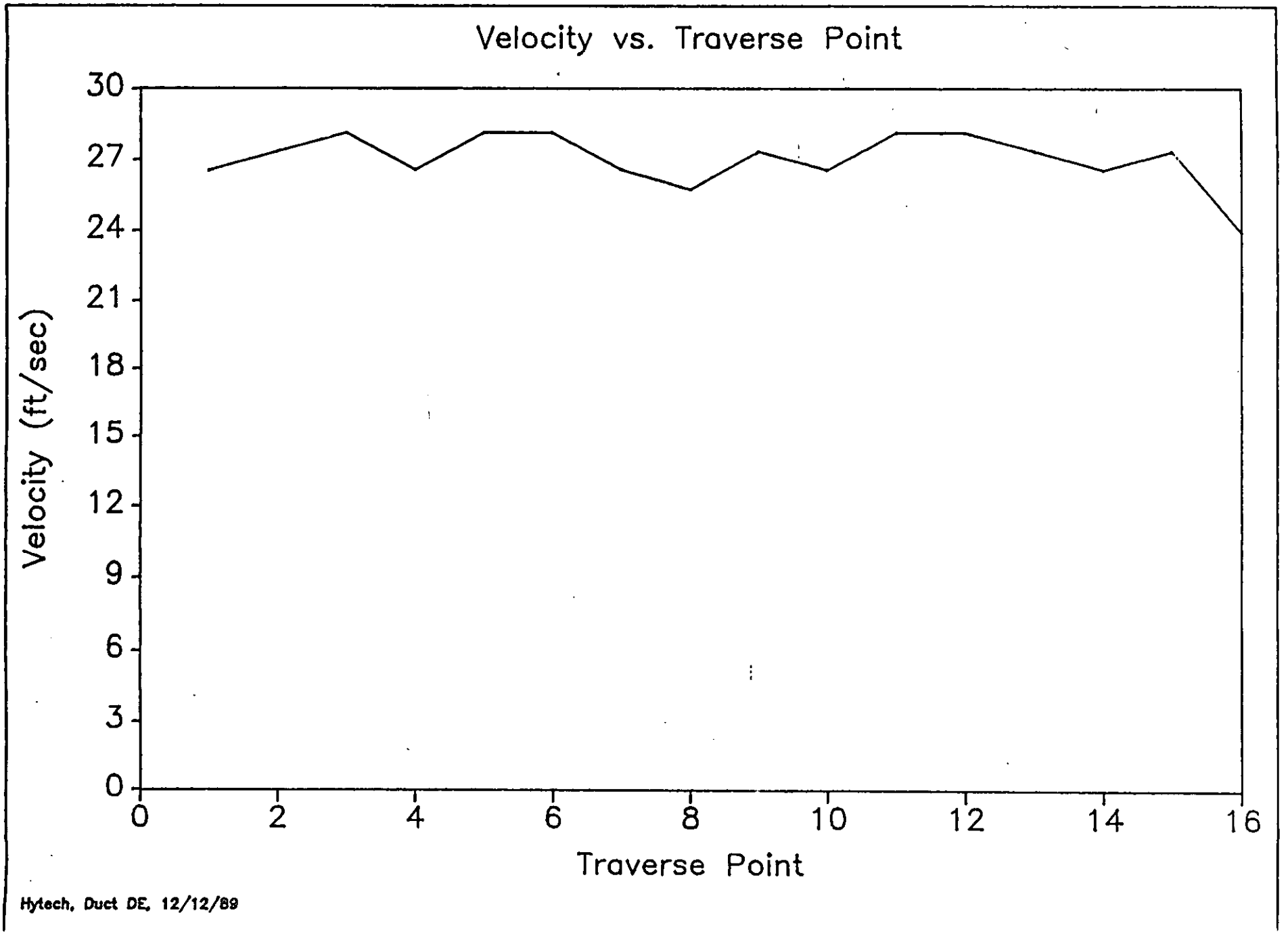
27.1055



$M_{dry} = 28.84($

$M_d = (.32)(20.95) + 0.26(78.09)$ (Argon) $+ 0.39944(.93) + 44.01(.03)$ (CO_2)

$\sim 6.70 + 21.87 + .3714 + 01.320 = 28.955$


Velocity vs. Traverse Point
Velocity (ft/sec)
30
27
24
21
18
15
12
9
6
3
0
0
2
4
6
8
10
12
14
16
Traverse Point
Hytech, Duct DE, 12/12/89

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hytech, Yelm Date: 12/12/[illegible]

Location in Plant: East SW

Location in Duct: at 125 sf Duct Dimensions: 34"

Atm. Barometric Press: 30.35 Duct Static Press: —

Dry Gas Mol. Wt. 28.84 % Water Vapor: —

Date of EPA Mth 3 Orsat Test: _____ Date of EPA Mth 4 Moisture Test: _____

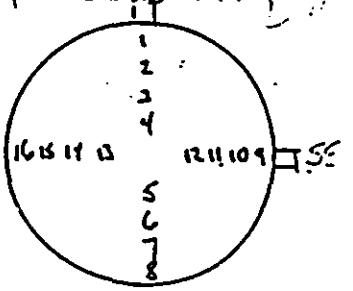
Pitot Tube Cp: .84 Pitot Tube ID No. [illegible]

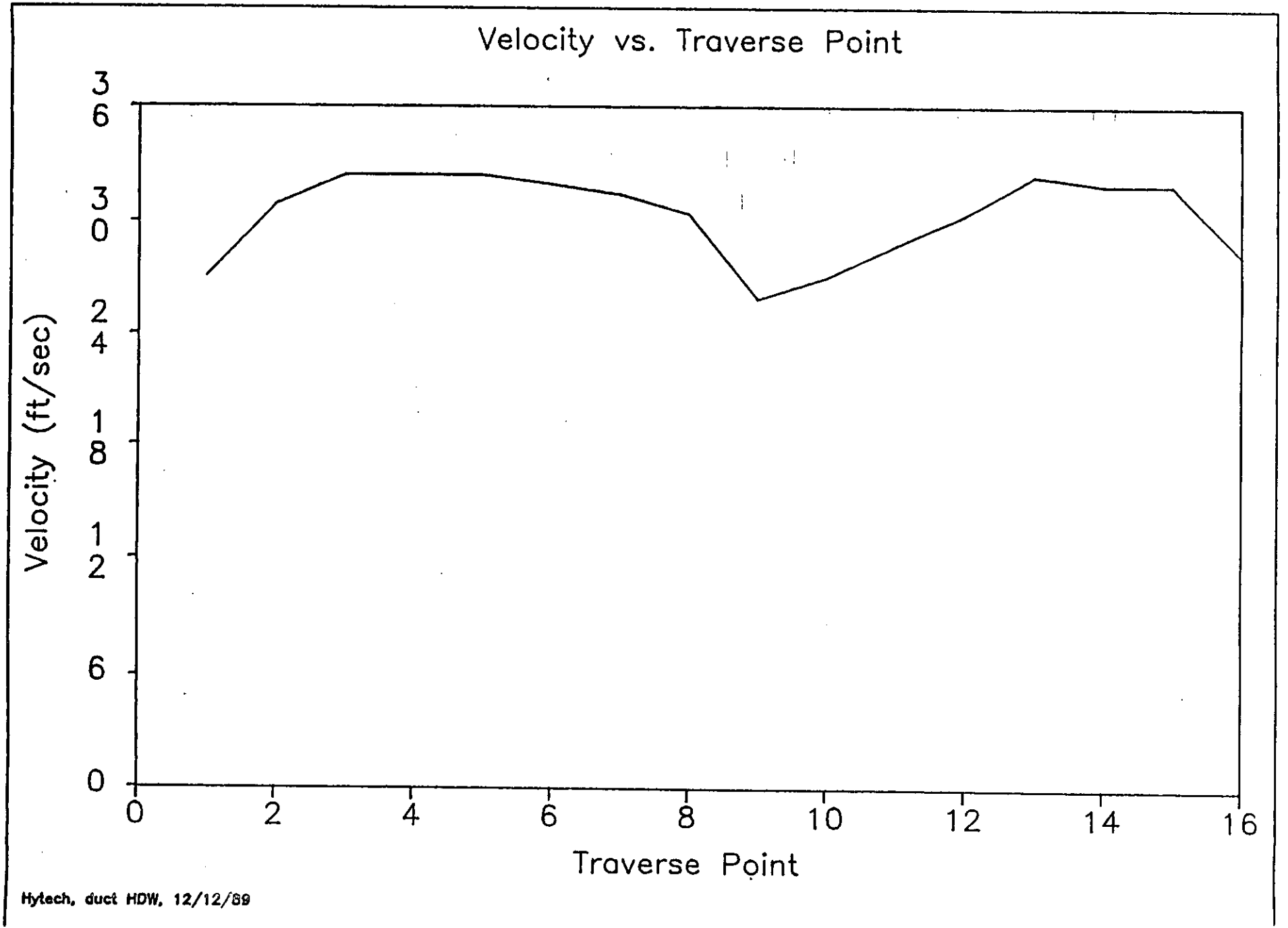
Time of Vel. Traverse Measurements: 12:30 Operators: Dugan S

Sampling Location ID: HCW1 E. Stack

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1.09	.23	27°C	31.899	
2	3.57	.3	〃	36.431	
3	6.60	.33		38.209	
4	10.98	.33		38.209	
5	23.02	.33		38.209	
6	27.04	.32		37.626	
7	30.43	.31		37.033	
8	32.91	.29		35.819	
9		.21		30.480	
10		.23		31.899	
11		.26		33.916	
12		.29		35.819	
13		.33		38.209	
14		.32		37.626	
15		.32		37.626	
16		.25		33.257	

35.767




Velocity vs. Traverse Point
Velocity (ft/sec)
36
30
24
18
12
6
0
0
2
4
6
8
10
12
14
16
Traverse Point
Hytech, duct HDW, 12/12/89

VHEES

Gas Velocity Data Sheet (EPA Method 2)

Plant: HYTECH Date: 8/[illegible]

Location in Plant: Duct 55 - [illegible]

Location in Duct: _____ Duct Dimensions: 34"

Atm. Barometric Press: 30.07 Duct Static Press: ~~[illegible]~~

Dry Gas Mol. Wt. 28.89 % Water Vapor: —

Date of EPA Mth 3 Orsat Test: - Date of EPA Mth 4 Moisture Test: _____

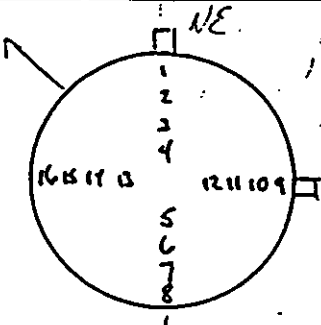
Pitot Tube Cp: 0.84 Pitot Tube ID No. Type S, crt6

Time of Vel. Traverse Measurements: 9:41am Operators: _____

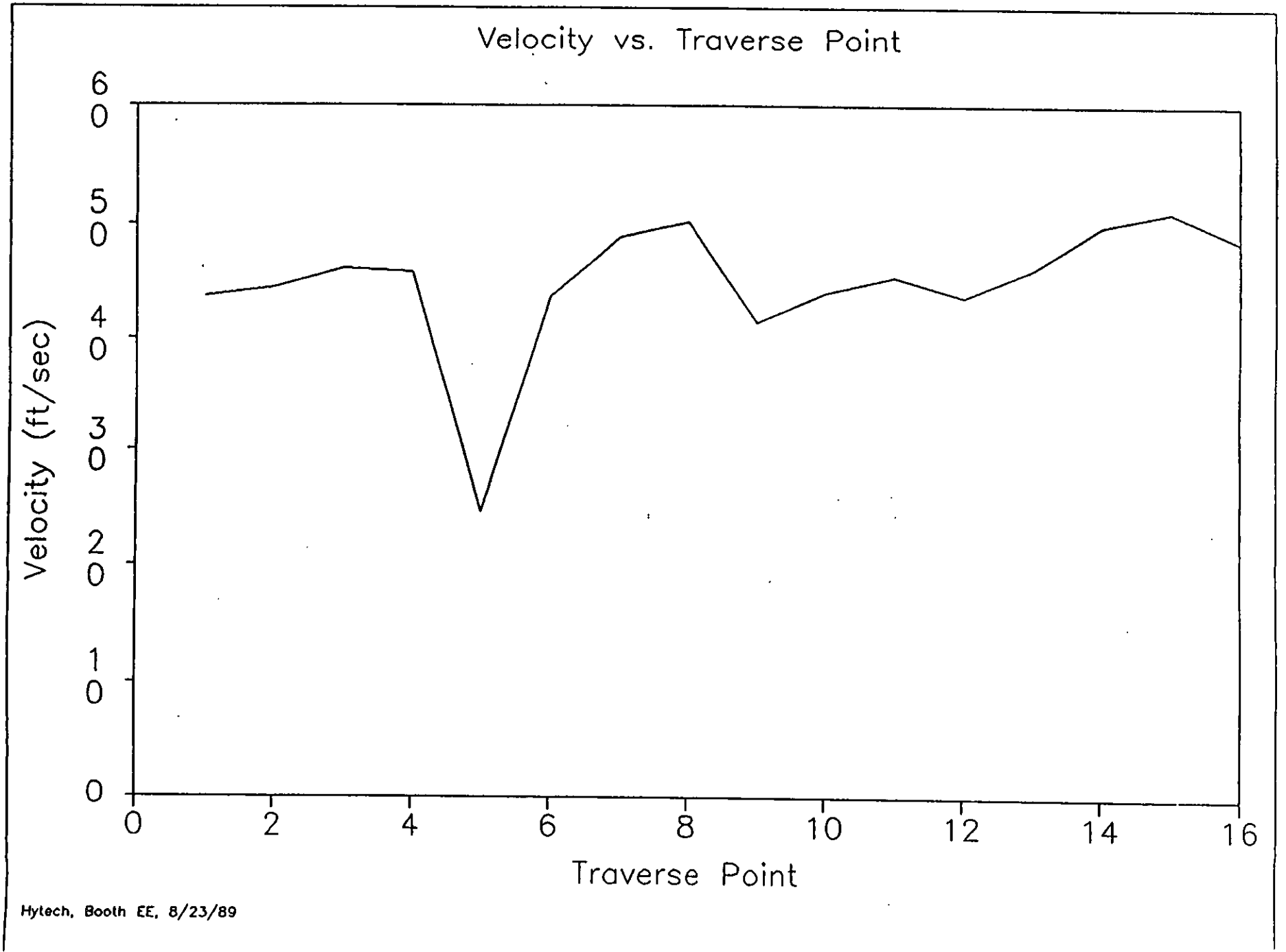
Sampling Location ID: E Ambient Air 20°C

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1		0.60	25°C	42.5916	
2		0.62	77°C	43.2956	
3		0.67		45.0076	
4		0.66		44.6704	
5		0.19		23.9676	
6		0.60		42.5916	
7		0.75		47.6158	
8		0.79		43.8722	
9		0.54		40.4059	
10		0.61		42.9450	
11		0.65		44.3307	
12		0.60		42.5916	
13		0.67		45.0076	
14		0.78		48.5619	
15		0.82		49.7915	
16		0.71		47.3003	

$\Delta p_{ave} = 0.6431$



$V_s = 43.7219$ fps


Velocity vs. Traverse Point
Velocity (ft/sec)
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
Traverse Point
Hytech, Booth EE, 8/23/89

VHEW

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hytech Date: 8-22-89

Location in Plant: Duct E W

Location in Duct: Over top. Across top Duct Dimensions: 34"

Atm. Barometric Press: 30.07 Duct Static Press: 0.96 @ center

Dry Gas Mol. Wt. 28.84 lb/lb Mol % Water Vapor: -

Date of EPA Mth 3 Orsat Test: _____ Date of EPA Mth 4 Moisture Test: _____

Pitot Tube Cp: 0.84 Pitot Tube ID No. Type S, Crtb

Time of Vel. Traverse Measurements: 11:00 am Operators: Duggan & Hall

Sampling Location ID: _____

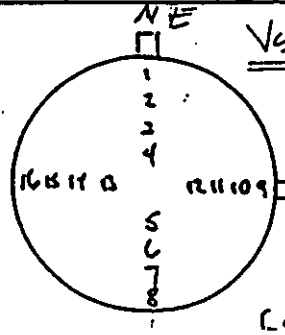
Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1	1.09	0.60		43.2531	
2	2.57	0.78		48.5141	
3	6.60	0.80		49.1322	
4	10.98	0.56		41.1069	
5	23.02	0.72		46.6109	
6	27.04	0.79		48.9241	
7	30.43	0.74		47.2538	
8	32.91	0.82		49.7425	
9		0.51		39.2289	
10		0.52		39.9907	
11		0.64		43.9451	
12		0.54		41.3345	
13		0.62		43.6005	
14		illegible		48.2021	
15		0.84		50.3455	
16		0.87		51.2366	

Temp 22°C ASSUM

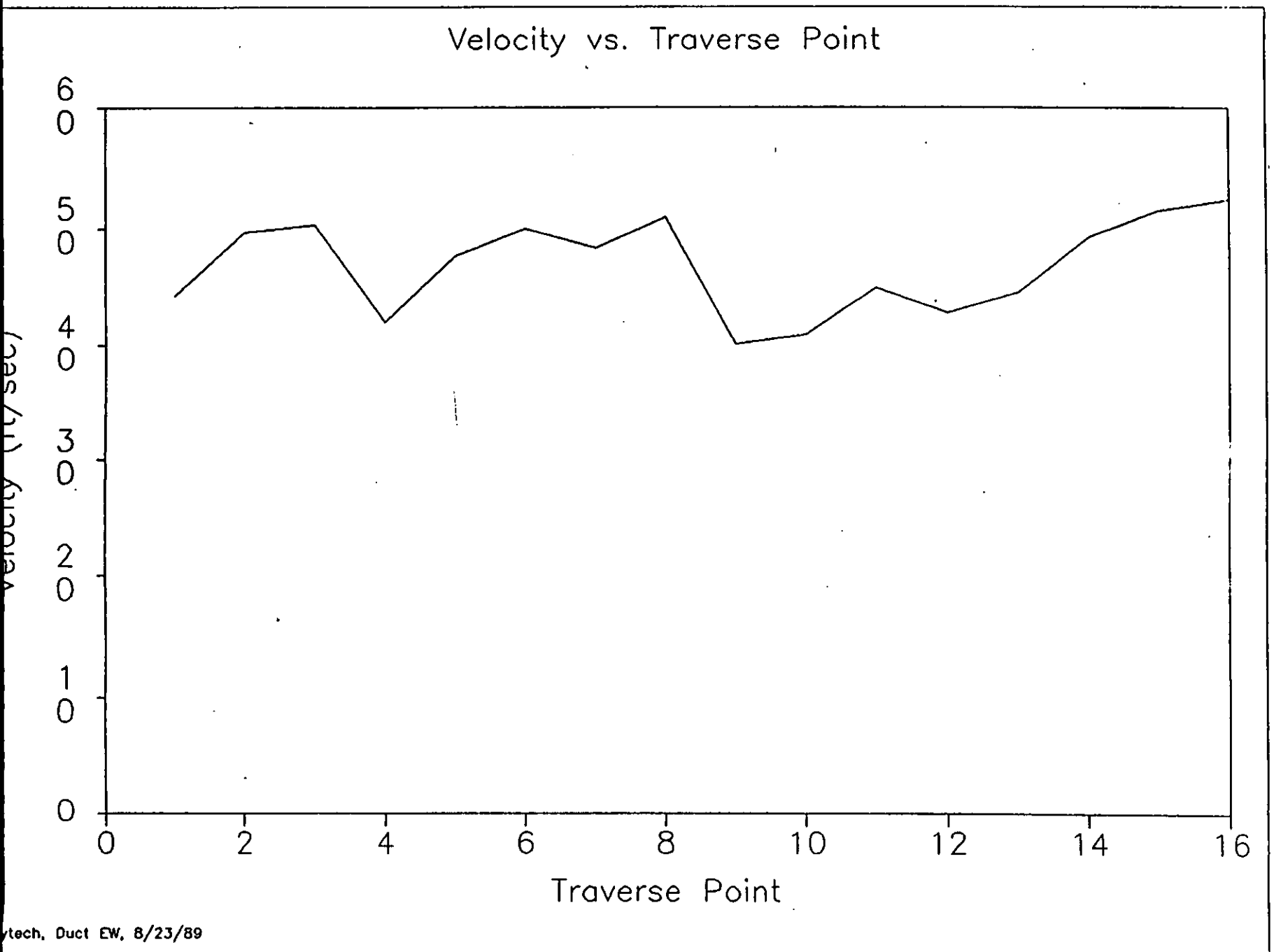
ΔPave = 0.70

Vs = 45.5013 fps

71.6°



Looth E



ytech, Duct EW, 8/23/89

Gas Velocity Data Sheet (EPA Method 2)

Plant: Hydrotex Yoakum Date: 12/12/07

Location in Plant: Duct FE

Location in Duct: Across top Duct Dimensions: 39"

Atm. Barometric Press: 30.36 "Hg Duct Static Press: 0.0

Dry Gas Mol. Wt. 28.84 % Water Vapor:

Date of EPA Mth 3 Orsat Test: N/A Date of EPA Mth 4 Moisture Test: N.A.

Pitot Tube Cp: .99 Pitot Tube ID No. U.W. 60" Standard

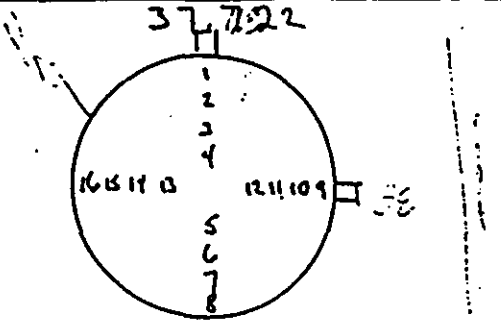
Time of Vel. Traverse Measurements: 13:40 Operators: [illegible]

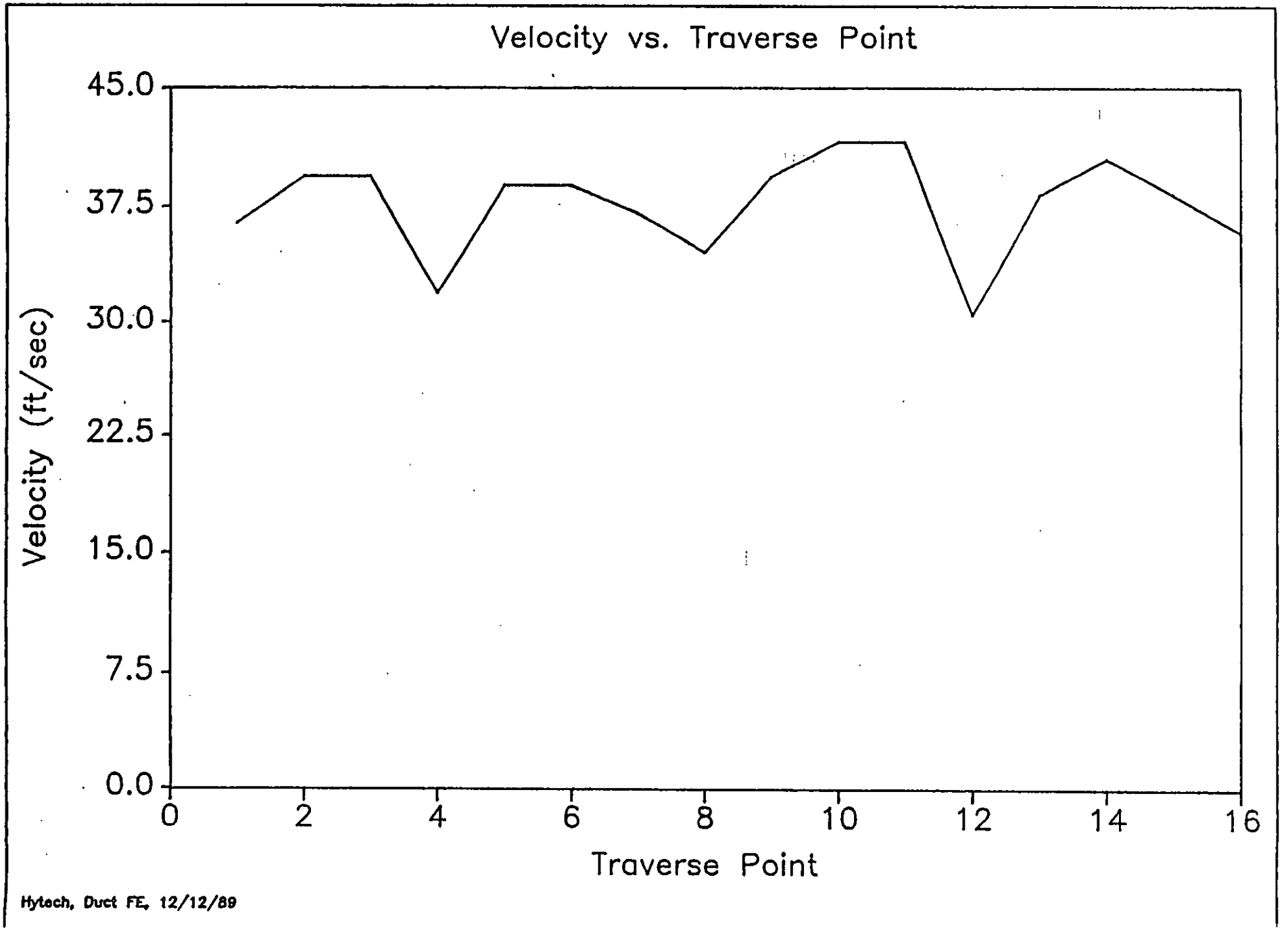
Sampling Location ID:

SV1

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1		.38	275°C	36.455	
2		.35		39.376	
3		.35		39.376	
4		.23		33,279	
5		.34		38.810	
6		.34		38.810	
7		.31		37,058	
8		.27		34.585	
9		.35		39.376	
10		.39		41.566	
11		.39		41.566	
12		.21		30,501	
13		.33		38.235	
14		.37		40.486	
15		.33		38.235	
16		.29		35.843	

37,722




Velocity vs. Traverse Point
45.0
37.5
30.0
22.5
15.0
7.5
0.0
Velocity (ft/sec)
0
2
4
6
8
10
12
14
16
Traverse Point
Hytech, Duct FE, 12/12/89

Gas Velocity Data Sheet (EPA Method 2)

Plant: [illegible] Date: 12/12

Location in Plant: [illegible] F/1

Location in Duct: _____ Duct Dimensions: 34

Atm. Barometric Press: 30.35 Duct Static Press: —

Dry Gas Mol. Wt. 28.84 % Water Vapor: —

Date of EPA Mth 3 Orsat Test: _____ Date of EPA Mth 4 Moisture Test: _____

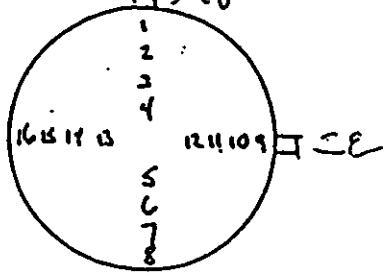
Pitot Tube Cp: .99 Pitot Tube ID No. _____

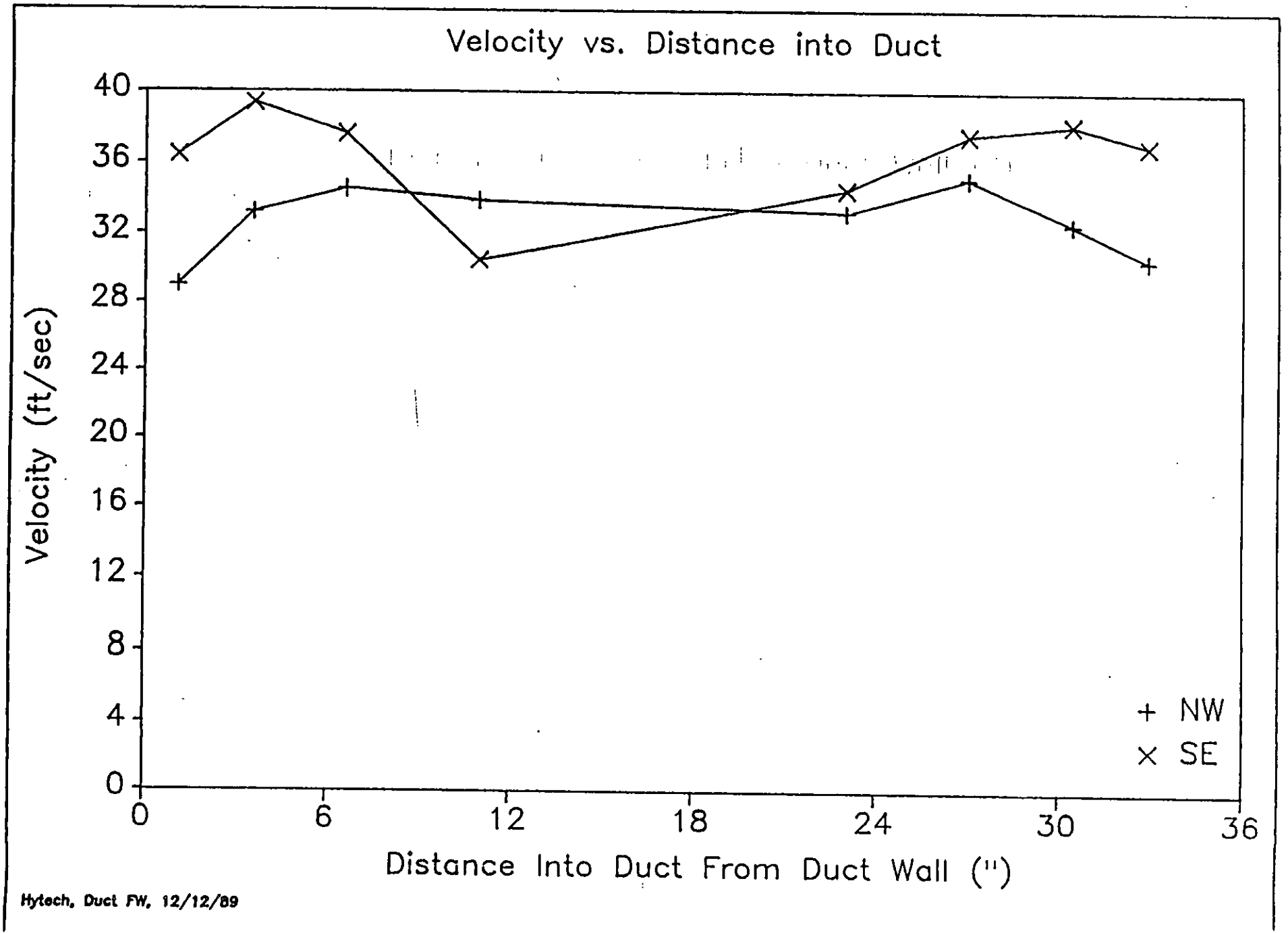
Time of Vel. Traverse Measurements: 2:10 Operators: Dave

Sampling Location ID: F/1 [illegible]

Traverse Pt. No.	Distance into duct from duct wall (")	Pitot ΔP (" H_2O)	Temp (°F)	Gas Vel. (ft/sec)	
1		.19	27°C	28.993	
2		.25	80.6°F	33.257	
3		.27		34.562	
4		.26		33.915	
5		.25		33.257	
6		.28		35.196	
7		.24		32.588	
8		.21		30.480	
9		.31		36.431	
10		.35		39.350	
11		.32		37.626	
12		.21		30.480	
13		.27		34.562	
14		.30		37.626	
15		.33		38.209	
16		.31		37.633	

34 5/8 598




Velocity vs. Distance into Duct
Velocity (ft/sec)
40
36
32
28
24
20
16
12
8
4
0
0
6
12
18
24
30
36
Distance Into Duct From Duct Wall (")
+ NW
× SE
Hytech, Duct FW, 12/12/89

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OCT 26 1989
AIR PROGRAM
BRANCH

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

Department of Civil Engineering, FX-10

October 24, 1989

Memo To: Elizabeth Waddell
EPA Region 10
1200 Sixth Ave
Seattle, WA 98101

Teddy Le
Washington State Dept. of Ecology
Air Programs PV-11
Olympia, WA 98504-8711

Subject: Styrene Emissions Data from Hytec

Attached is a table of preliminary data from styrene emission source tests conducted Sept. 6, 1989 at Hytec in Yelm. There are "holes" in the table because of missing data (i.e. for duct BS the air sampling pump failed; for ducts DE, DW, FE, and FW no air velocity traverse measurements were made).

The total styrene emissions from the plant can be estimated by using the average styrene concentration of 180.90 mg/m^3 or .079055 $grain/ft^3$ or 1.1293587×10^{-5} lb/ft^3.

$$\text{Styrene Emissions} = (1.1293587 \times 10^{-5} \frac{lb}{ft^3})(10 \text{ ducts})(13{,}992 \frac{ft^3}{min}) = 1.58 \text{ lb styrene/min.}$$
$$= 94.8 \text{ lb/hr}$$

Assuming a 16 hr. work day, this provides an emission of 1,517 lb styrene/day.

We would like to request that the risk assessment calculations, which the Washington State Department of Ecology will be making, be initiated soon so that we can ensure that the required parameters, data, details, etc. are made available. If an example of the risk assessment calculation procedure can be mailed to us, this would help to see that we obtain the needed data.

Stacia Dugan will be making additional tests at Hytec. Also, she has analyzed sorbent samples obtained later than the Sept. 6, 1989 data shown in the attached table. However, I wanted to send you some data to illustrate the data format and the magnitude of the styrene emissions.

Please phone me at (206) 543-4789 or Stacia Dugan at 543-8195 (lab phone) if you have questions about this. Your continued assistance is greatly appreciated.

Sincerely yours,

Michael J. Pilat
Professor

cc: Stuart Clark
Jay Willenberg

Emission Rates From a Fiberglass Fabrication Industry

Calculations performed by: Stacia Dugan

Duct ID	Area of Duct (ft^2)	Air Velocity in Duct (ft/sec)	Date of	Volumetric Flow Rate (ft^3/min.)	Styrene Concentration Date measured	(grams/sec)	(lb/hr)	(lb/day)	($\frac{mg\ styrene}{m^3}$)
AE	6.305	40.76		15,421	9/6/89	2.250	17.86		327.23
AW	6.305	36.55		13,829	9/6/89	1.776	25.04		272.18
BN	6.305	29.88		11,302	9/6/89	0.877	6.96		164.47
BS	6.305	33.48		12,667	9/6/89	-	-	-	-
DE	6.305				9/6/89				158.23
DW	6.305				9/6/89				168.71
EE	6.305	35.44		13,405	9/6/89	0.638	5.06		100.80
EW	6.305	45.80		17,327	9/6/89	0.555	4.40		67.84
FE	6.305				9/6/89				232.18
FW	6.305				9/6/89				136.46
				13,992				Average	180.90

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Bibliography

R. H. Bogue, *The Chemistry of Portland Cement*, 2nd ed., Reinhold Publishing Corp., New York, 1955.

W. H. Duda, *Cement Data Book*, 3rd ed., Bauverlag Gmbh, Weisbaden and Berlin, 1985.

O. Labahn and B. Kohlhaas, *Cement Engineers Handbook*, 4th Ed., Bauverlag GmbH, Wiesbaden and Berlin, 1983.

K. E. Peray, *Cement Manufacturers Handbook*, Chemical Publishing Co., New York.

K. E. Peray, and J. J. Waddell, *The Rotary Cement Kiln*, Chemical Publishing Co., New York, 1972.

VDZ Congress '85, *Process Technology of Cement Manufacturing*, Bauverlag GmbH, Wiesbaden and Berlin, 1987.

FIBERGLASS OPERATIONS

Aaron J. Teller and Joseph Y. Hsieh

The production of fiberglass consists of two different forms of product—continuous-filament fiberglass or textile products and fiberglass blown wool or insulation products.

The general-purpose textile fiberglass, which is moisture and alkali resistant with good electrical and physical properties, is also called E- (electrical) Glass. The major applications of the general-purpose textile fiberglass are in the production of fireproof cloth, fiberglass-reinforced plastics (FRP), and composites. The insulation product lends itself for the application of thermal and acoustical insulation because the small cell of air entrained in the wool or blanket prevents the movement of the air and sound wave. The manufacturing process consists of (Figure 1): materials blending and transport, melting and refining, and fiberforming and textile operation.

As in the manufacturing of glass, the major air emission problem where acid-gas recovery in addition to particulate is required is related to the melting and refining furnace operation. The fiberforming and textile operations produce, primarily, particulate emissions and some volatile organic compounds (VOCs). The textile product manufacture presents a more complex emissions control problem than does insulation manufacture because of the presence of boron and fluorine in the most flexible E-Glass product.

PROCESS DESCRIPTION

The composition of textile and insulation fiberglass, although varied as a function of the producer, has the general composition[1] shown in Table 1.

The raw materials are unloaded from freight cars or trucks and transported to specific silos in the batch house. The materials are then withdrawn to automatic weight machines and blended. The mix is transported by air conveying to the holding vessel at the melter and then fed as a batch to the furnace or melter.

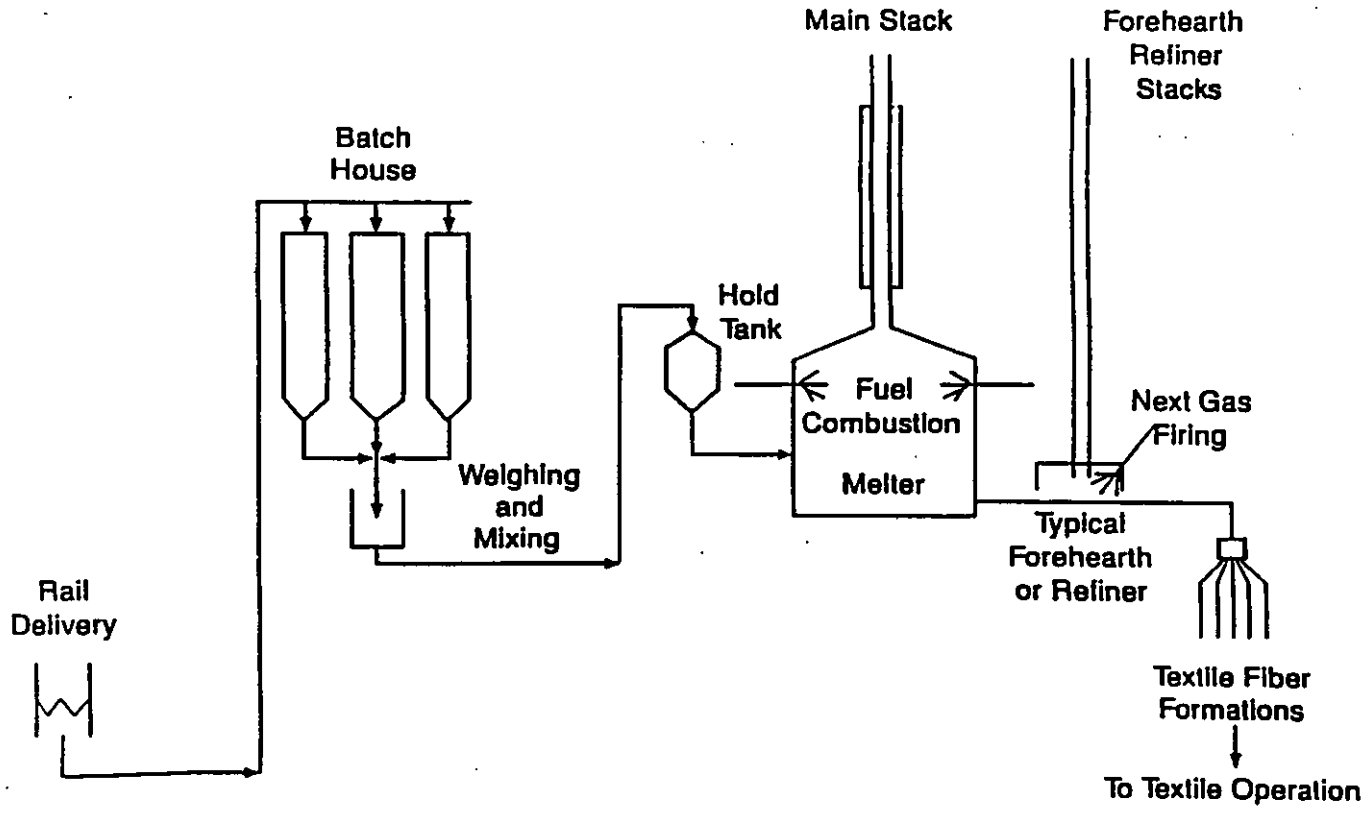

FIGURE 1. Fiberglass Manufacturing Process

TABLE 1. Composition of Textile and Insulation Fiberglass

Component	Textile, % Weight	Insulation, % Weight
SiO_2	54–55	59–65
Al_2O_3	13–14	4–8
Na_2O	0.5	15–18
CaO	22–24	4.5–9
MgO	0.3–0.4	0–4
B_2O_3	5.5–6.8	0–2
Fe_2O_3	0.3	0.1–5
F	0.7	
K_2O		0.3
MnO		0–4
BaO		0–5
SO_3		≤0.6

The melters are of the reverberatory type with gas firing, although oil may be used. There is a significant difference from the container or float glass furnace. Thermal recovery is achieved by a recuperator in a continuous manner rather than cyclical. A part of the reasoning is that the fiberglass (especially textile) melt is extremely sensitive to very small pressure variations and that boron emissions can clog the brick-lattice regenerator.

Because of the time–temperature sensitivity of the final product, liquid glass flows through channels with zones of refiners and forehearths, in addition to the melter. These forehearths and refiners are generally fired with natural gas. The flue gas from the melter flows upward from the combustion zone through the stack containing an annular zone heat exchanger. Combustion air flows in the annular zone of the recuperator for preheating. The flue gas at 500–800°C is emitted, generally by passing through an air damper, to the stack. The forehearth and refiner flue gases are emitted through individual stacks. These flue gases are often combined with the melter flue gas.

AIR EMISSIONS CHARACTERIZATION

The air emissions for the fiberglass operation can be characterized according to the three phases of manufacturing processes. Emission factors for the fiberglass operations are given in Tables 2 and 3.

TABLE 2. Emission Factors for Glass Fiber Manufacturing Without Controls[a]
Emission Factor Rating: B

	Particulates		SO_x		CO		NO_x		VOC[b]		Flourides	
	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg
Unloading and conveying[c]	3.0	1.5	d	d	d	d	d	d	d	d	d	d
Storage bins[c]	0.2	0.1	d	d	d	d	d	d	d	d	d	d
Mixing and weighing[c]	0.6	0.3	d	d	d	d	d	d	d	d	d	d
Crushing and batch charging[c]	Neg	Neg	d	d	d	d	d	d	d	d	d	d
Glass furnace—wool												
Electric	0.5	0.25	0.04	0.02	0.05	0.025	0.27	0.14	e	e	0.002	0.001
Gas—regenerative	22	11	10	5	0.25	0.13	5	2.5	e	e	0.12	0.06
Gas—recuperative	25–30	13–15	10	5	0.25	0.13	1.7	0.85	e	e	0.11	0.06
Gas—unit melter	9	4.5	0.6	0.3	0.25	0.13	0.3	0.15	e	e	0.12	0.06
Glass furnace—textile												
Recuperative	2	1	3	1.5	0.5	0.25	20	10	d	d	2	1
Regenerative	16	8	30	15	1	0.5	20	10	d	d	2	1
Unit melter	6	3	e	e	0.9	0.45	20	10	d	d	2	1
Forming—wool												
Flame attenuation	2	1	d	d	d	d	d	d	0.3	0.15	e	e
Forming—textile	1	0.5	d	d	d	d	d	d	Neg	Neg	d	d
Oven curing—wool												
Flame attenuation	6	3	e	e	3.5	1.8	2	1	7	3.5	e	e
Oven curing and cooling—textile	1.2	0.6	d	d	1.5	0.75	2.6	1.3	Neg	Neg	d	d

[a]Expressed as units per unit weight of raw material processed. Neg = negligible.
[b]Includes primarily phenols and aldehydes, and to a lesser degree, methane.
[c]Reference 10.
[d]Not applicable.
[e]No data are available.

TABLE 3. Uncontrolled Emission Factors for Rotary Spin Wool Glass Fiber Manufacturing[a]

Products	Particulate			Organic Compounds[b]		
	Front Half	Back Half	Total	Phenolics[c]	Phenol	Formaldehyde
R-19	17.81 (36.21)	4.25 (8.52)	22.36 (44.72)	3.21 (6.92)	0.96 (1.92)	0.75 (1.50)
R-11	19.61 (39.21)	3.19 (6.37)	22.79 (45.59)	6.21 (12.41)	0.92 (1.84)	1.23 (2.46)
Ductboard	27.72 (55.42)	8.55 (17.08)	36.26 (72.50)	10.66 (21.31)	3.84 (7.68)	1.80 (3.61)
Heavy density	4.91 (9.81)	1.16 (2.33)	6.07 (12.14)	0.88 (1.74)	0.53 (1.04)	0.43 (0.85)

[a]Reference 7. Expressed kg/Mg (lb/ton) of finished product. Gas stream did not pass through any added primary control device (wet electrostatic precipitator, venturi scrubber, etc.)
[b]Included in total particulate catch. These organics are collected as condensible particulate matter and do not necessarily represent the entire organics present in the exhaust gas stream.
[c]Includes phenol.

Materials Blending and Transport

The primary air pollution problem in this phase of the operation is that of containment and fugitive dust handling inasmuch as fine particulates are not involved. The raw materials are generally in the size range of 20–500 μm.

Melting and Refining

The emissions from the melting–refining furnace during the textile fiberglass operation contain:

1. Fine particulates, including calcium carbonate, sodium fluoride, sodium fluosilicate, silica, calcium fluoride, aluminum silicate, sodium sulfate, boron oxides—boric acid.
2. Gases, including fluorides—hydrogen fluoride, silicon tetrafluoride, sulfur oxides, nitrogen oxides, boric acid, carbon dioxide, water vapor.

The solid particulates emitted in the melter flue gas are in the class of fine particulates with most of the particle size below 10 μm. Another class of particulates is formed downstream of the stack for the untreated emissions. This consists primarily of sublimed boric acid. It can form very opaque, long-lasting white plume after cooling resulting from sublimation. This "formed particulate" is created in the emissions from the melter, forehearths, and refiners. About 70% of the boron and fluorine emissions are emitted by the melter.

The concentration of the particulates and condensible vapor boric acid in the efflunt gases are as follows:

Solid particulates	200–1500 mg/nm^3
Boron oxide, solid plus equivalent boric acid	100–1000 mg/nm^3

The gaseous components of the emissions are hydrogen fluoride, silicon tetrafluoride, sulfur oxides, and the boric acid considered in the discussion of particulates. They are present in concentrations ranging as follows:

HF, SiF_4(equivalent HF)	20–160 ppm
SO_x	40–80 ppm

The emissions from the melting–refining furnace of the insulation fiberglass operation contain only small quantities of boron and no fluoride. The emissions from the fiberforming and textile operations include particulate and VOC emissions. The VOC emissions are lower for textile fiberglass than for insulation fiberglass operation because of the small quantities of lubricant and VOC used in the textile fiberglass operation.

AIR POLLUTION CONTROL MEASURES

Materials Blending and Transport

In the materials storage and transport area, the railroad discharge is generally partially sleeved and under either positive or negative pressure. The silos are provided with bin vent filters for collecting the fugitive dust. The blending vessels are vented with airflow directed to bag filters. These are generally pulse jets operating at an air-to-cloth ratio in the range of 4–7 fpm. The solid discharge is recycled to the blending zone.

Melting and Refining

A major consideration in the control of emissions from E-Glass furnaces is the suppression by capture of the boron compounds. If this is not achieved, then the prospect of opaque plumes resulting from sublimation of boric acid and

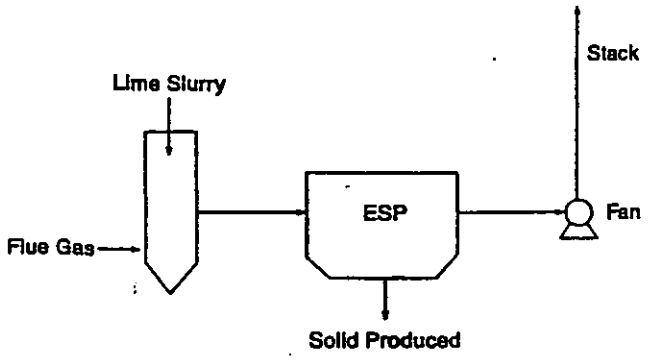

FIGURE 2. Spray Dryer—Electrostatic Precipitator System

the potential for forming a complex of HF and H_3BO_3 such as HBF_4 both exist.

A significant factor in the design of the air pollution control system is the maintenance of the melter pressure, with the permissible variation, as requested by furnace operators, ±0.01 inch wc. Both wet and dry scrubbing methods have been utilized in controlling the emissions from the melting and refining operation.

Wet Scrubbing

Either the venturi-packed bed scrubber or a nucleation cross-flow scrubber can be used. The venturi system is a modification of the conventional packed-tower–venturi–cyclone arrangement for recovering the particulate and acid gases. The treatment of blow-down stream required appears to have limited its application.

A low-energy (less than 15 inches wc) nucleation cross-flow scrubber was operated in a Canadian facility[8]. The system used a cooling tower to circumvent the steam plume appearance. The major problems encountered were the dual alkali transfer for (Na→ Ca), resulting in excess solubility of calcium ions. This often resulted in plugging of the scrubbers by deposition of insoluble calcium salts.

Dry Scrubbing

Two types of systems have been installed in the United States for E-Glass production.

1. Spray drier–electrostatic precipitator (ESP) (Figure 2)
2. Quench reactor–dry venturi–Baghouse (Figure 3).

The latter type has also been installed in the U.S.S.R. and Taiwan.

Spray Dryer–Electrostatic Precipitator

The gases are cooled by a water-lime slurry quench to about 100°C and then flow to the ESP, the system fan, and out the stack. Although gaseous fluoride was reduced to the 5-ppm range, there was evidence of significant plume opacity,

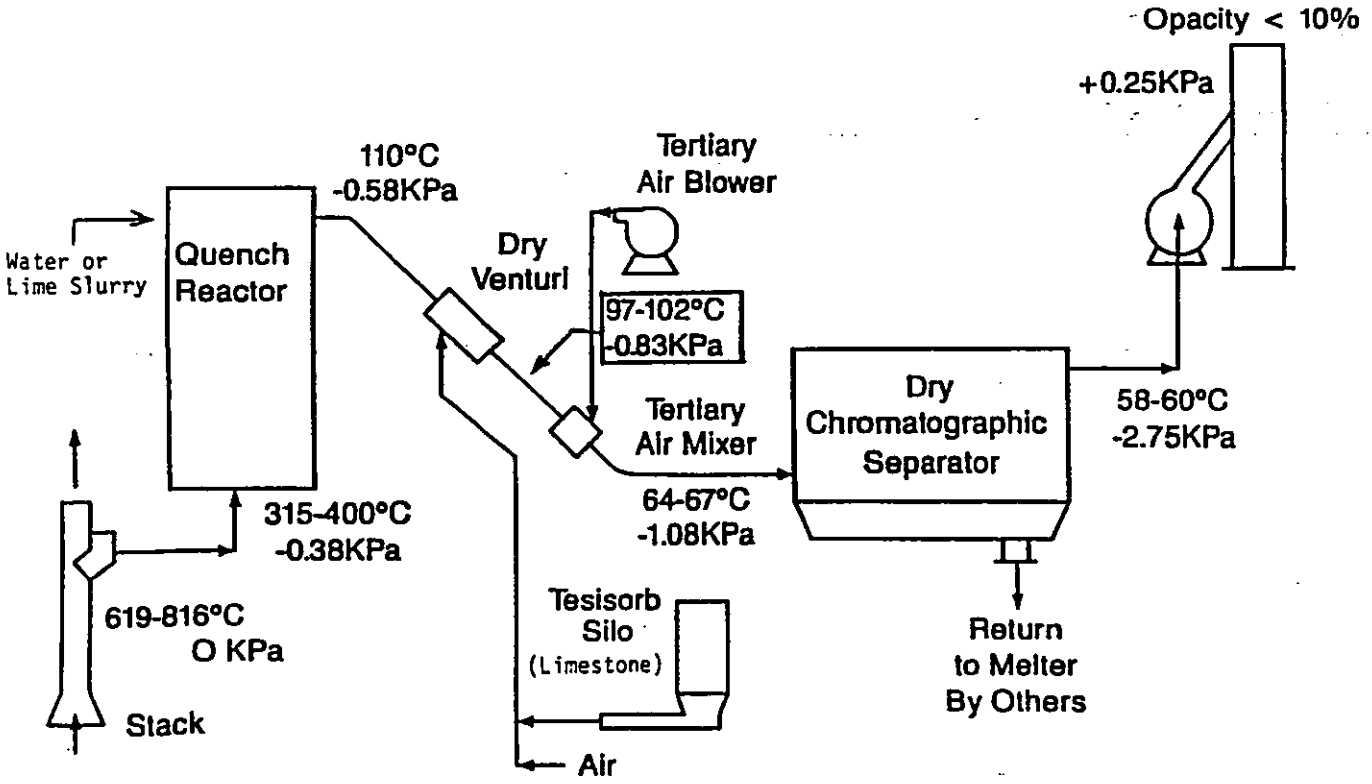

FIGURE 3. Typical Teller Dry Chromatographic System for the Fiberglass Industry—HF, SO_x, and Particulate

TABLE 4. Performance of Semi-Dry System Fiberglass Emission Control

		Outlet Composition					
		Fluoride			Boron		
Dry Gas Flow, sdcfm	Particulate, mg/nm³	Solid, lb/hr	Gas, lb/hr	ppm	Solid, lb/hr	Gas, lb/hr	mg/nm³
18,500	1.5	0.015	0.11	2.12	0.03	0.92	13.7
14,600	2.3	0.004	0.009	0.28	0.030	0.475	9.2
15,500	2.1	0.005	0.017	0.45	0.032	0.568	10.3
14,800	4.5	0.003	0.007	0.21	0.019	0.208	4.1
15,100	1.8	0.003	0.002	0.10	0.03	0.52	9.8

Source: Reference 9.

reflecting the presence of boron compounds in the emitted gases.

Problems were reported regarding condensation and adhesion melting of particulate on the ESP electrodes.[2]

Quench Reactor–Dry Venturi–Baghouse[3,4]

This system is operated with either water quench or lime slurry quench as a function of requirements for reduction of SO_2 and HF. Where the only SO_x reduction requirement is related to opacity, and SO_3 only is to be removed, water quench in the quench reactor is utilized.

The quenched gas, at about 100°C proceeds to the dry venturi, where limestone is introduced into the gas stream as both reagent and cake modifier.[3] The gas is then further cooled by air dilution to the range of 60–70°C. The limestone acts to neutralize the fluorides and aid in the formation of a low-compressibility layer in the baghouse. A significant part of the neutralization reaction occurs in equivalent renewable "fixed bed" cake on the bags. The cleaning cycle is approximately six hours.

The reduction of temperature to 60–70°C results in the sublimation of the boric acid. This boric acid is deposited on the surface of the baghouse cake along with the crystalline reagents. Filtration in a temperature region only 20°F greater than the dew point is maintained with a system pressure drop in the range of 8 inches wg. The performance of the system, with greater than 98% on-line reliability, is given in Table 4.

For the insulation fiberglass operation, inasmuch as the emissions from the melter contains no fluoride and only small quantities of boron, the emission control can be achieved by a system such as a spray dryer–ESP (Figure 2) or spray dryer–baghouse.

Fiberforming and Textile Operation

Fiber formation does not present emission control difficulties. However, the spraying of the mat with lubricants and/or binders to minimize erosion of the fibers can create either VOC or inorganic particulate emissions.

The predominantly inorganic discharges are treated in a cross-flow scrubber with particulate emissions reduced to less than 25 mg/nm³.[6] The organic emissions are treated by condensation processes for high-molecular-weight emissions and, if necessary, adsorption for low-molecular-weight compounds.

References

1. Duffy, "Glass technology," *Chem. Tech. Rev.*, 184 (1981).
2. Noll, *Glass Tech.*, 25(2); 91–97 (1984).
3. A. J. Teller, U.S. Patent 2,018,157, 1972.
4. A. J. Teller, U.S. Patent 4,319,890, 1982.
5. A. J. Teller, *Glass Indus.* 18–26 (June 1982).
6. Private communications, Ceilcote
7. *Wool Fiberglass Insulation Manufacturing Industry: Background Information for Proposed Standards*, EPA-450/3-83-022a, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1983.
8. A. J. Teller, *Glass Indus.*, 15–19 (February 1976).
9. Private communications, PPG Industries
10. J. R. Schorr, et al., *Source Assessment: Pressed and Blown Glass Manufacturing Plants*, EPA-600/2-77-005, U.S. Environmental Protection Agency, Research Triangle Park, NC, January 1977.

GLASS MANUFACTURING

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The production of glass products, although based on an old art, has emerged into sophisticated automated processes, both batch and continuous. The major forms of glass produced are container glass and flat glass, about 75% of the total production. Lesser amounts produced as pressed and blown glasses include lead and borosilicate glass and frit for ceramic coatings.

A typical flow diagram for the production of container glass (Figure 1) establishes three major components of the manufacturing process, raw-material blending and trans-