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Stationary Source Compliance Series

EVALUATION OF STATIONARY SOURCE PERFORMANCE TESTS

Special Problems and Concepts

US ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR, NOISE AND RADIATION
STATIONARY SOURCE COMPLIANCE DIVISION
WASHINGTON DC 20460

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DRAFT

EVALUATION OF STATIONARY SOURCE PERFORMANCE TESTS

Special Problems and Concept

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INTENDED PURPOSE

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SECTION A. UNCONFINED FLOW

PROCEDURES FOR SAMPLING SOURCES NOT CONFINED TO A DUCT

by
Walt Smith

INTRODUCTION

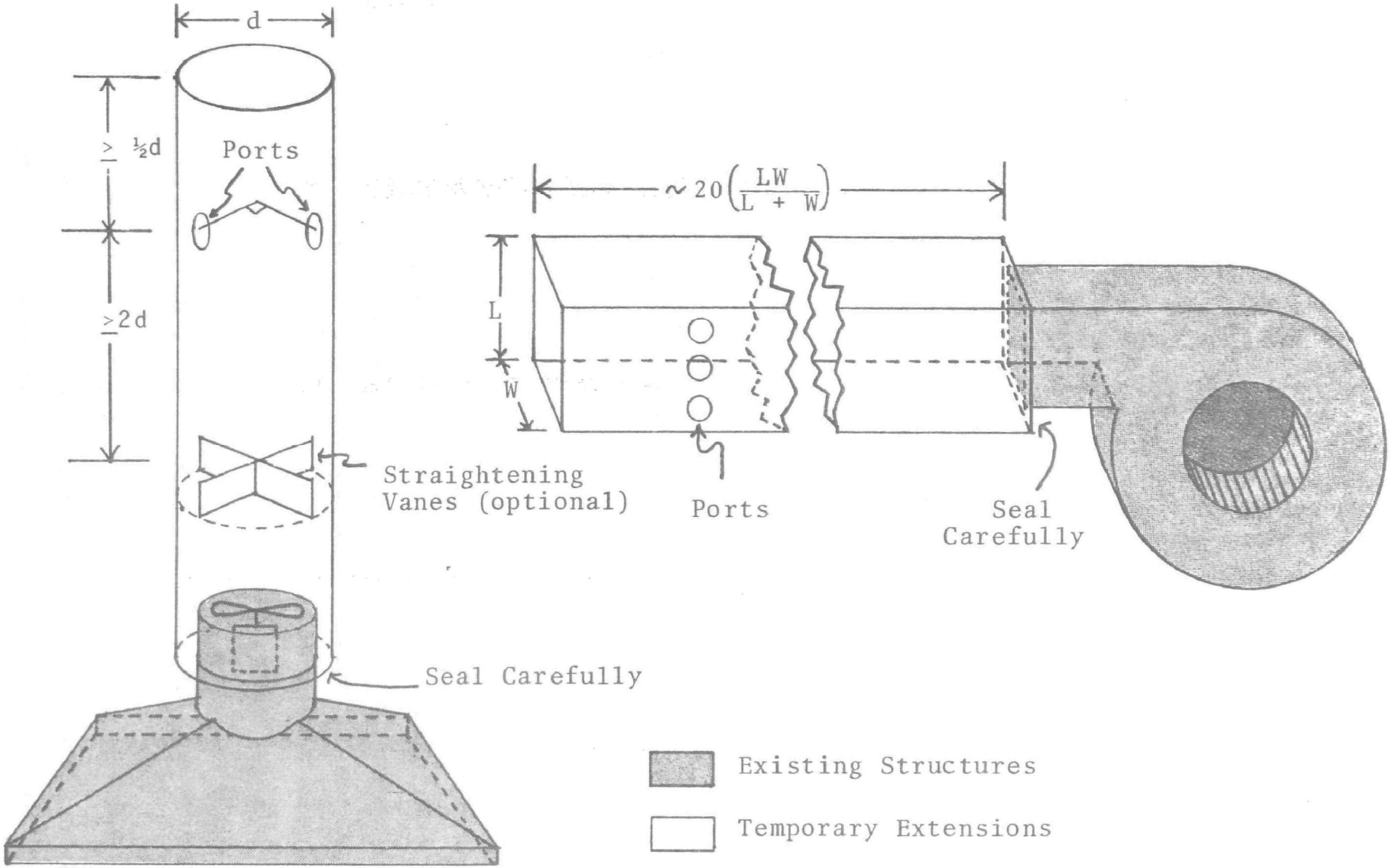
Most sources of air pollution emissions travel through stacks or duct work on their way to the atmosphere from the point of generation. Conventional source test methods are based upon this fact. Occasionally, though, an unconfined source may be encountered. Adapting current methods or devising a new method to handle such a source raises a multitude of questions concerning the method's equivalency with accepted procedures. A simpler approach entails modifying the source so that approved methods may be employed.

CONFINING A SOURCE

When no flue or ductwork is present at a source, a temporary or permanent flue should be affixed if at all possible. Care should be taken that an effective seal is achieved at the interface between flue and source. Sheet metal is a good material for the extension, due to its resistance to high temperatures, its rigidity and its relatively light weight. Plywood is often employed when high temperature is not a factor. Some examples of temporary flues are shown in Figure 1.

In order to conform to EPA's Method 1 guidelines, the extension should have a length equal to about ten times its own diameter. Obviously, the smaller the diameter the more manageable the apparatus becomes. A lower limit of about 18" in diameter should be observed, however, so that flue gas acceleration due to probe blockage will not become a factor during sampling. Exit velocity of the effluent must also be considered, as S type pitot tubes are unreliable at flow significantly below 600 feet per minute. If possible, the flue diameter should be chosen such that this minimum velocity condition is met.

If a high degree of turbulence is expected, as with an exhaust fan, straightening vanes can be installed as a built-in feature of the extension. As an added dividend, the vanes will lend rigidity to sheet-metal cyclinders.



Examples of temporary ducts for sampling unconfined sources

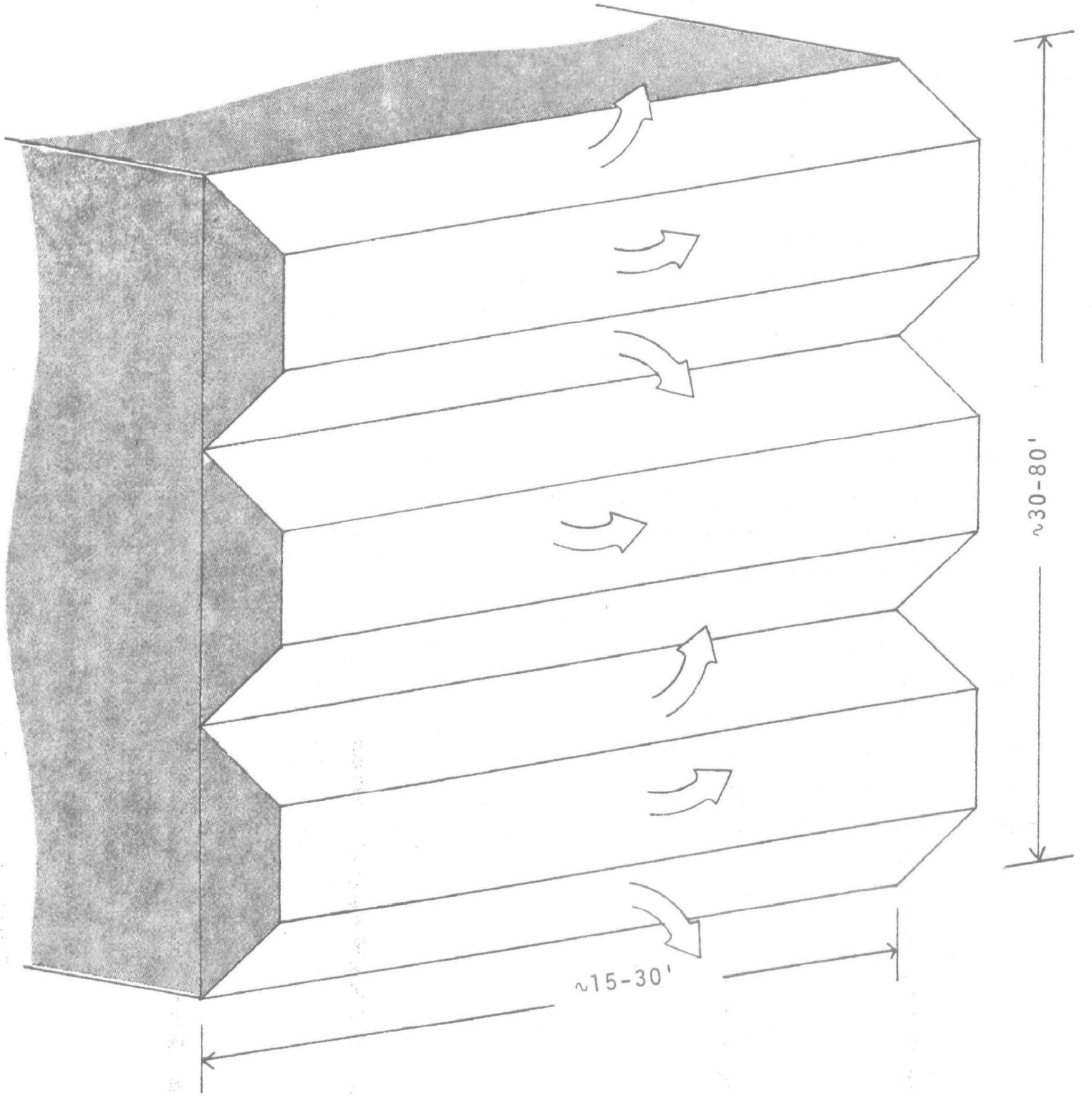
Sampling ports can be cut ahead of time if their location are known in advance.

WHEN CONFINING ISN'T PRACTICAL

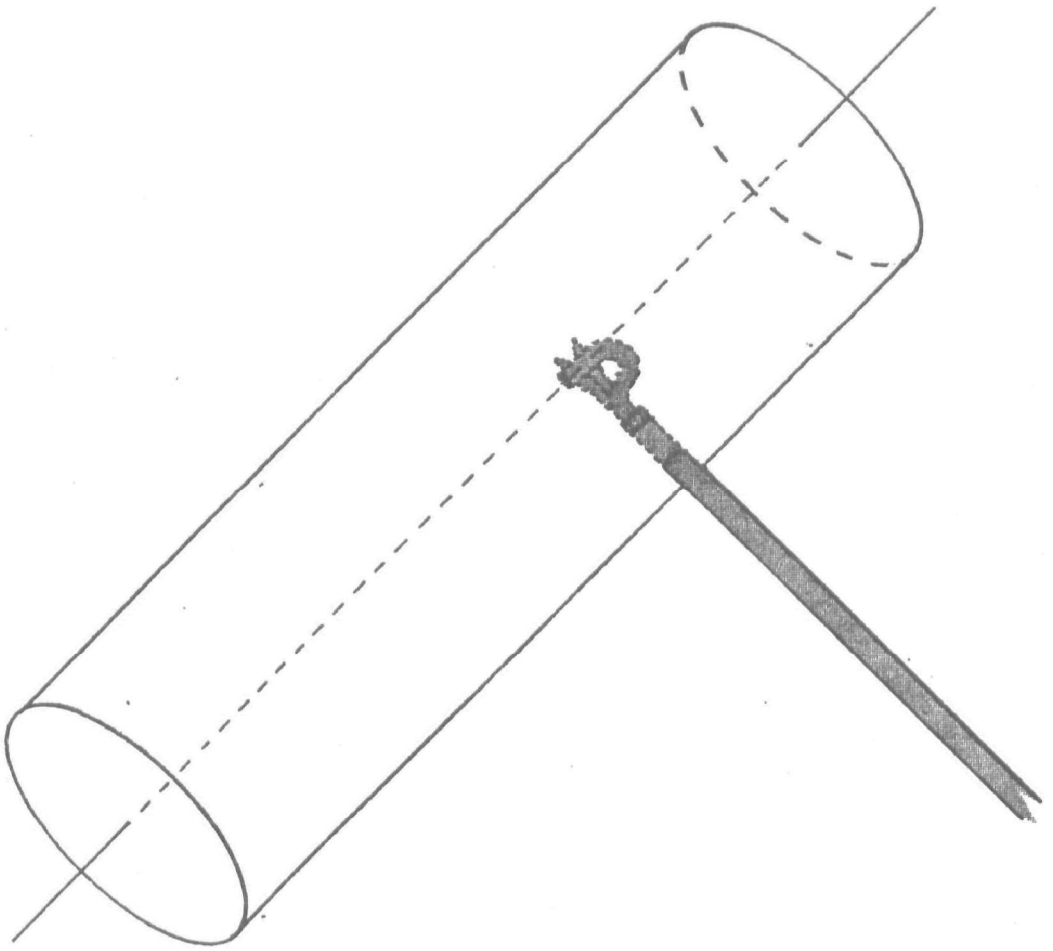
The foregoing discussion presumes that the installation of a flue at the point of emission is a practical matter. Some sources are too large or irregular for such modification. One approach to sampling these sources is to confine a small portion of the flow at a time, rather than the entire volume.

In one instance, an open-faced grain dryer was to be sampled for particulate emissions. The geometry of the exit grating was such that total confinement was impractical (Figure 2). A cylindrical "stack" was affixed to the end of a standard Method 5 sampling probe, such that the nozzle was aligned along the axis of the cycliner (Figure 3). The face of the dryer was partitioned at the centroids of these areas. Placement of the open-ended cylinder directly against the screen covering the face of the dryer blocked out the effects of ambient air motion.

When a stack extension is not feasible and a method such as the one outlined here must be resorted to, all equipment and procedures used in sampling and analysis should be discussed with and agreed upon by appropriate representatives of the firm being tested and the regulatory agency involved.



Sketch of an open faced grain dryer showing multi-faceted exhaust area.



Open-ended Cylinder Attached To Probe For Sampling Unconfined Sources.

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NOTES

UNCONFINED EMISSIONS

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SOURCES

1. Pressurized Baghouses
2. Roof Monitors
3. Open-faced Grain Dryers

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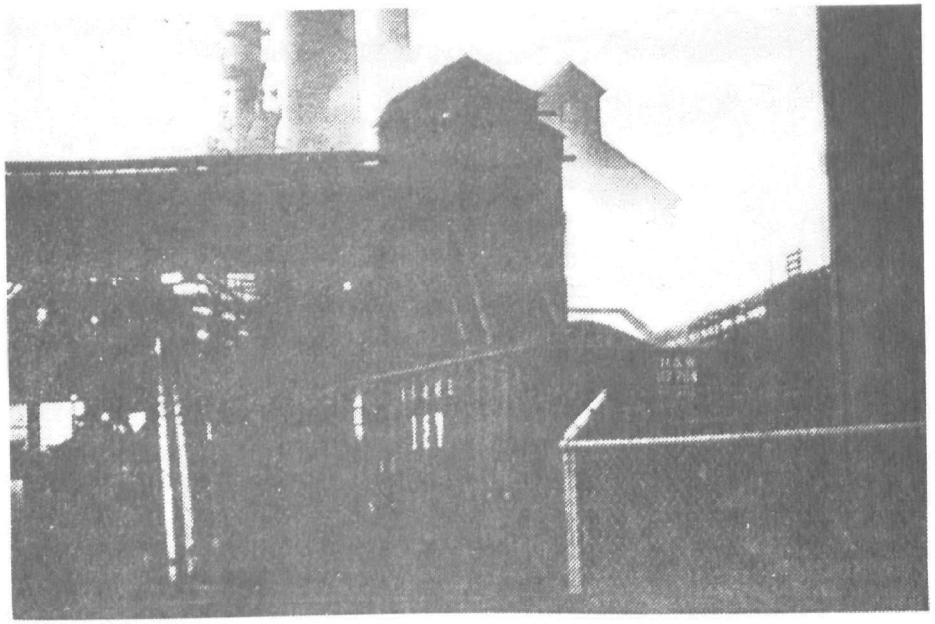
NOTES



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(picture of grain dryer)

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SAMPLING CONDITION I

CONFINE THE SOURCE

- o Obtain effective seal at interface between flue and source
- o Determine if modification affects emissions from source

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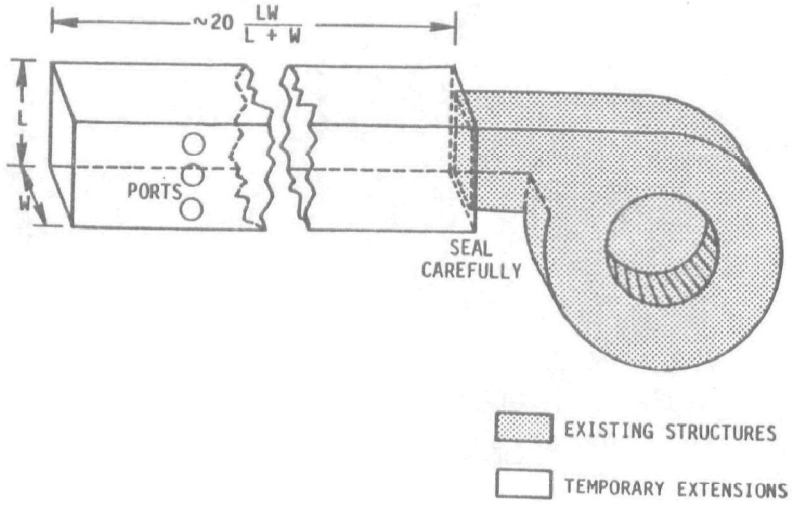
NOTES

RECTANGULAR UNCONFINED SOURCE



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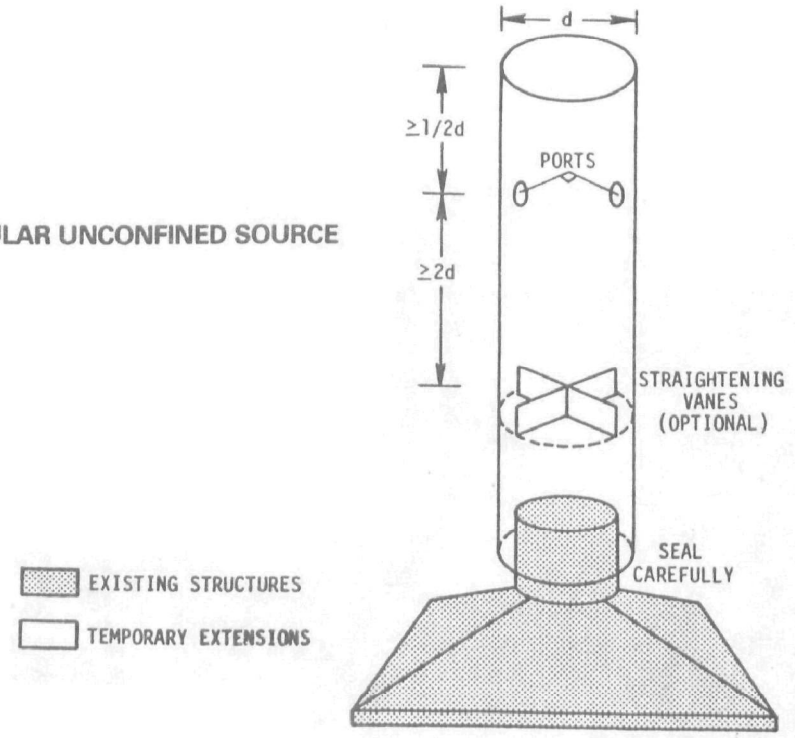
CIRCULAR UNCONFINED SOURCE



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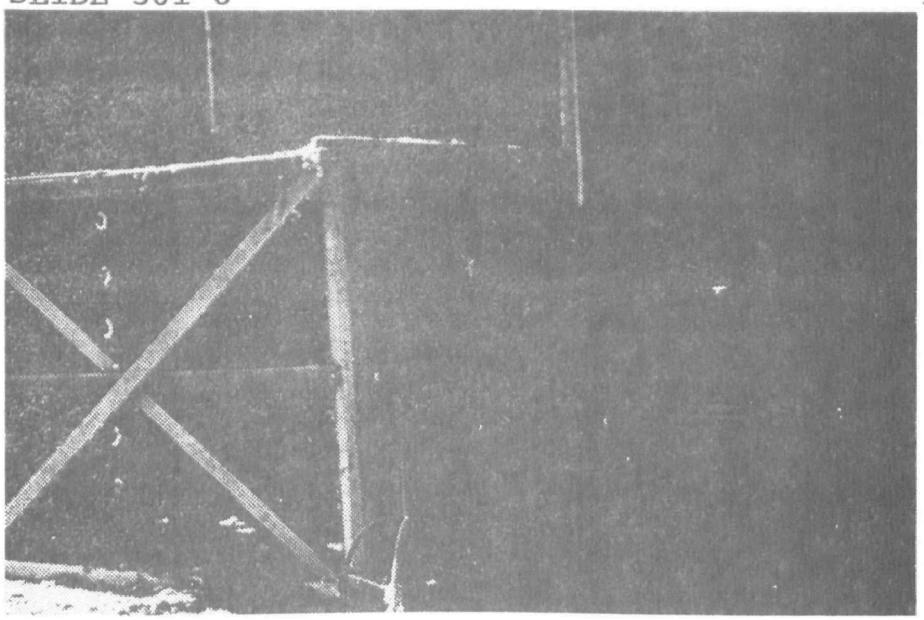

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SAMPLING CONDITION II

CONFINING SOURCE IMPRACTICE

Equipment and procedures used in sampling and analysis should be agreed upon by representatives of:

- o organization being tested
- o regulatory agency involved

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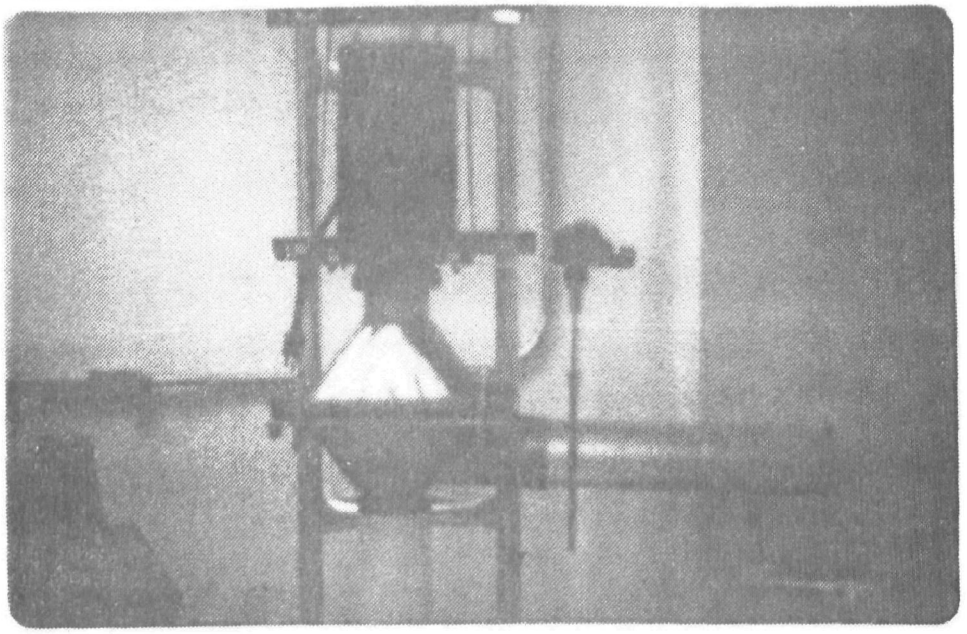

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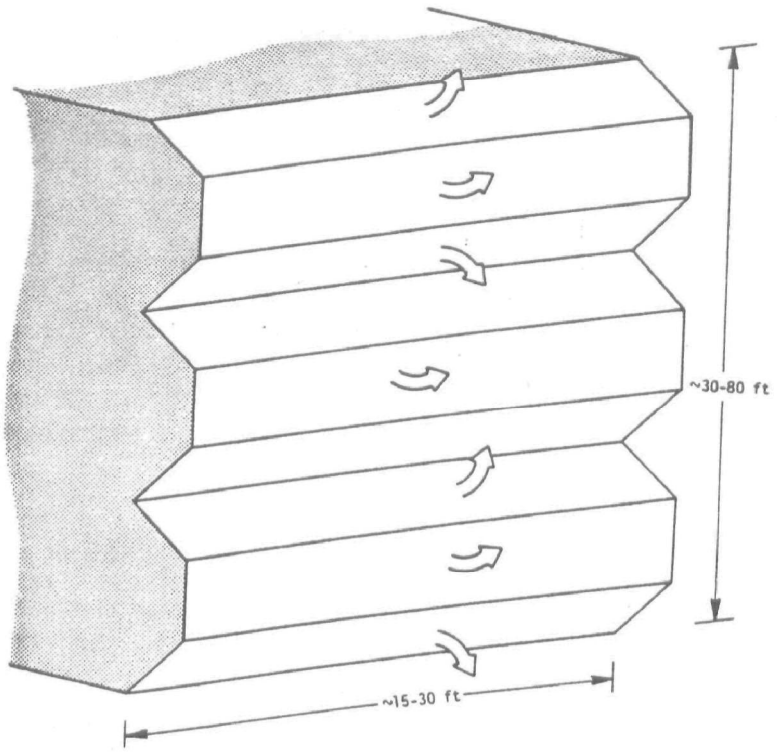
NOTES

GRAIN DRYER



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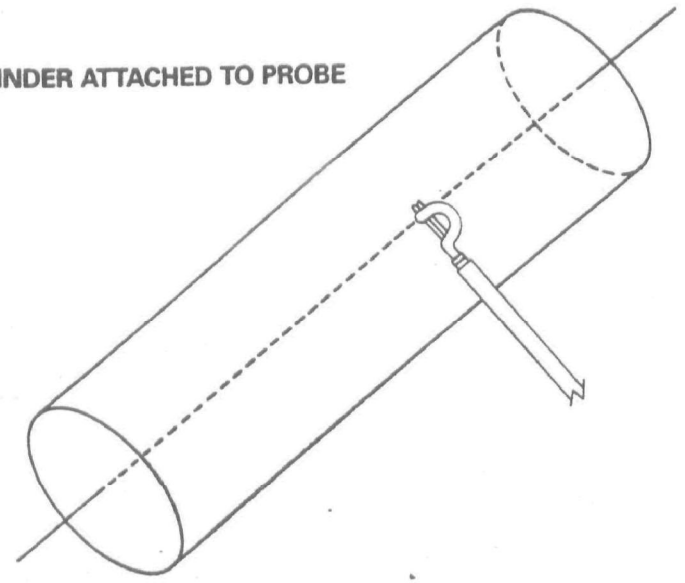
CYLINDER ATTACHED TO PROBE



SECTION B. HIGH TEMPERATURE SOURCES

PROBLEMS ASSOCIATED WITH SAMPLING HIGH-TEMPERATURE SOURCES

by
Jim Peeler

Testing teams are encountering increasing numbers of high-temperature sources. Municipal incinerators and gas turbines, for example, usually emit effluents well in excess of 750°F; temperatures 2000°F have been encountered on occasion.

Standard, commercially available EPA Method 5 train sampling equipment is not designed for use at stack temperatures much above 700°F. Clearly, modifications are required when temperatures higher than this are expected.

THE PROBE AND PROBLEMS

Most problems arising from high-temperature sources involve the one element of the train whch is in constant, direct contact with the gas stream--the probe. A standard EPA shielded probe is unsatisfactory above 800°F, for a variety of reasons.

An early problem in high-temperature sampling was achieving a seal between the nozzle and the probe lines which would remain air-tight at the sampling temperature. Viton 'o' rings and Teflon seals are useless at temperatures above 450°F, necessitating the use of asbestos string as a gasket material. Asbestos does not have the resiliency to fill the gap which opens as the glass probe liner and metal sheath expand at different rates. In addition, asbestos is characterized by a lack of cohesion. Stray filters may find their way into the train and contaminate the particulate sample. Despite these drawbacks, asbestos string can be, and has been, used with success.

At temperatures above 800°F, the difference between the coefficients of thermal expansion of glass and stainless steel begins to have a large effect. The probe sheath may bend as it expands, due to uneven heating and/or the presence of attachments such as pitot lines, causing glass liners to break. Another frequently encountered problem is breakage of the glass liner near the nozzle connection. As the sheath expands, the liner becomes unseated at this connection; following the test, probe cooling and contraction causes breakage as the liner fails to reseat itself.

Use of stainless steel (or other alloy) liners is one solution to thermal expansion problems. However, metal probe liners introduced a major problem of their own. At temperatures sufficiently high to require their use, there is almost a certainty that substances in the effluent gas will react with sample-exposed metal surfaces. Solid waste incinerators, for example, can be expected to emit large amounts of chlorides from plastic materials.

In general, the standard EPA probe is limited to applications below 750°F. The stainless steel probe sheath will expand and distort above this temperature. Softening of the nozzle and pitot openings may affect their calibrations, as well.

THE PROBE AND SOLUTIONS

Given the fact that standard probes are unusable at sampling temperatures above 750°F, what sort of probe will do the job? There are two basic approaches to fabricating high-temperature probes: 1) devise a cooling system which will allow use of standard stainless steel and/or glass components or 2) construct the probe of materials able to withstand the temperatures expected.

Probe cooling is accomplished by constructing a jacket around the probe and circulating a liquid or gas through it. Coolants which have been used include ambient air, water, and steam. Gaseous coolants are usually vented into the stack; liquids are recirculated.

Cooled probes present the immediate disadvantage of requiring support equipment. This is usually expensive and bulky, and will require maintenance. Malfunction of the cooling system during a run will necessitate a delay at best, and perhaps abandonment of the test.

When liquid coolants are used, the formation of vapor pockets inside the jacket must be considered. Pop-off valves should be installed, and the probe should be aligned during operation so that gases can be vented as needed. Otherwise, rupturing of the jacket is a very real possibility.

Care must be taken with regards to the placement of gas coolant vents or liquid coolant pop-off valves near the nozzle end of the jacket. Venting must not bias results obtained from the pitot lines or the thermocouple, and the sample entering the nozzle must not be diluted.

Even with an efficient cooling system in operation, some softening of the outside surface of the jacket can occur. Similarly, the protruding tips

of the nozzle and pitot tubes may be sugject to softening. While these eventualities are unlikely, they should not be dismissed out of hand.

Thus far, the disadvantages of cooled probes which have been discussed are not prohibitive problems. Rather, they are drawbacks which can be surmounted or tolerated. However, there are other problems introduced by cooled probes which are not as easily dismissed.

The nozzle of a cooled probe will be at a lower temperature than the stack gases. Even if the nozzle itself is not directly involved in the cooling, one must consider conduction to the cooler parts of the probe. This being the case, a question arises as to the effects of a "cold" nozzle on stack gas flow around the nozzle tip. Will contraction of gases in and around the nozzle be as sufficient to affect isokinetics? If so, by how much? Will the pitot openings be similarly affected? These questions need further study.

Another adverse effect can be predicted with greater certainty. With the probe liner cooled significantly below the temperature of the gas sample, condensation in the probe must be expected. This complicates cleanup as well as decreasing the assurance of obtaining representative data.

Despite these questions regarding the validity of the data obtained, cooled probes have been used successfully in high-temperature applications; air-cooled probes have been used at temperatures of at least $1000^{o}F$, water-cooled probes at $1700^{o}F$, and a steam-cooled probe was effective at well over $2000^{o}F$. Steam offers an advantage over other coolants in that sample gases will not be overcooled on their way to the filter, thus satisfying Method 5 requirements for probe temperature.

As an alternative to complicated cooling systems, one may instead construct the probe using materials which will withstand high temperatures. Special alloys, as mentioned before, may react with stack gases, and to a largely unpredictable extent.

Probes constructed of quartz (SiO_2) have been used successfully, though quartz has its own drawbacks. These probes are unsheathed, and the nozzle is an extension of the quartz tubing, making a one-piece "L" shaped construction.

Quartz is considerably harder than glass--and considerably more brittle. Extreme care must be taken in handling the probe, as there is no protective

sheath. Contact with liquids, such as raindrops, can suddenly shatter a hot probe. Moreover, probe lengths greater than about five feet are impractical.

One-piece construction dictates a fixed nozzle size of a given probe. Absence of the stainless steel sheath means that pitots, thermocouples, etc. cannot be directly attached to the probe. Standard S-type stainless steel pitot tubes can be used separately to get "quicker" readings at the nozzle location.

Quartz probes should be about a foot longer than necessary for the traverse of the duct. This will leave part of the probe exposed to ambient conditions at all times so that the sample will be cooled somewhat. Care should still be taken that the filter is not burned.

Thus, each approach to fabricating a high-temperature probe nas numerous disadvantages. Which approach to use to solve a given high-temperature problem will be dictated by the particulars of that problem and by the relative merits of the two types of probes.

Cooled probes offer the principal advantage of durability. Length is not severely limited; a water-cooled probe 20 feet in length has been used successfully. Breakage is not an overriding concern. Cooling of the sampled gases also ensures that the filter temperature can be maintained within operating limits. Sensing lines can be included inside the cooling jacket, so continuous velocity and temperature readings are not a problem.

In the case of quartz probes, perhaps the most significant advantage is the assurance that the effluents will not react with the probe during sampling. This is a major consideration at high temperatures. Incinerators represent a large number of high temperature sources, and caustic substances in their effluents must be expected.

The absence of a cooling system with its attendant pump, tubing, connections and heat exchanges, simplifies the sampling process and precludes mechanical failure. Not having to deal with a heavy, bulky probe is also a consideration.

Condensation in the probe will not be a probem with an uncooled quartz probe. Cleanup is also simplified considerably. There are no leak problems, as the probe and nozzle are one piece. Gases are not in danger of being cooled below 250^{o}F, a situation which may happen with cooled probes and which violates Method 5 guidelines. Heat expansion and possible distortion of the probe and nozzle are no longer problems.

MISCELLANEOUS PROBLEMS

Certain hazards and problems inherent in high-temperature sampling must still be dealt with regardless of the type of probe selected. It is especially important that these be anticipated, and advance preparations made to lessen their effects.

If the pitot lines are not included in a cooling jacket, discrete velocity measurements may be necessary to avoid sagging of stainless steel pitot tubes. A thermocouple can be attached to the pitot tubes also, and the assembly hand-held in the stack just long enough to get reliable readings.

Heat radiated directly from the process heat source will affect thermocouple readings if the source is within line-of-sight of the sampling location. Opaque shielding around the hot junction will guard against erroneous high readings.

Sampling teams should also be prepared to deal with an abnormally hot ambient environment. Conditions around the duct or stack should enter into the selection of the sampling site (Method 1, Section 2.1). The impinger ice bath and other equipment may need shielding from the stack wall. Asbestos panels may be useful as insulation material around the work area. Fans, plenty of drinking water, and salt tablets could come in prove quite useful for personnel welfare.

CONCLUSION

High-temperature stack sampling is not impossible; it is merely difficult. But the problems can be solved and the hazards avoided with the proper equipment, thoughtful preparation, and a liberal dose of ingenuity.

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NOTES

HIGH TEMPERATURE SOURCES

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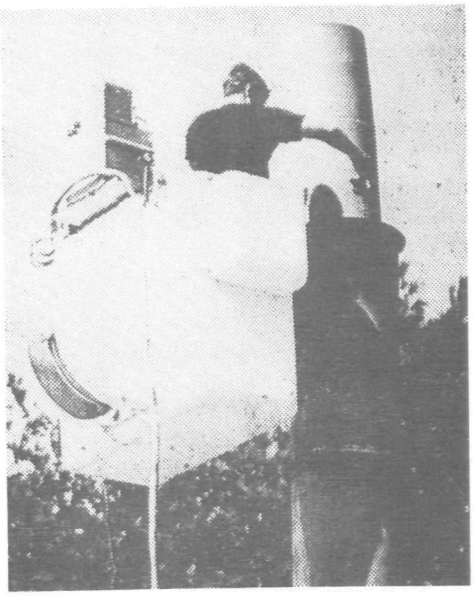
HIGH TEMPERATURE SOURCES

- Municipal Incinerators
- Gas Turbines
- Glass Furnaces
- Other Sources

SLIDE 302-2



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NOTES

THE PROBE

(Unsatisfactory above 800°F)

PROBLEMS

- achieving airtight seal between nozzle and probe liner
- breakage of glass probe liner due to different coefficients of thermal expansion between probe liner and stainless steel jacket

Note: Teflon ferrels and Viton-O rings must not be used at temperatures exceeding their softening point. Also, the organic material in the glue of the tape used to wrap the heating wire on the probe can burn off and bias the test. The probe should be free of tape since there is no need to heat the probe.

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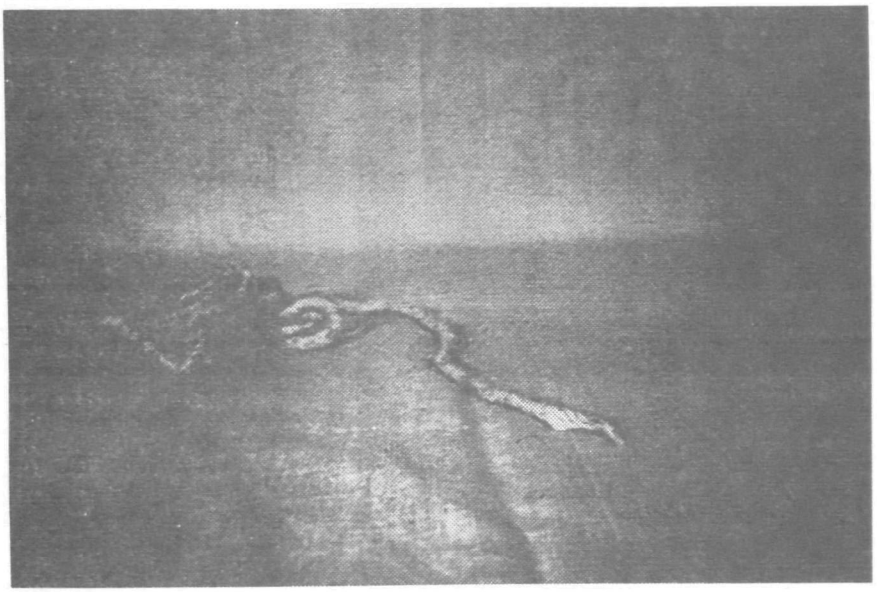

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METAL PROBE LINERS

At high temperatures, reactive substances in effluent gas will react with exposed surfaces of metal liners

High effluent gas temperatures could cause softening of the nozzle and pitot tube

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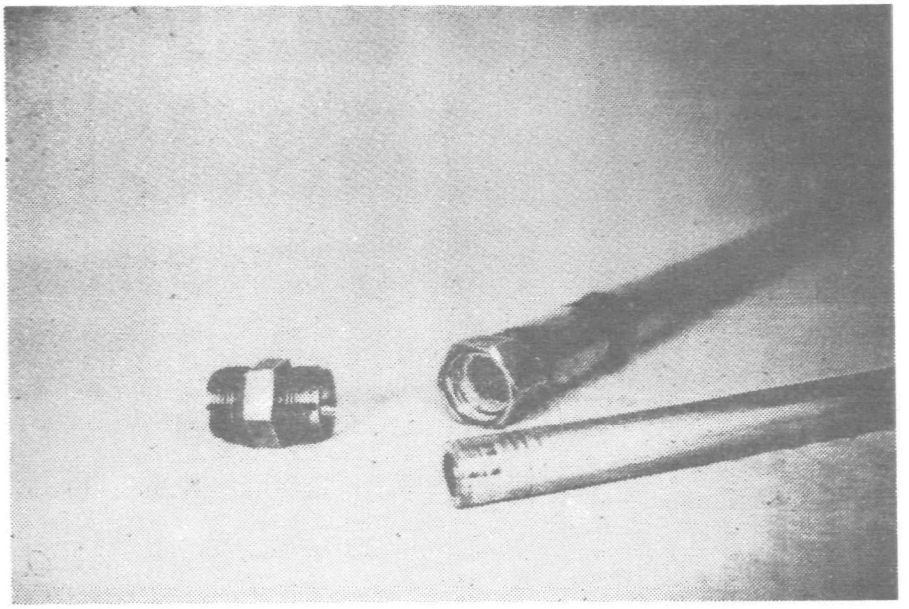

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CONSTRUCTION OF HIGH TEMPERATURE PROBES

1. Devise a cooling system allowing use of standard material. Coolant may be:
   - o ambient air
   - o water
   - o steam
2. Construct probes of materials which can withstand high temperatures. Materials may be:
   - o special alloys
   - o quartz (SIO_2)

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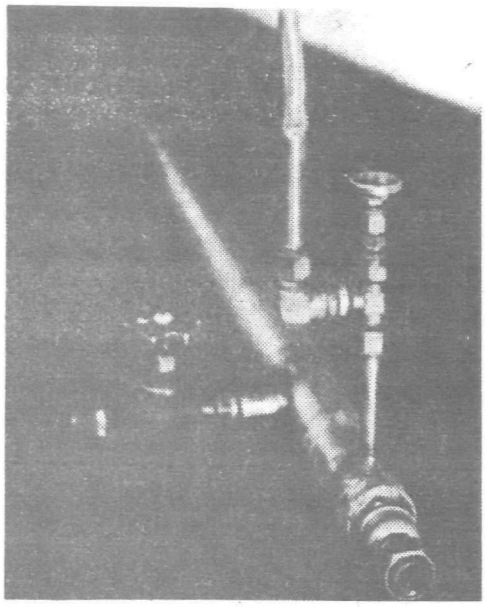

NOTES

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USE OF PROBE COOLING TECHNIQUES

ADVANTAGES

° durability of probe
° unrestricted probe length
° cooling of gases ensures that filter temperature can be maintained within limits
° sensing lines can be included within cooling jackets

DISADVANTAGES

° requires structural support equipment
° vapor pockets may form which may rupture jacket
° venting may bias results or dilute sample
° cooler nozzle/pitot tube gives variable effects on stack gas flow
° consdensation in probe

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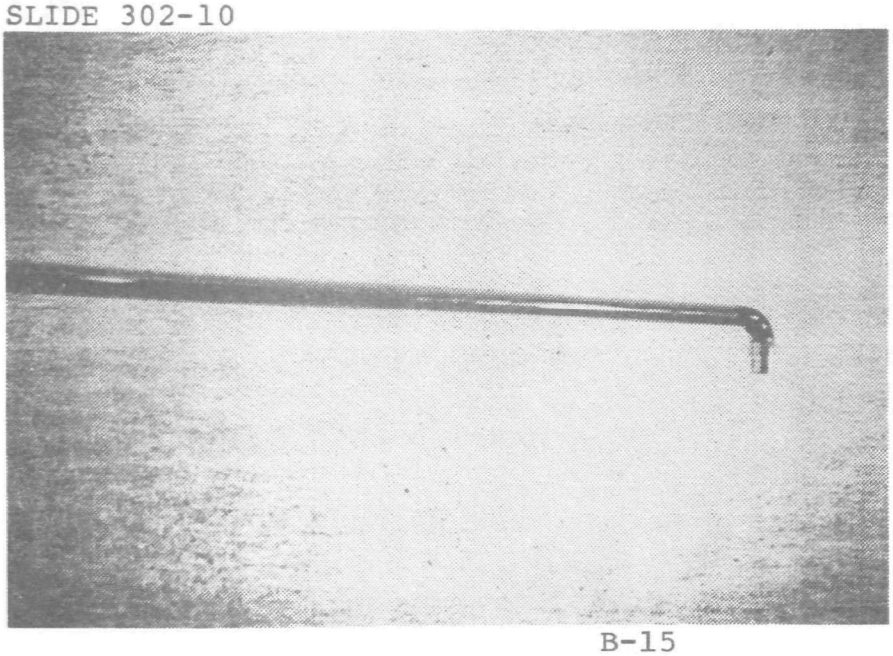

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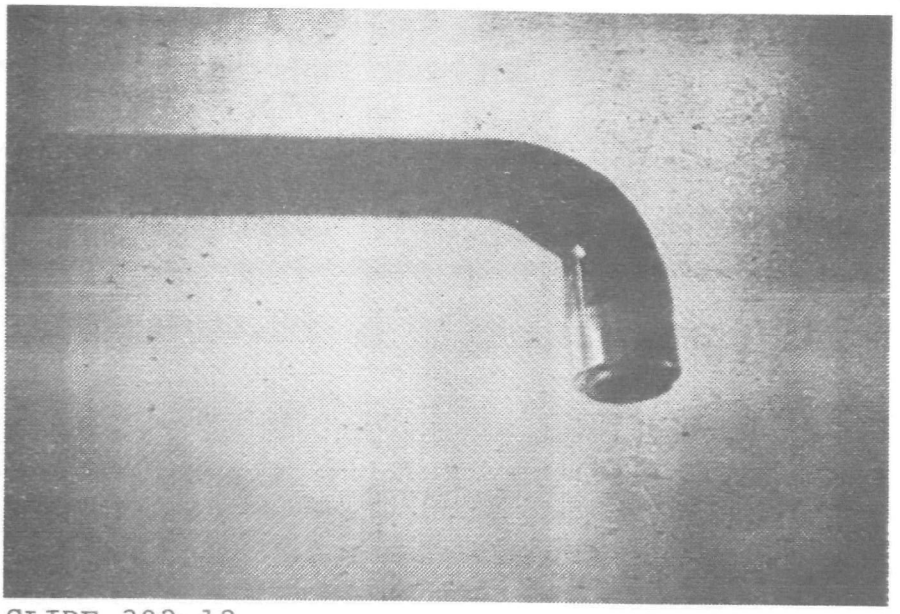

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QUARTZ PROBE

ADVANTAGES

- o effluents will not react with probe during sampling
- o absence of bulky cooling system
- o no condensation in probe
- o probe and nozzle are one piece eliminating leaks
- o no heat expansion and distortion of probe and nozzle
- o gases not cooled below 250^{o}F

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DISADVANTAGES

- o very brittle/no protective sheath
- o fixed nozzle size
- o pitot tube and thermocouple cannot be attached
- o probe lengths greater than 5 ft are impractical
- o potential for burning the filter

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NOTES

MISCELLANEOUS SAMPLING PROBLEMS

- o sagging of stainless steel pitot tube
- o heat radiation from process affects temperature measurement

SECTION C. HIGH MOISTURE CONTENT

SAMPLING METHODS FOR STACKS WITH HIGH MOISTURE CONTENT

by
Robert A. Estes

INTRODUCTION

In most sampling situations, EPA Method 5 is prescribed as the accepted method for measuring particulate emissions. However, if the moisture content of the sampled gas is significantly above 50%, Method 5 may give unreliable results or become completely unworkable. Examples of such high-moisture sampling situations are ammonium nitrate prilling facilities, lime-hydrators, evaporators, and coke oven quench towers. The purpose of this paper is to present the three most noted approaches to sampling high moisture stacks. These methods were developed by JACA Corporation, the EPA, and Entropy Environmentalists.

BACKGROUND

Before dealing with the individual methods, some background information is in order. Method 5 is generally becoming the most widely accepted method for determining particulate emission rates. Proper use of Method 5 depends upon the relationship established by the nomograph equation:

$$\Delta H = D_n^4 \left[\frac{\pi K_p C_p}{4K_m}\right]^2 \left[\frac{M_d(1-B_{ws})^2}{M_d(1-B_{ws}) + 18(B_{ws})}\right] \frac{T_m}{T_s}\frac{P_s}{P_m}\,\Delta p \qquad (1)$$

This equation relates the pressure differential across the pitot tube (used to determine local stack velocity) to the pressure drop across the orifice meter (used to determine sampling rate) in maintaining isokinetic sampling conditions. With a given set of equipment and stack conditions that can be assumed constant, Equation (1) can be reduced to the form:

$$\Delta H = K\Delta p \qquad (2)$$

The pressure drop across the orifice meter is measured after the sample gas has been filtered and the moisture removed by the impingers and the silica gel. The remaining dry gas is metered to determine the total volume sampled and to determine overall

isokinetics by post-test calculations.

In stacks with a low moisture content, the percent moisture may be provided by plant data, determined by Method 4, or simply estimated. The effect of an error in determining moisture at low moisture levels is relatively small. However, as the moisture content increases, the effects of error increase. Eventually, a point may be reached where a 2% error (or a 2% change in the moisture content from the initial value) will result in a sampling rate outside of the allowed ± 10% range from 100% isokinetic sampling. This is due to the non-linearity of the correction factor for water removal found in the nomograph equation and represented by the term:

$$\frac{M_d(1-B_{ws})^2}{M_d(1-B_{ws}) + 18B_{ws}} \qquad (3)$$

found in Eq.(1).

As sample gas from a stack at nearly 100% moisture passes through the impingers (condenser) of a Method 5 train, the majority of the sample is left behind as condensed water. There is very little dry air exiting the impingers. In a standard Method 5 train, the impingers are followed by the pump, control valves, dry gas meter, and orifice flow meter. With only a small fraction of the gas volume entering the nozzle being passed through these components, three problems become apparent.

First, the low flow rate through the orifice may give rise to erroneous readings. An orifice meter only gives linear results over a given operating range. Low gas flow can fall outside of the operating range over which the orifice was calibrated. Second, with very little gas passing through the pump and control valves, the sampling rate cannot be accurately controlled. Finally, even if the sample contains enough dry gas to enable accurate orifice readings and flow control, fluctuations in the moisture content of the stack gas will still upset isokineticity. In cases where there is a large variation

in moisture content, such as during a coke oven quenching operation, measurement and control of the dry gas fraction of the total sample volume will be insufficient to detect and make allowances for the fluctuations in the total gas flow rate (including water vapor) through the nozzle. Should post-test calculations demonstrate 100 ±10% isokinetics in spite of these uncontrolled fluctuations, the fact that the sampling rate was substantially over-and under-isokinetic at various times during the sampling run could void the test results.

Due to these problems a standard Method 5 particulate sampling train is inappropriate for sampling effluents with a high moisture content, meaning those significantly above 50% water vapor by volume.

A COMMON APPROACH

The common approach to these problems is the placement of the orifice meter before the impingers, where condensation of the moisture occurs. This allows the total sample volume to be passed through the orifice. The significance in this placement is that the moisture content does not have to be known beforehand, nor do changes in moisture content affect the isokinetic sampling rate. The mathematical significance of this orifice placement is the elimination of the correction factor (Eq. 3) in the standard EPA Method 5 nomograph equation, yielding the relationship:

$$\Delta H = D_n^4 \left[\frac{\pi K_p C_p}{4K_m}\right]^2 \frac{T_m}{T_s} \frac{P_s}{P_m} \Delta p \qquad (4)$$

The above equation is the isokinetic relationship between the pressure differential across the pitot tube and the pressure drop across the orifice meter, upon which all three high moisture methods are based.

JACA CORP. METHOD FOR PARTICULATE SAMPLING OF HIGH-MOISTURE STACKS

The design chosen by JACA to measure particulate matter in high moisture stacks resembles a Method 5 train. The major exception is that the orifice meter is placed in the heated box

with the filter assembly. The orifice design was chosen to encompass typical sampling volumetric flow rates (centered around .7 acfm). JACA concluded that the risks of orifice fouling, and thereby of change in the calibration coefficient, were high enough to warrant placement of the orifice after the filter. The advantage of this placement is the prevention of condensation at the orifice (hot box temperature: 250°F) and protection from particulate fouling of the orifice. The disadvantage of this placement is that the meter pressure (P_m) is not constant as in Method 5 because of the changing pressure drop induced by the glass frit and particulate build-up on the filter. The absolute pressure at the meter must be monitored and compensated for in the isokinetic equation (Eq.4).

A technical paper was presented at the June 20-24, 1977 annual APCA meeting by Uday Patankar and Wayne Ott of the JACA Corporation on the use and performance of the JACA method. The authors acknowledged two problems which occurred during sampling on their first test (a lime-hydrator). First, a great deal of condensation occurred in the manometer lines from the orifice. It was felt that much of this had to do with the incorrect sizing of the nozzle, leading to excessively high flow rates. Second, controlling the sampling train to match the prescrubed isokinetic sampling rates was difficult. The sampling team had to settle for maintaining an average flow rate. Fortunately, the velocity profile of the stack was fairly flat and allowed the test to maintain an overall $\pm$10% isokinetic sampling rate.

A second test was performed on a concentrator/evaporator for diagnostic purposes. It was felt that the solution to both the problems encountered previously hinged mainly upon attaining more manageable flow rates by use of a smaller nozzle size. The difference in the total gas volume sampled by the smaller nozzle was balanced by longer sampling times at each point along the traverse. Also, U-tube condensate traps were placed on the manometer lines to allow accurate manometer readings to be obtained. These traps could be periodically emptied as needed.

JACA reported no significant problems on the second test. The sampling was reported to be controllable and post-test calculations indicated that the ± 10% overall isokinetic requirement had been met.

EPA METHOD FOR PARTICULATE SAMPLING OF HIGH-MOISTURE STACKS

The EPA method was developed for use in sampling ammonium nitrate production facilities for the determination of particulate (ammonium nitrate) emissions from neutralizers, evaporators, and prilling towers. However, this method should be able to sample most high moisture stacks or those with wide variation in stack gas moisture content with relatively few problems. (This method is currently under technical review by EPA.)[2]

The EPA method incorporates an in-stack orifice of a third generation design which allows interchangeability of the orifice plate. A venturi design was considered because it has the same operating characteristics as an orifice. However, an orifice is easily fabricated and can be changed to allow for different flow rates.

The first-generation design incorporated the orifice in the sampling nozzle. However, this design was unusable in standard three-inch ports. It also showed different calibration coefficients depending on whether dry room air or a flowing stream was used in the calibration procedure. The source of this problem was not determined, though it was felt that the proximity of the nozzle to the orifice was a contributing factor. The second generation design placed the orifice meter between the nozzle goose-neck and the probe. The present third-generation design provides an easier way of accomodating different flow rates by changing the orifice plate rather than changing the entire meter assembly as in the second-generation meter. In the second and third generation designs no significant difference was found in the orifice coefficient when calibrated with dry room air or a flowing stream.

Since the sampling train is designed to sample ammonium nitrate, the design takes advantage of the hygroscopic nature of ammonium nitrate by capturing it in the impinger water. A filter at 250° would tend to allow ammonium nitrate to pass through. Thus, the filter is placed before the impinger containing the silica gel. The probe is heated to prevent condensation prior to the impingers.

The in-stack orifice meter is not heated and thereby samples at stack conditions. The isokinetic sampling equation now becomes:

$$\Delta H = D_n^4 \left[\frac{\pi K_p C_p}{4K_m}\right]^2 \Delta p \qquad (5)$$

Problems with controlling the sampling rate and condensation of moisture in the manometer lines did occur, though not as acutely as experienced with the JACA Method.

The EPA method has only been used in short 20-30 minute diagnostic runs. However, no major problems are foreseen if this method is approved for use at ammonium nitrate production facilities. With minor modifications, this method should be usable in most other sampling situations where high moisture content is encountered.

ENTROPY ENVIRONMENTALISTS HIGH MOISTURE PARTICULATE SAMPLING METHOD

The method developed by Entropy Environmentalists, Inc. has been used successfully at an ammonium nitrate production facility. The sampling train has been designed with the flexibility to meet any sampling situation encountered by allowing use of either an orifice or venturi meter (in high particulate loadings), and an option in filter placement dependent upon the source tested. The meter, however, is not as easily interchangeable as the orifice in the EPA method.

The Entropy method incorporates the orifice meter in the heated filter box, followed by a sampling valve. Under circumstances where a non-hygroscopic particulate is encountered in a

high moisture stack, the filter would be placed between the orifice and the sampling valve. This would allow particulate to be defined as in Method 5: that which can be captured on a specified filter type at 250°F. The advantage to having the orifice in front of the filter assembly is that filter loading and the glass frit have no effect on meter pressure, which remains constant and does not require monitoring. The disadvantage is that precautions must be taken to prevent orifice fouling, which would change the orifice calibration. As mentioned above, a venturi may replace the orifice since it would tend to foul less and has the same general operating characteristics. Another alternative is to place a coarse filter of glass wool before the orifice, which would protect the orifice and not affect meter pressure. In situations where particulate loadings are exceptionally high, both a coarse filter and venturi meter could be used.

The Entropy method employs a sampling valve in the hot box, before condensation takes place in the impingers. This allows for positive flow control of the total sample rather than just control of the smaller amount of dry air leaving the impingers.

Since condensation in the manometer lines was seen to be a common problem, a system utilizing solenoid operated 3-way T-valves connected to the manometer lines with a small pressurized air supply was utilized to clear the lines periodically. The volume of air thus introduced into the sample line is insignificant when compared to the total sample volume.

PROBLEMS COMMON TO ALL THREE METHODS

When sampling sources with high moisture content, a problem which must be considered is the possibility of entrained water droplets. Generally, sources of high moisture content will have sampling conditions of approximately atmospheric pressure and temperatures above 220°F. This is high enough above saturation conditions that water droplets should not pose any problem. However, as saturation conditions are approached, special care must be taken.

If water droplets are encountered when sampling using Method 5 the sample gas stream is usually assumed saturated, and wet bulb/dry bulb measurements are taken to determine the saturated water volume. Any excess water captured must be accounted for as entrained water droplets. Saturated volumes from wet bulb/dry bulb data may be found by psychrometric charts or by partial pressure calculations. This procedure cannot be applied to any of the high moisture methods.

Water droplets that enter the nozzles of any of the moisture-method sampling trains will cause a problem with the isokinetic sampling rate. Fouling of the orifice would also be a problem for the EPA method. The water droplets would vaporize in the probe and hot box of the JACA and Entropy methods, affecting the isokinetic sampling rate. This effect would not be obvious from post-test calculations, because total volume sampled and total water captured in the impingers are used to determine the overall isokinetics. The sampling would take place under-isokinetically though calculations indicate otherwise. A way has not yet been developed for these high moisture methods to sample in situations where both high moisture content and entrained water droplets are encountered. Fortunately, most high most high moisture processes are designed to prevent condensation.

A second problem common to all the high moisture methods is condensation in the manometer lines. Diffusion is the initial driving force for placing water vapor in the manometer lines. Water vapor changes its volume approximately 1600 times in condensing, and the condensation thereby creates a vacuum. This draws in more water vapor, which condenses and continues the cycle. It would seem that this problem may be more severe in the EPA method because of the long manometer lines running along the probe from the in-stack orifice. However, this problem did not appear severe in the test runs performed. In any case, the manometer lines must be "running uphill" or incorporate a condensate trap to prevent condensed water vapor from running into the manometers. A means for periodically clearing the lines should also be included.

Another problem can arise if the ice around the impingers is allowed to melt completely. If the temperature in the last impinger rises above 90°F, the silica gel will saturate quickly. The high rate of condensation in the impingers releases a great amount of heat, consuming a great deal of ice. The remedy is to have plenty of ice on hand and to monitor the impingers closely draining water as necessary, or perhaps adding salt, to keep the exit gas temperature around 70° F or less.

The JACA method is intended to handle all sampling situations of high moisture content with one train design, while the Entropy method allows flexibility in filter placement and meter type, which is dependent upon sampling requirements and source type. The EPA method, with certain modifications, should be usable in sampling situations other than ammonium nitrate production facilities. The Entropy design is the only one capable of controlled sampling in a 100% moisture stack. It should be noted at at 100% moisture conditions there would be no dry gas to control beyond the impingers, and the control valves and pump would become useless. Condensation (heat transfer) would become the driving force and rate determining factor. Without a control valve prior to the impingers, isokinetic sampling could not occur. Therefore, the Entropy method would allow positive control at 100% moisture conditions (assuming the rate of heat transfer within the impingers was high enough).

Few 100% moisture sources exist, and under less severe conditions there is no reason why the results from one sampling train design should differ significantly from the results of another. One would simply have to consider the advantages, disadvantages, and operating characteristics of each design.

NOMENCLATURE

B_{ws} = Mole fraction, water in stack gas, dimensionless

C_p = pitot tube coefficient, dimensionless

D_n = nozzle diameter, in.

K_m = orifice calibration, constant, $\sim 0.72 \pm 0.05 \frac{ft^3}{sec} \sqrt{\frac{lb}{lb\text{-}mole°R}}$

K_p = units conversion constant, $85.48 \frac{ft}{sec} \sqrt{\frac{lb}{lb\text{-}mole°R}}$

ΔH = orifice pressure differential, in. H_2O

M_d = molecular weight of stack gas, dry, lbs/lb-mole

Δp = pitot tube pressure differential, in. H_2O

P_m = absolute pressure of dry gas meter, in. Hg.

P_s = absolute pressure in stack, in. Hg.

T_m = meter temperature, °R

T_s = stack temperature, °R

18 = molecular weight of H_2O, lbs/lb-mole

JACA HIGH MOISTURE SAMPLING TRAIN

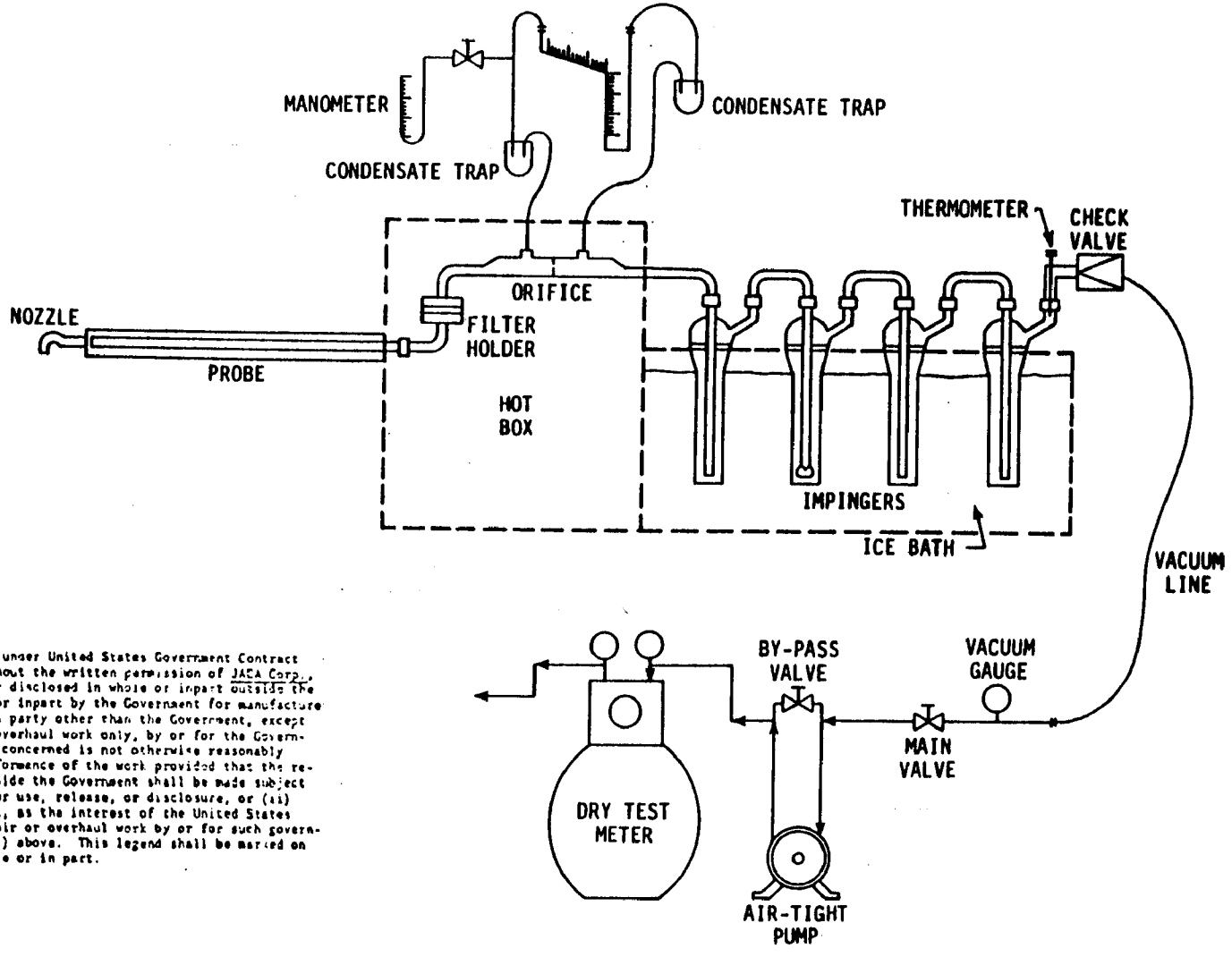


FIGURE 5-1.

EPA HIGH MOISTURE SAMPLING TRAIN

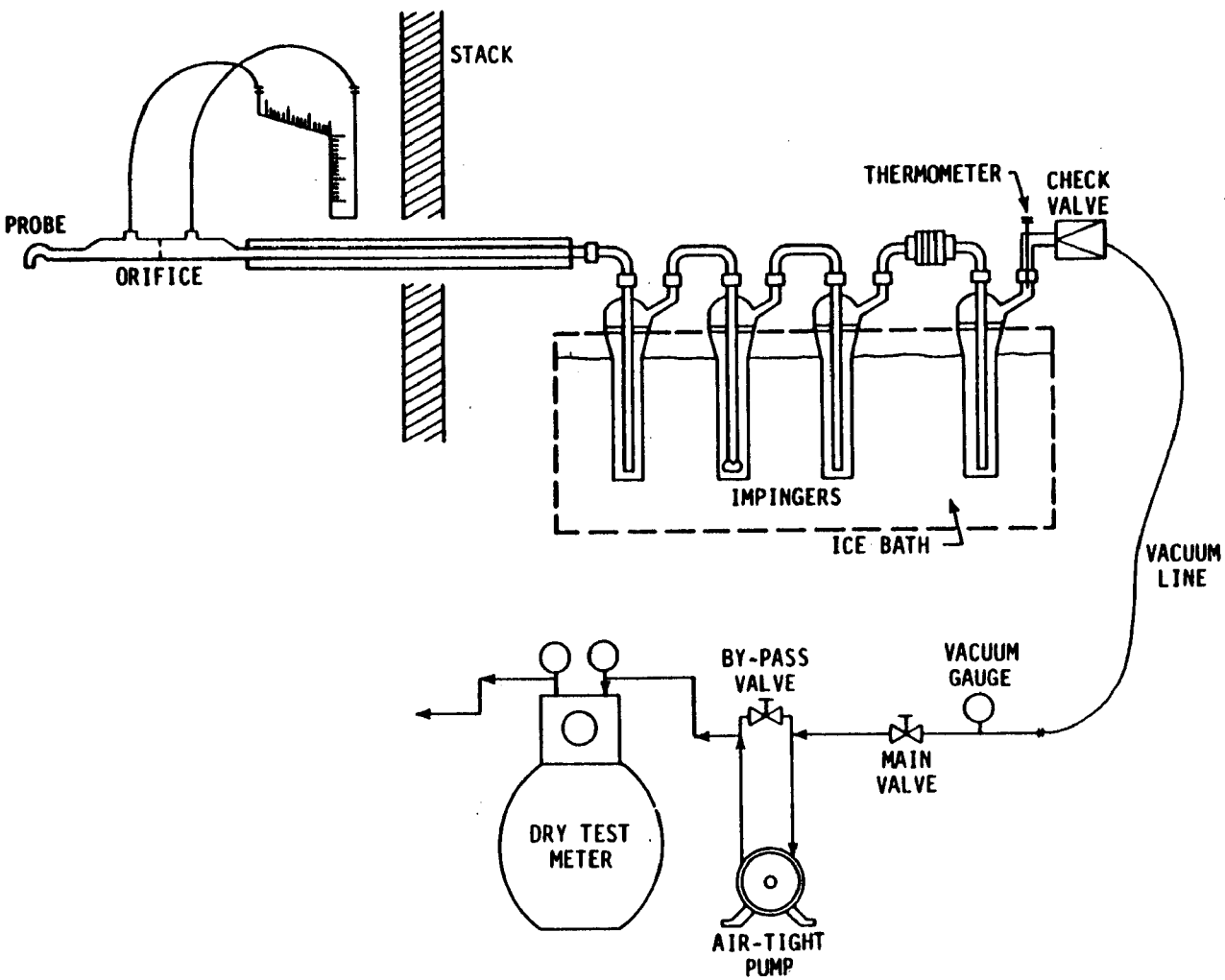


FIGURE 5-2.

ENTROPY HIGH MOISTURE SAMPLING TRAIN

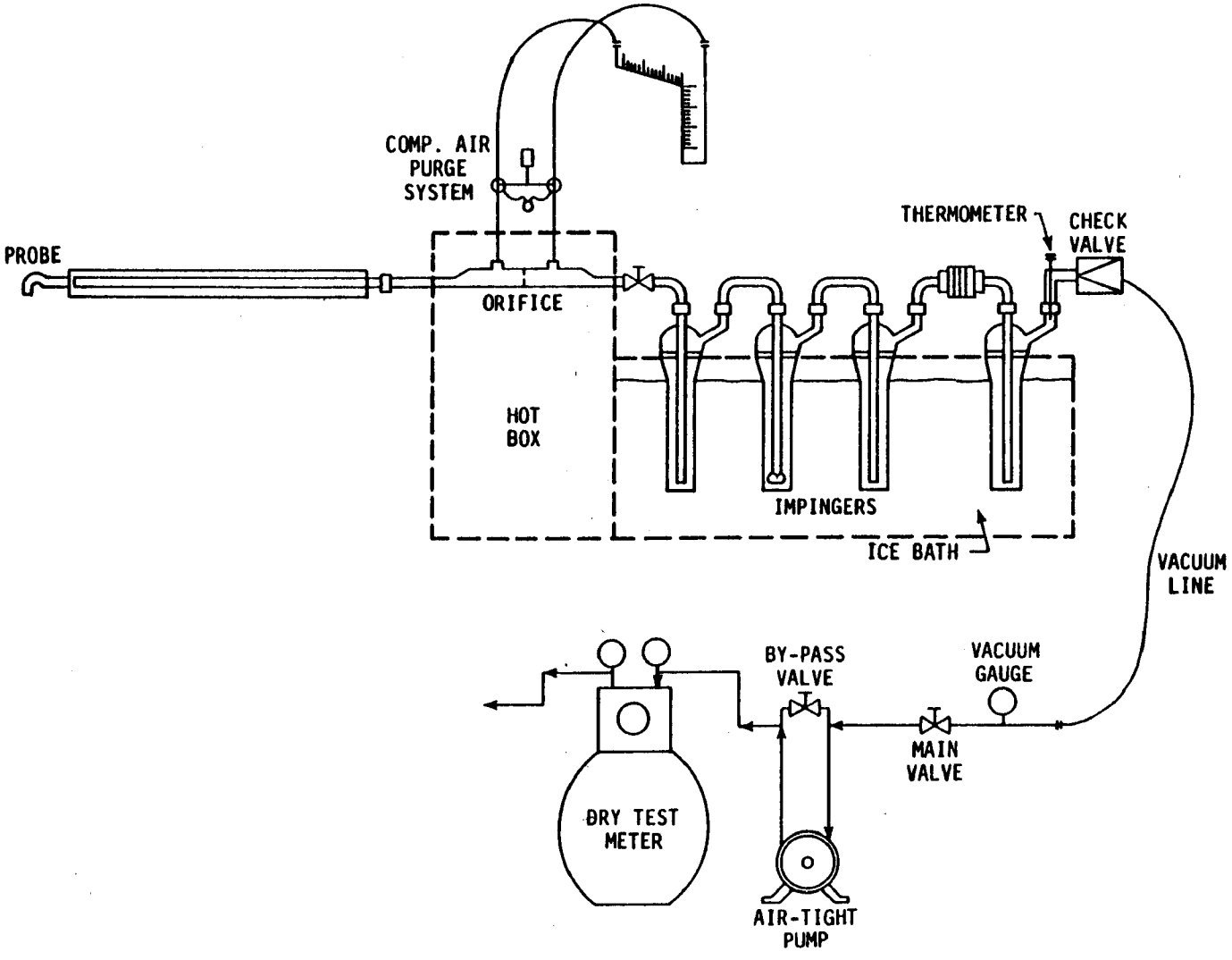


FIGURE 5-3.

SLIDE 303-0

NOTES

HIGH MOISTURE CONTENT

SLIDE 303-1

SAMPLING METHODS FOR STACKS WITH HIGH MOISTURE CONTENT

HIGH MOISTURE SOURCES

- O Ammonium Nitrate Prilling Facilities
- o Lime Hyrators
- o Evaporators
- o Coke Oven Quench Towers

SLIDE 303-2

(picture of high moisture source)

SLIDE 303-3

NOTES

THE PROBLEM

$$\Delta H = D_n^4 \left[\frac{\pi K_p C_p}{4 K_m}\right]\left[\frac{M_d (1-B_{ws})^2}{M_d(1-B_{ws})+18(B_{ws})}\right]\left[\frac{T_m P_s}{T_s P_m}\right]\Delta P$$

SLIDE 303-4

SAMPLING PROBLEMS

- o erroneous readings due to low flow rate through orifice
- o inaccurate control of sampling rate due to small volume of gas passing through control valves
- o non-isokinetic sampling due to fluctuations in moisture content of stack gas

SLIDE 303-5

SOLUTION

PLACE ORIFICE METER BEFORE IMPINGERS

- o total sample volume passes through orifice meter
- o moisture content measurement unnecessary
- o isokinetics not affected by moisture changes

SLIDE 303-6

NOTES

THE SOLUTION

$$\Delta H = D_n^4 \left[\frac{\pi K_p C_p}{4 K_m} \right] \frac{T_m P_s}{T_s P_m} \Delta P$$

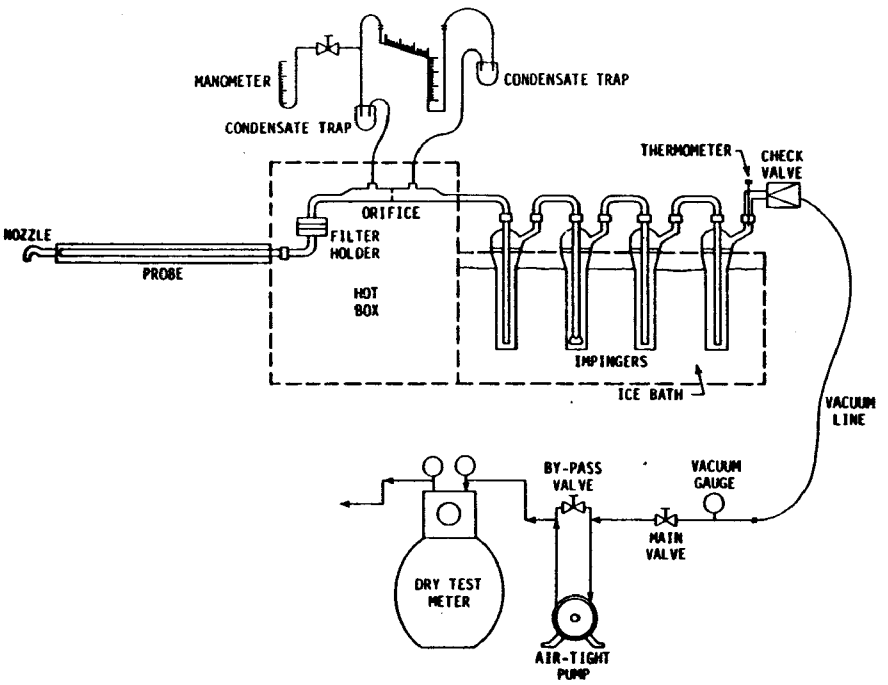
SLIDE 303-7

HIGH MOISTURE CONTENT
SAMPLING METHODS

- o JACA Corporation Method
- o EPA Method
- o Entropy Method

SLIDE 303-8

JACA HIGH MOISTURE SAMPLING TRAIN



SLIDE 303-9

NOTES

JACA CORPORATION METHOD

Orifice meter is located in heated sample box behind filter

ADVANTAGES

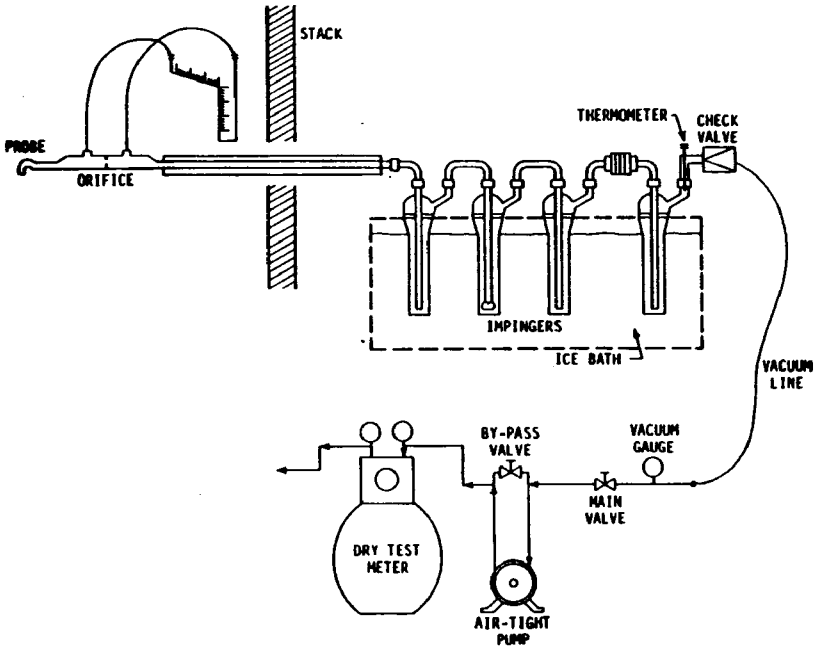
- o prevention of condensation at orifice
- o protection from particulate fouling

DISADVANTAGES

- o orifice meter pressure does not remain constant

SLIDE 303-10

EPA HIGH MOISTURE SAMPLING TRAIN



SLIDE 303-11

EPA METHOD

- o developed for use at ammonium nitrate facilities
- o consists of an in-situ orifice with a changeable orifice plate
- o filter located before silica gel impinger
- o probe heated to prevent condensation

SLIDE 303-12

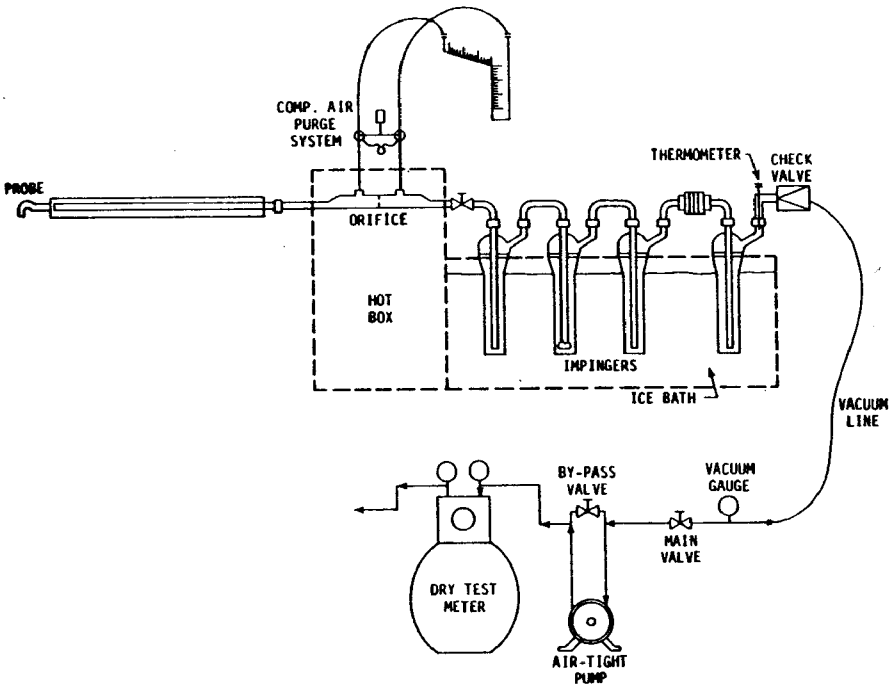
NOTES

EPA METHOD
Isokinetic Sampling Rate Equation

$$\Delta H = D_n^4 \left[\frac{\pi K_p C_p}{4 K_m}\right]^2 \Delta P$$

SLIDE 303-13

ENTROPY HIGH MOISTURE SAMPLING TRAIN



SLIDE 303-14

ENTROPY METHOD

- o used at ammonium nitrate facility
- o orifice or venturi meter located in heater box
- o sample control valve located in back of metering device
- o manometer lines cleaned by pressurized air

SLIDE 303-15

NOTES

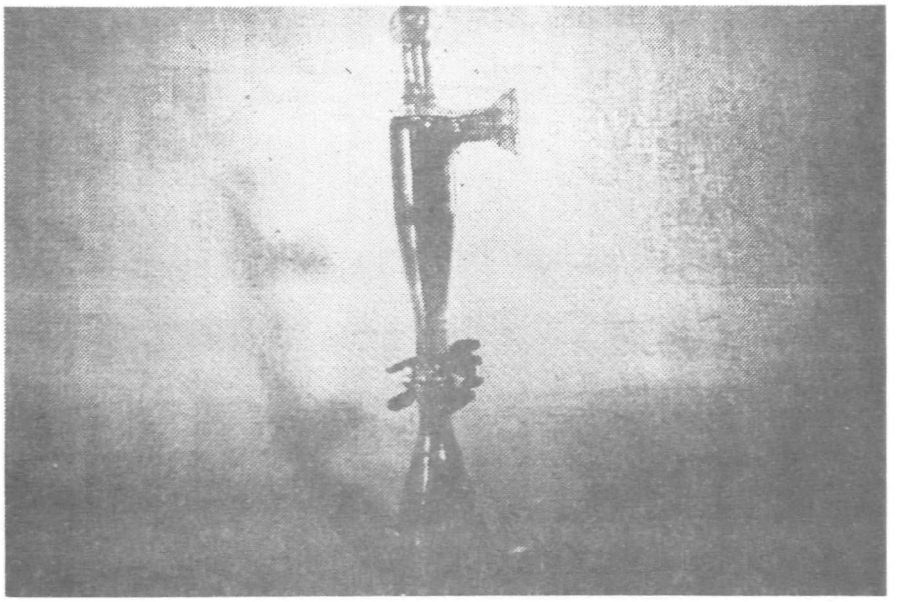
(picture of needle valve on probe)

SLIDE 303-16

PROBLEMS COMMON TO
ALL THREE METHODS

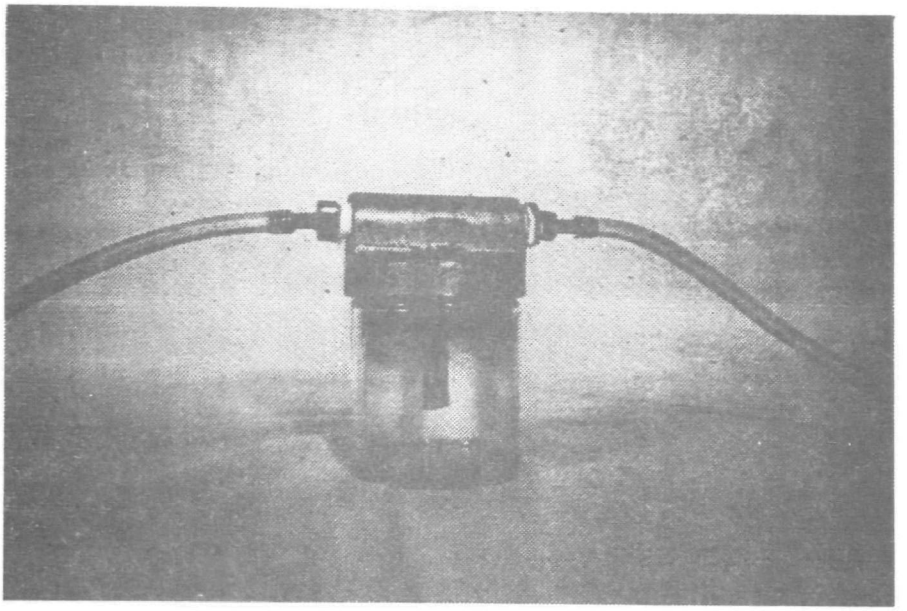
1. Entrained water droplets
2. Condensation in manometer lines
3. Improper condensation in impingers

SLIDE 303-17



SLIDE 303-18

NOTES



SLIDE 303-19

MOISTURE EQUATION - PARTIAL PRESSURE

$$B_{ws} = \frac{S.V.P.}{P}$$

Where: B_{ws} = proportion (by volume) of water vapor in a gas mixture

S.V.P. = saturated vapor pressure of water at average stack temperature

P = absolute pressure of the stack

SECTION D. LOW VELOCITY FLOW

A SURVEY OF COMMERCIALLY AVAILABLE INSTRUMENTATION FOR THE MEASUREMENT OF LOW-RANGE GAS VELOCITIES

Robert F. Vollaro

INTRODUCTION

Gas velocities in industrial smokestacks and ducts typically range from about 1000 to 5000 ft/min; velocities in this range can be measured satisfactorily with a Type-S pitot tube and gauge-oil manometer. Stacks are occasionally encountered, however, in which the velocities are consistently below 1000 ft/min. Measurement of gas velocity is less straightforward below 1000 ft/min than in the 1000 to 5000 ft/min range, because most gauge-oil manometers are not sensitive enough to give accurate low-range readings. The purpose of this paper is to evaluate several commercially available instruments which are capable of measuring gas velocities below 1000 ft/min.

SURVEY OF LOW-RANGE VELOCITY INSTRUMENTATION

The following paragraphs provide a brief description and evaluation of 11 commercially available instruments, along with cost data. A summary of the descriptive information is presented in Table 1.

1. Instrument and Manufacturer: Inclined manometer, Model 125-AV (Figure 1) manufactured by Dwyer Instruments, Inc., Michigan City, Indiana.

a. Operating principle - A differential pressure signal from a primary sensing element (e.g., a Type-S pitot tube) causes a positive displacement of gauge fluid along a calibrated, inclined scale.

b. Velocity range - The full-scale range of the manometer is 0 to 1 in. water column; the scale divisions are 0.005 in. H_2O. The manometer is readable to the nearest 0.003 in. H_2O.

Table 1. LOW-RANGE VELOCITY INSTRUMENTATION

Instrument and manufacturer	Lower velocity limit, ft/min	Temperature range	Resistance to particulate	Applications
Inclined Manometer * Model 125-AV Dwyer Instruments, Inc.	700	Same as primary sensor	Same as primary sensor	Industrial stacks, ducts, vents; also lab applications; air or non-air streams
Micromanometer * Model 10133 Thermo-systems, Inc.	700 in field 400 in lab	Same as primary sensor	Same as primary sensor	Lab applications; limited use in industrial stacks, ducts, vents; air or non-air streams
Microtector * Hook Gauge Dwyer Instruments, Inc.	700 in field 100 in lab	Same as primary sensor	Same as primary sensor	Lab applications; limited use in industrial stacks, ducts, vents; air or non-air streams
Electronic Manometer * Model 1023 Datametrics, Inc.	700 in field 100 in lab	Same as primary sensor	Same as primary sensor	Lab applications; limited use in industrial stacks, ducts, vents; air or non-air streams
Mechanical Vane Anemometer Davis Instrument Co.	70	To 250°F (est.)	Fair	Industrial vents and grilles; special calibration needed for non-air streams
Extended Range Propeller Anemometer R.M. Young Co.	75	To 180°F for continuous duty	Fair	Roof monitors and vents; special calibration needed for non-air streams
Hot-wire Anemometer Model VT-1610 Thermo-Systems, Inc.	30	To 212°F	Fair to good	Industrial stacks, vents, ducts; lab applications; special calibration needed for non-air streams
Hot-film Wedge Sensor Model 1234-H Thermo-Systems, Inc.	60	To 570°F	Good	Industrial stacks, vents, ducts, lab applications; special calibration needed for non-air streams
Fluidic Velocity Sensor Model 308 R Fluidynamic Devices, Ltd.	200	To 450°F	Fair to good	Industrial stacks, vents, ducts; air or non-air streams
Stack Velocity Sampler * Model GSM-1D5K Teledyne Hastings-Raydist	100	Same as primary sensor	Excellent	Industrial stacks, vents, ducts; air or non-air streams
Differential Pressure * Transmitter Brandt Industries, Inc.	150	Same as primary sensor	Excellent	Industrial stacks, vents, ducts; air or non-air streams

* Must be used in conjunction with a Type - S pitot tube or other appropriate primary sensing element.

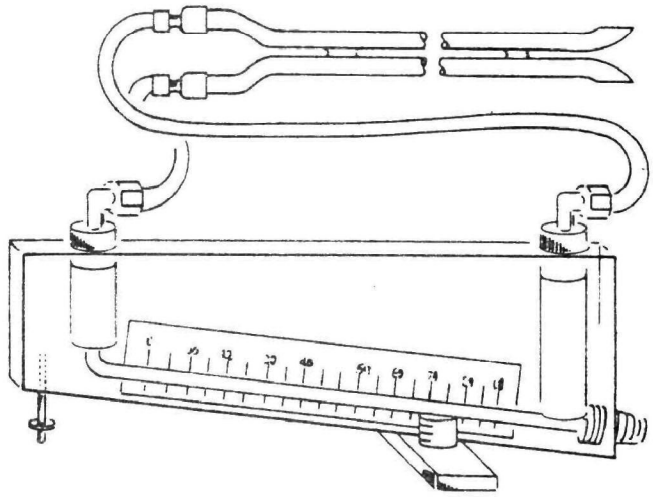


Figure 1. Dwyer inclined manometer, model 125-AV, connected to a Type-S pitot tube.

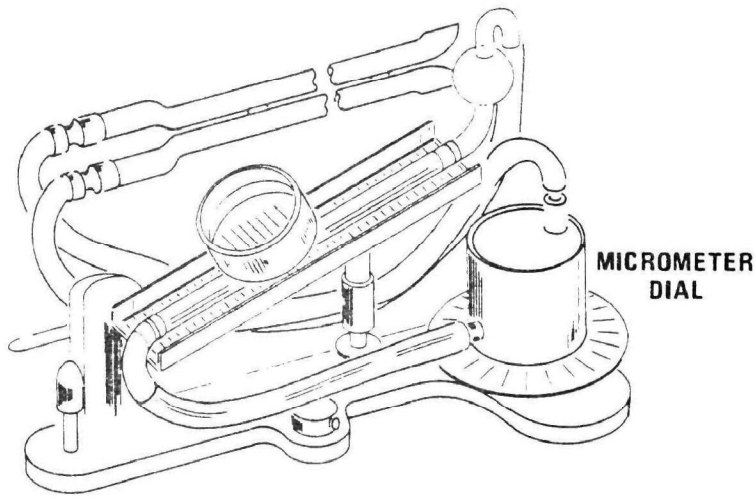


Figure 2. Thermo-Systems micromanometer, model 10133, connected to a Type-S pitot tube.

c. Temperature range - The operating temperature range of the manometer is the same as that of the primary sensing element.

d. Resistance to particulate matter - Governed by particulate resistance of primary sensor.

e. Evaluation - As previously noted, the manometer has scale divisions of 0.005 in. H_2O, and is readable to the nearest 0.003 in. H_2O. Thus, it has greater sensitivity than most inclined manometers, which have 0.01 in. H_2O divisions and are readable to 0.005 in. H_2O. Therefore, with the 125-AV, accuracy of better than 10 percent in velocity head (ΔP) readings can be ensured, provided that the manometer is not used to measure values of ΔP lower than about 0.03 in. H_2O (which corresponds to a velocity of about 700 ft/min for air flowing at 70^oF).

f. Cost - Approximately $125.

2. Instrument and Manufacturer: Micromanometer, Model 10133 (Figure 2), manufactured by Thermo-Systems, Inc., St. Paul, Minnesota.

a. Operating principle - A differential pressure signal from a primary sensing element causes a displacement of gauge fluid along a calibrated, inclined scale.

b. Velocity range - The full-scale range of the micromanometer is 0 to 1.2 in. water column. The scale divisions are 0.01 in H_2O, but the instrument has a micrometer dial, making it possible to read velocity head to the nearest 0.001 in. H_2O.

c. Temperature range - Governed by the primary sensing element.

d. Resistance to particulate matter - Same as primary sensor.

e. Evaluation - The Model 10133 micro-manometer is better suited for laboratory work than for source-sampling applications, particularly at

velocities below 700 ft/min. The reason is that the performance of the manometer is adversely affected by flow pulsations, vibrations, etc. Even when it is in a vibration-free environment, the instrument cannot be used to read ΔP values below 0.01 in. H_2O, if ΔP readings within $\pm$ 10 percent of true are desired.

f. Cost - $200 or less (estimated).

3. Instrument and Manufacturer: Micro-tector Hook Gauge (Figure 3), manufactured by Dwyer Instruments, Inc., Michigan City, Indiana.

a. Operating principle - A differential pressure signal from a primary sensing element causes a slight displacement of gauge fluid. A metal "hook" mounted in a micrometer barrel is carefully lowered until its point "just" contacts the gauge fluid. The instant of contact with the fluid is detected by completion of a low-power AC circuit. On indication of contact, the operator stops lowering the hook, and reads the micrometer to determine ΔP.

b. Velocity range - The full-scale range of the gauge is 0 to 2 in. water column. The micrometer scale is readable to the nearest 0.00025 in. H_2O.

c. Temperature range - Governed by primary sensing element.

d. Resistance to particulate matter - Same as primary sensor.

e. Evaluation - The manufacturer's estimated readability (to the nearest 0.00025 in. H_2O) implies that one should be able to read ΔP values as low as 0.0025 in. H_2O with $\pm$ 10 percent confidence. In practice, however, this readability is only possible if the instrument is perfectly leveled and used in an absolutely vibration-free environment. Generally, the hook gauge will not be a useful field instrument for measuring velocities lower than about 700 ft/min.

f. Cost - About $200.

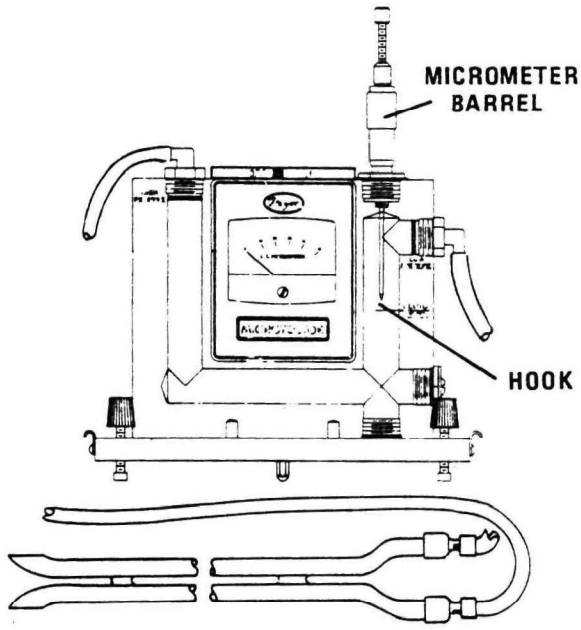


Figure 3. Dwyer microtector hook gauge, connected to a Type-S pitot tube.

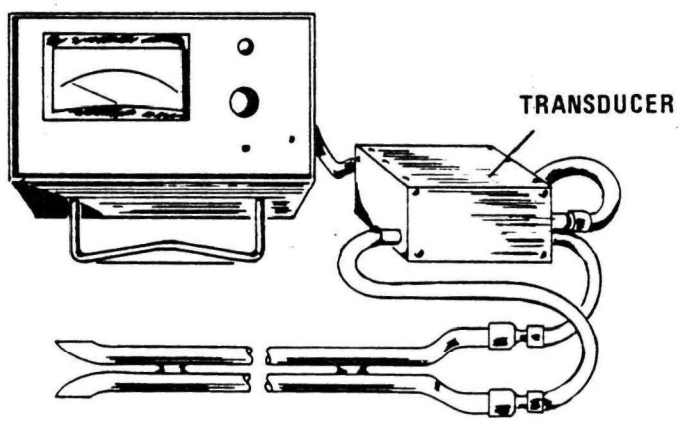


Figure 4. Datametrics electronic manometer, model 1023, connected to a Type-S pitot tube.

4. Instrument and Manufacturer: Electronic Manometer, Type 1023 (Figure 4), manufactured by Datametrics, Inc., Wilmington, Massachusetts.

a. Operating principle - A differential pressure signal from a primary sensing element is converted to an electrical signal by transducers. The output signal can, if desired, be read on a digital voltmeter or recording chart.

b. Velocity range - The manometer is useful over a wide range of velocities because of its multi-scale readout system. The least sensitive scale is 0 to 100 in. water column, and the most sensitive is 0 to 0.01 in. H_2O, full-scale. The rated accuracy of the manometer is 2 percent of full-scale for all operating ranges.

c. Temperature range - Governed by the primary sensing element.

d. Resistance to particulate matter - Same as primary sensor.

e. Evaluation - The 1023 manometer is a high-precision instrument; if zeroed with a digital voltmeter, it is capable of measuring velocity heads as low as 0.001 in. H_2O with acceptable accuracy. Note, however, that readings made on the most sensitive (0 to 0.01 in. H_2O) scale are adversely affected by connecting-line vibrations; thus, the lines from the primary sensor to the transducer must be perfectly still during use in this range. The manometer is, therefore, better suited for laboratory, rather than field, applications for measuring ΔP values below 0.01 in. H_2O.

f. Cost - About $1000.

5. Instrument and Manufacturer: Mechanical Vane Anemometer (Figure 5), manufactured by Davis Instrument Co., Baltimore, Maryland.

a. Operating principle - A gas stream flowing through the anemometer (see Figure 5), causes the propeller blades to rotate. The propeller rpm is proportional to the velocity of the flowing gas. The readout is in linear feet; dividing this readout by the total measurement time gives the gas velocity in ft/min.

b. Velocity range - The anemometer can measure velocities between 70 and 5000 ft/min with acceptable accuracy.

c. Temperature range - (The author does not have a reliable estimate of the instrument's temperature capabilities; however, there seems to be no reason why the anemometer could not be used in gas streams as hot as 200 or 250^{o}F.)

d. Resistance to particulate matter - The propeller blades provide fairly good resistance to particulate matter, especially when the instrument is used for brief periods of time.

e. Evaluation - A mechanical vane anemometer is best suited for making a "quick check" of the exit velocities from a vent or grille. The anemometer is calibrated for use in air streams; special calibration is needed for use in non-air streams. Although the anemometer can accurately measure velocities in the 70 to 700 ft/min range (out of range of most primary sensor-manometer combinations), the instrument can only be used for a short time before it must be stopped, reset, and restarted manually. Thus, the anemometer is not easily adaptable for use in source-sampling applications.

f. Cost - Estimated at $100 or less.

6. Instrument and Manufacturer: Extended Range Propeller Vane Anemometer (Figure 6), manufactured by R. M. Young Co., Traverse City, Michigan.

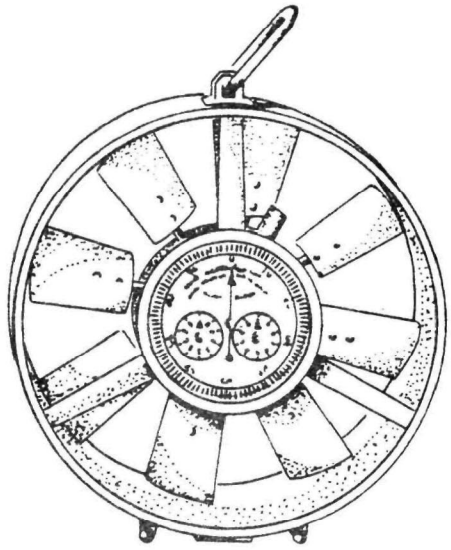


Figure 5. Mechanical vane anemometer, manufactured by Davis Instruments, Inc.

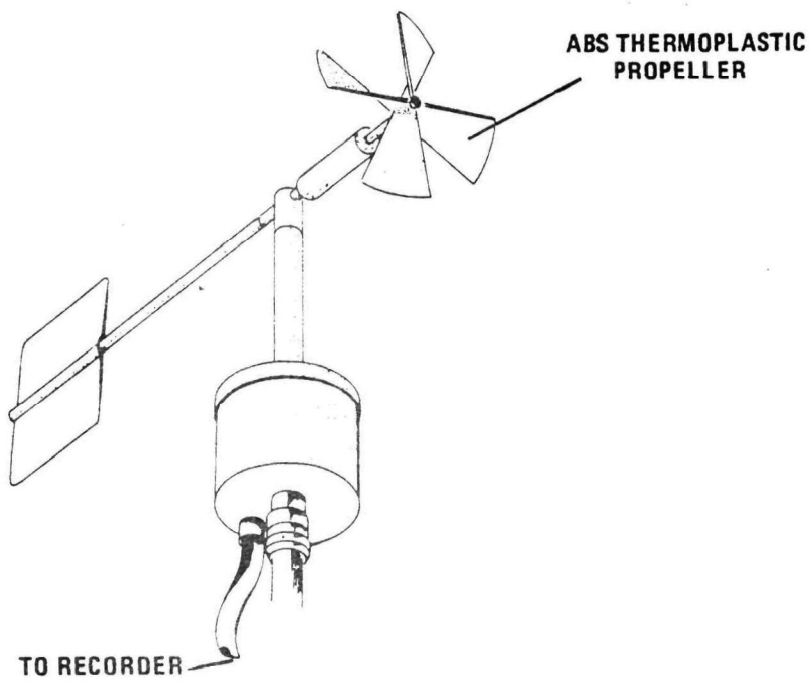


Figure 6. Extended-range propeller vane anemometer, manufactured by R.M. Young Company.

a. Operating principle - Flowing gas causes the propeller (see Figure 6) to turn at a rate proportional to the gas velocity. The propeller shaft is coupled to a d.c. generator. The generator output is an analog voltage, proportional to shaft rpm. The output signal is monitored continuously by means of a recording chart.

b. Velocity range - The velocity range for the anemometer is 75 to 6000 ft/min; 75 ft/min is the threshold velocity at which the propeller begins to turn.

c. Temperature range - With an ABS thermoplastic propeller, the anemometer can be used continuously in gas streams as hot as 180°F and, intermittently, in streams as hot as 300°F.

d. Resistance to particulate matter - The propeller blades provide fairly good resistance to particulate matter.

e. Evaluation - Because it cannot be used for extended periods of time at temperatures above 180°F, the anemometer is of limited value for source-sampling applications. It would probably be useful for continuous velocity measurement in roof monitors. The anemometer is calibrated for use in air streams; special calibration is required for use in non-air streams.

f. Cost - About $700 with recording chart.

7. Instrument and Manufacturer: Velocity Transducer, Model 1610, manufactured by Thermo-Systems, Inc., Minneapolis, Minnesota.

a. Operating principle - The VT-1610 measures the velocity of a flowing gas stream by sensing the cooling effect of the stream as it moves over the heated surface of the sensor, the "hot-wire" principle. The output signals from the sensor are electrical and non-linear. A signal conditioner

is available to linearize the output. The output signals are temperature compensated so that the readings will be in ft/min, corrected to 70°F.

b. Velocity range - The instrument can measure velocities as low as 30 ft/min (on the low scale) and as high as 12,000 ft/min (on the high scale), with acceptable accuracy (± 2 percent).

c. Temperature range - The instrument can be used in gas streams as hot as 212°F.

d. Resistance to particulate matter - Unlike many hot-wire devices, the VT-1610 sensor is ruggedized and has fairly good resistance to particulate matter.

e. Evaluation - It appears that the VT-1610 would be most suitable for short-term use in low-temperature air streams, particularly when velocities are too low (under 700 ft/min) to be measured with most primary sensor-manometer combinations. If used continuously in a dusty environment, the instrument will tend to foul after several hours. The sensor is calibrated for use in air streams; special calibration is required if it is to be used in non-air streams.

f. Cost - About $1000 for sensor and signal conditioner.

8. Instrument and Manufacturer: Wedge Hot-Film Sensor, Model 1234-H (Figure 8), manufactured by Thermo-Systems, Inc., Minneapolis, Minnesota.

a. Operating principle - The 1234-H measures the velocity of a flowing gas stream by sensing the cooling effect of the stream as it moves over the heated sensor surface, the "hot-film" principle. The output signal is electrical and can be read continuously on a recording chart, if desired. When used with a temperature compensator, the readout will be in ft/min, corrected to 70°F.

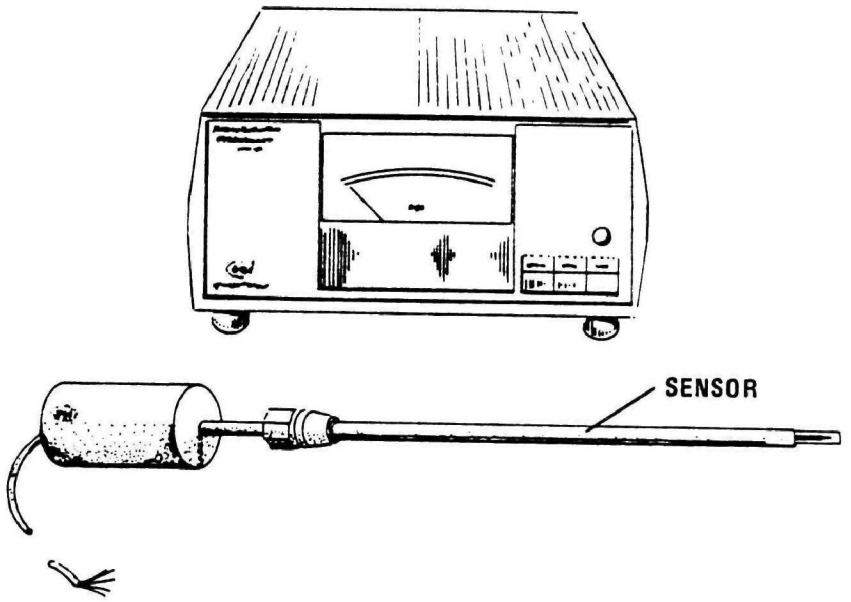


Figure 7. Thermo-Systems hot-wire anemometer, model VT-1610.

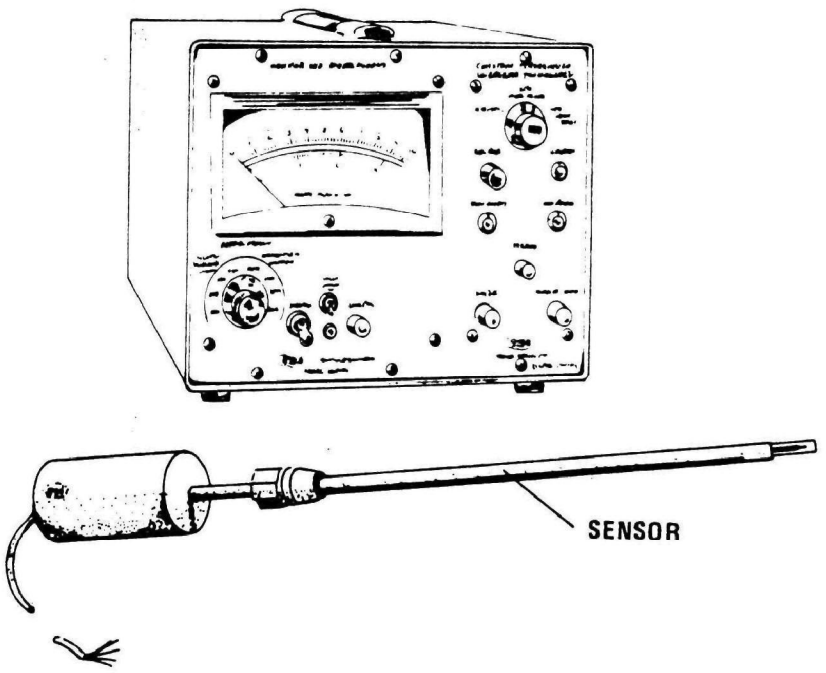


Figure 8. Thermo-Systems hot-film wedge sensor, model 1234-H.

b. Velocity range - The sensor can measure velocities as low as 60 ft/min (on the low-scale) or as high as 12,000 ft/min (on high-scale), with acceptable accuracy ($\pm$ 2 percent).

c. Temperature range - The sensor can be used in gas streams as hot as 570^{o}F.

d. Resistance to particulate matter - The sensor is ruggedized and offers good resistance to particulate matter.

e. Evaluation - The 1234-H is best suited for short-term use in air streams, particularly when velocities are too low to be measured with primary sensor-manometer combinations. It may prove to be useful for measuring total flow rate from roof monitors, because several sensors, positioned at different points along a roof vent, can be connected to a multi-channel readout system. Like the VT-1610, the 1234-H requires special calibration for use in non-air streams.

f. Cost - About $1500, for one temperature-compensated sensor and readout system; about $500 for each additional sensor.

9. Instrument and Manufacturer: Fluidic Velocity Sensor, Model 308R (Figure 9), manufactured by FluiDynamics, Ltd., Ontario, Canada.

a. Operating principle - The following description refers to Figure 9: A free jet of supply fluid (air or N_2) is issued from a nozzle (point B), and impinges on two pick-up ports (point C). At zero cross-flow velocity, the differential pressure across the pick-up ports is zero. Any cross-flow causes the supply air jet to deflect, yielding a differential pressure signal proportional to the velocity. The output signal can be read with a differential pressure gauge or transducer.

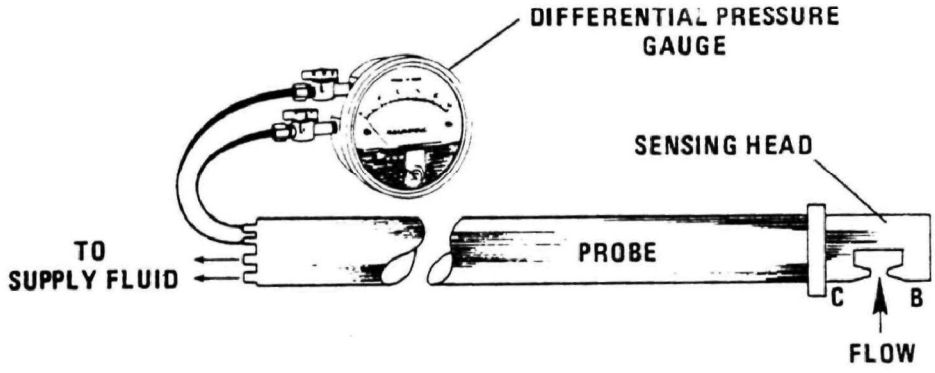


Figure 9. Fluidic velocity sensor, model 308R, manufactured by FluiDynamic Devices, Ltd.

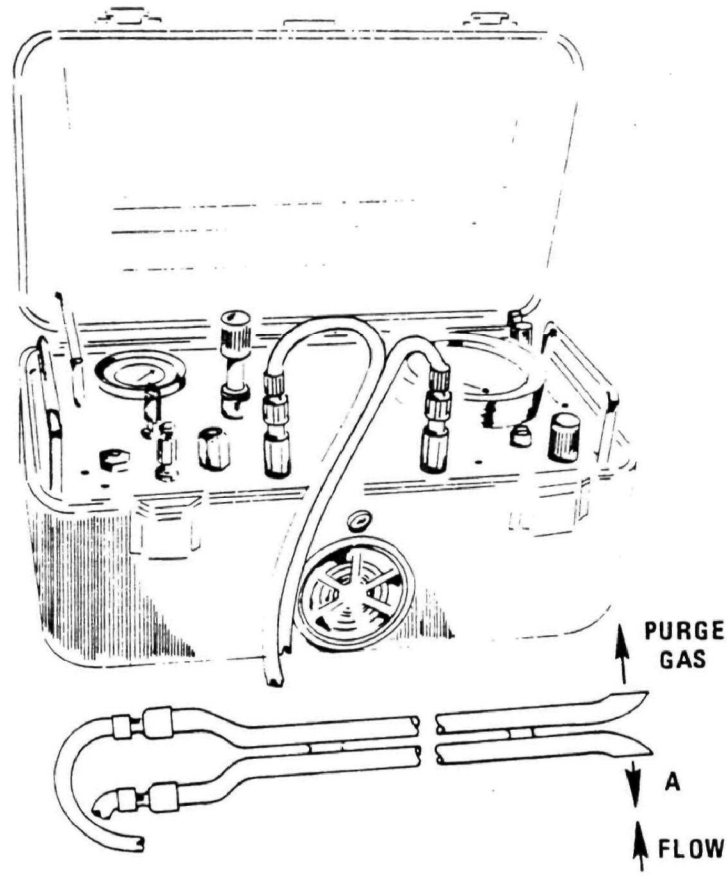


Figure 10. Stack velocity sampler, model GSM-1D5K manufactured by Teledyne Hastings-Raydist.

b. Velocity range - The sensor has a full-scale velocity range of 0 to 3600 ft/min. The accuracy of the sensor is about $\pm$ 3 percent for velocities above 600 ft/min, and $\pm$ 5 to 10 percent for velocities below 600 ft/min.

c. Temperature range - The sensor can be used in gas streams as hot as 450^{o}F.

d. Resistance to particulate matter - The sensor has fairly good resistance to particulate matter.

e. Evaluation - One of the outstanding features of the sensor is that it has a linear, high-amplitude output signal, even at low velocities. For example, when the cross-flow velocity (v_c) is 600 ft/min, the sensor output is about 12 in. H_2O; at v_c = 200 ft/min, the output is about 4 in. H_2O. Note, however, that the sensor is difficult to zero; for this reason, its accuracy falls off appreciably for v_c < 200 ft/min. The sensing head is mounted on a cylindrical probe, making it convenient to use in source-sampling applications. The sensor can be used in non-air streams, provided that the gas density is known.

f. Cost - About $2000.

10. Instrument and Manufacturer: Stack Velocity Sampler, Model GSM-1D5K (Figure 10), manufactured by Hastings-Raydist, Hampton, Virginia.

a. Operating principle - The following description refers to Figure 10: At zero cross-flow, supply fluid (air or N_2) is continually purged at equal rates, out of both impact openings of the Type-S pitot tube. Any cross-flow velocity causes a back-pressure against the purge gas, at point A. The back-pressure signal is proportional to the fluid velocity; thermoelectric

sensors (transducers) interpret and convert this signal. The output voltage from the transducers is linear over about 90 percent of the scale; output voltage can be read with a digital voltmeter or recording chart, if desired.

b. Velocity range - The velocity range is 0 to 1500 ft/min, full scale. The lower limit of readability is about 100 ft/min.

c. Temperature range - The instrument is operable at all temperatures at which a Type-S pitot tube can be used.

d. Resistance to particulate matter - The continuous-purge principle of the sensor gives it excellent resistance to particulate matter.

e. Evaluation - The most outstanding feature of the Hastings instrument is that it works with a Type-S pitot tube; thus, it is easily adaptable for use with conventional source-sampling equipment. The voltmeter on the control panel is adequate for reading velocities between 200 and 1500 ft/min. To read accurately velocities between 100 and 200 ft/min, a digital voltmeter or sensitive chart recorder is needed. The sensor can be used in non-air streams if the density of the gas is known. Note that the instrument must be calibrated exactly as it is to be used, because different calibration curves will be obtained for different pitot tube and connecting-line lengths.

f. Cost - About $1500 to $2000.

11. Instrument and Manufacturer: Differential Pressure Transmitter (Figure 11), manufactured by Brandt Industries, Inc., Raleigh, North Carolina.

a. Operating principle - The following description refers to Figure 11: Supply fluid (air on N_2) exhausts equally out of both sides of the pitot tube at zero cross-flow velocity. Any cross-flow will cause a

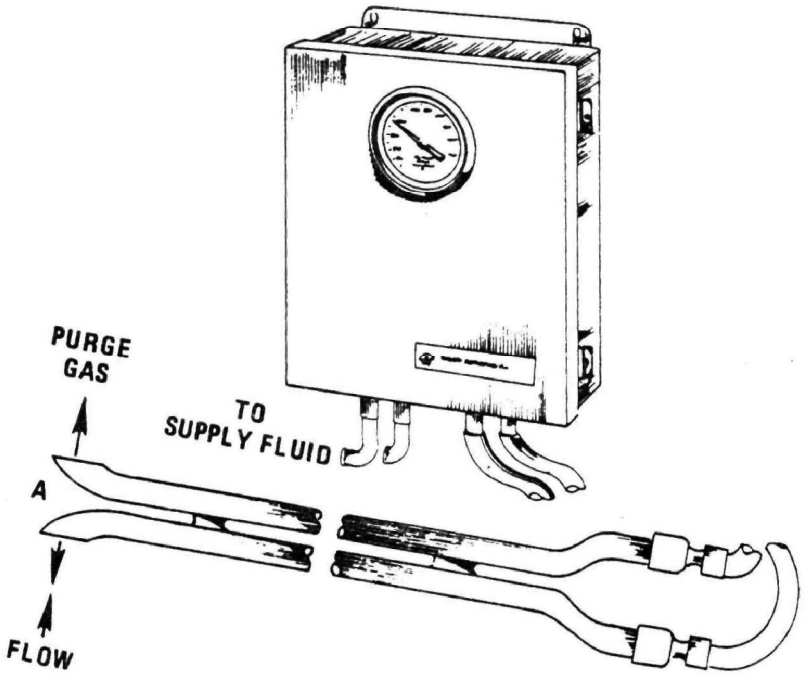


Figure 11. Differential pressure transmitter, series 200; manufactured by Brandt Industries, Inc.

back-pressure against the purge gas at point A. The magnitude of the back-pressure signal is proportional to the fluid velocity. Transducers receive and convert the back-pressure signal. The output signal from the transducers is pneumatic and linear; the output can be read continuously on a pneumatic recorder if desired.

b. Velocity range - The full-scale range of the transmitter is 0 to 0.05 in. water column. The accuracy of the transmitter is estimated at ± 2 percent of span.

c. Temperature Range - The transmitter can be used at any temperature at which the primary sensing element (pitot tube or other sensor) can be used.

d. Resistance to particulate matter - The continuous-purge action of the supply fluid gives the sensor excellent resistance to particulate matter.

e. Evaluation - The Brandt transmitter is a versatile device; it can be used as a single-point sensor, or adapted for multipoint sensing (e.g., it can be used with a pitot "rake"). The transmitter is easily adaptable for use with conventional source-sampling equipment. An especially attractive feature of the transmitter is a damping control, which allows true, time-integrated average velocity head readings to be made. Velocities as low as 150 to 200 ft/min can be read with acceptable accuracy. The instrument can be used in non-air streams if the gas density is known. One drawback of the instrument is that there is a practical upper-limit (30 ft) on the length of the connecting lines; note, also, that the connecting lines are somewhat vibration-sensitive and should be still when measurements are made.

VELOCITY MEASUREMENTS AT LOW FLOW RATES

by
Robert F. Vollaro

INTRODUCTION

Accurate determination of the volumetric flow rate of a gaseous effluent is one of the most important measurements the stack sampler has to make. Flow rate is usually calculated from the mean velocity of the effluent stream and the cross-sectional area of the duct. For velocity determinations, the S-type pitot tube in combination with a pressure differential measuring device, usually an incline manometer or magnehelic gauge, has become the standard of the stack sampling industry.

In rare cases, stack gas velocities will be so low that the velocity head does not register on these pressure gauges. The lower limit for a 0- .25 inch water manometer, for instance, is 0.0025 inches, and the accuracy in this region is questionable. Roughly speaking, S-type pitot tubes are ineffective at velocities below 600 feet per minute.

When velocities below 600 feet per minute are encountered or expected, an alternative approach to velocity measurement must be devised. These alternatives fall into three categories: use of velocity measurement techniques other than pitot tubes, modification of the source to effect a sufficiently high velocity for using pitots, and computational methods.

ALTERNATIVE VELOCITY MEASUREMENTS TECHNIQUES

Methodologies for measuring gas stream velocities fall into five general categories, based on their principle of operation: measurement of a pressure drop, measurement of a temperature differential, measurement of a mechanical displacement, measurement of the progress of a tracer inserted into the gas stream, and measurement of the amount of dilution of an indicator material. Numerous mechanisms have been developed for making each of these measurements. Many of these are discussed below, arranged categorically by operating principle.

A. Measurement of a Pressure Drop - In a flow measuring device which incorporates a tube with a constriction, the gas velocity through the device is proportional to the pressure drop across the constriction. For incompressible fluids, the flow rate is given by an equation of the type.

$$Q = CA \frac{2g}{\gamma} \Delta p$$

where

Q = volumetric flow rate, in^3/sec
C = flow coefficient of the measuring device, dimensionless
A = cross-sectional area at minimum diameter, in^2
g = acceleration due to gravity, 386 in/sec^2
γ = fluid density, lb/in^3
Δp = pressure drop across the constriction, lb/in^2. (2)

Three types of constriction meters useful in gas flow measurements are the venturi meter, the orifice meter, and the laminar flow meter. With these devices, all the gases must pass through the meter.

Venturi meters--Venturi meters consist of a conical converging nozzle, a cylindrical throat about 1/3 the pipe diameter and no longer than its own diameter, and a diverging section. Static pressure taps are located upstream of the convergence and at the throat. Venturi meters offer high accuracy and relatively low head loss, and are highly resistant to abrasion from entrained particulates and the resultant alteration of performance characteristics. However, they are impractical for large diameter ducts.

Orifice meters -- An orifice meter consists of a plate placed across a duct, with a small, sharpd-edged opening at its center. Pressure taps are on either side of the plate. Orifice meters are cheaper than venturis and more readily adaptable to larger diameter ducts. Limitations include considerable head loss and sensitivity to abrasion or corrosion.

Laminar flow element--Driscoll (3) describes a device which can be used when the pressure drop associated with the venturi and orifice meters is unacceptable. A bundle of 3/4" by 15" steel tubing was brazed into a duct, and the pressure drop across the element measured. Flow is related to this pressure drop by the equation

$$Q = K \frac{\mu o}{\mu} \Delta p$$

where

Q = flow rate

K = calibration factor of the flow element

μo = gas viscosity at calibration conditions

μ = gas viscosity at measurement conditions, and

Δp = pressure drop.

This device was demonstrated experimentally to be an excellent gas flow meter at flow rates well below 100 cfm.

These devices yield a total volumetric flow rate measurement. They are applicable only if all gases can be passed through the meter. In many instances, as with large ducts, ducts with irregular cross-sections, or cases when the back pressure associated with these devices is undesirable, use of a pressure drop device to measure flow rates is precluded.

B. Measurement of a Temperature Differential - The principle in operation here is that the rate of transfer of heat from a stationary heat source to a gas stream is related to the velocity of the stream. (3) Instruments which employ this principle include hot-wire anemometers, thermistor anemometers, and hot film anemometers.

Hot-wire anemometers--Hot-water anemometers operate in one of two ways. Gas velocity is determined either from temperature change in a resistance wire, or by the amount the passing gases are heated. In the second instance two temperature-sensing elements are employed, one upstream, heated, and one downstream, unheated. An accurate determination of the flue gas temperature is necessary to use these instruments.

Thermistor anemometers--The thermistor anemometer, identical in principle to the hot-wire anemometer, uses thermistors rather than resistance wires as heating and sensing elements. Gases pass into a small opening, are heated by the first resistor, and the temperature increase determined by the second resistor. While hot-wire instruments have been found to be accurate at velocities down to 100 feet per minute, thermistor anemometers are sensitive to velocities of less than 20 feet per minute.

Hot-film anemometers--Hot-wire and thermistor anemometers are subject to a serious drawback insofar as stack sampling field application is concerned; they lose accuracy when coated with particulate. Shielded hot-wire anemometers

are commercially available, which return to calibration when the shield is wiped clean. The hot-film anemometer is one such instrument, with the sensing element coated with with a protective film. Particulates which impinge on the element can be removed, restoring the instrument to calibration. Shielded, or not, hot-wire anemometers are subject to inaccuracies when used in particulate-laden streams. They are quite useful for measuring low flows in clean gas streams.

C. Measurement by Mechanical Displacement - Numerous devices for the determination of gas velocities operate on the principle that mechanical displacement due to the impact pressure of a moving gas is proportional to the gas velocity. Among these are rotating vane and swinging vane anemometers, and drag body meters.

Rotating vane anemometers--These instruments consist of a series of radially-mounted, diagonal vanes which rotate when a gas stream moves past the unit. The rotating vanes either deive a series of dials which measure the mount of gas, in units of length, passing the meter, or provide a direct velocity readout through the use of magnetic pickups. Rotating vane anemometers are subject to damage and/or loss of accuracy in wet or dirty gas streams.

Swing vane anemometers--In this device, the gas stream impinges upon a metal strip vane connected at one end to a meter. The amount of deflection of the vane is proportional to the impact pressure, which in turn is related to the gas velocity. A direct readout for velocity is usually provided. As with the rotating vane type, swinging vane anemometers should not be sued at elevated temperatures or in dust-laden gases. (1)

Drag body meters--The drag force on a body inserted into a gas stream can be a very accurate measurement of the flow rate. A fixed body is usually mounted on a support incorporating a strain gauge in order to measure the drag force. With a symmetrical body, this meter works for flows in either direction. However, these instruments are ineffective below about 150 feet per minute. (2)

D. Injection of a Tracer Material - This technique is a simple one: introduce a readily identifiable tracer material into the gas stream a known distance upstream of a detection device, and measure the amount of time required for the tracer to traverse that distance. Tracers which have been used successfully include ballons, colored smoke, chemicals, and radioactive materials. (1)

Ballons--Ballons can be added to a duct and then spotted downstream at a window or at the duct exit. The gases cannot be so hot as to rupture the ballons, a severe limitation. Additionally, errors can be introduced due to the inertial properties of the ballons and due to their bouyance (positive or negative).

Colored smoke --Colored powders are injected into the gas stream with a squeeze bulb, and the time required for the smoke cloud to exit the stack is measured. This is a simple method, useful in plumes which are not extremely dense.

Chemicals--Instead of colored powder, a chemical which will react with a substance in the gas stream to form a visible cloud can be injected. Ammonium hydroxide, for example, will react with sulfur dioxide to form a white aerosol. In the absence of sufficient quantities of SO_2, hydrochloric acid can be injected along with the ammonium hydroxide. This method will not work in saturated stacks, as the white cloud cannot be easily seen.

Radioactive materials--Radioactive isotopes, detected with a geiger counter, have been used to measure stack flows, but this method is not highly recommended. It requires complicated and expensive equipment, highly trained personnel, and elaborate safety precautions, and provides no better results than colored powders or chemical reagents.

E. Dilution of an Indicator Material - The dilution technique is useful when measurements with pitot tubes or other devices is impractical, as when highly turbulent flow cannot be avoided. A tracer gas, preferably one not already present in the stack gas, is introduced at a known concentration and rate into the flue. The concentration of the injected gas is then measured at a point far enough downstream for complete mixing to have taken place. (3) Volumetric flow can then be calculated using the equation:

$$Q_s = Q_i\left(\frac{C_i}{C_s}\right) - 1$$

where

Q_s = stack gas flow rate
Q_i = indicator gas injection rate
C_i = indicator gas concentration at injection
C_s = indicator gas concentration at sampling.

Ethane, methane, and propane have been used with success, the downstream concentration monitored with a hydrocarbon analyzer. Expense of instrumentation and portability problems restrict this method; the latter can be circumvented by collecting grab samples for analysis in a laboratory. Radioactive materials (carbon-14, radioactive krypton, etc.) have also been utilized. (1)

SOURCE MODIFICATION TO ACHIEVE INCREASED VELOCITY

At a constant volumetric flow rate, the velocity of a gas stream confined to a duct is inversely proportional to the cross-sectional area of the duct. An increase in the velocity of flue gases can be effected by a reduction in the cross-sectional area. An extension, either temporary or permanent, which tapers from the duct size to an appropriate smaller cross-section is constructed and affixed to the duct opening. A velocity traverse of the smaller section can then be performed using a pitot tube.

The extent of the cross-sectional reduction will depend on the original velocity of the gas; an increase to above 600 feet per minute should be achieved. A lower area limit of about one square foot should be observed to avoid biased velocity readings due to probe blockage in the extension.

This method is limited in its application only by the size of the duct and the accessibility of its terminus.

COMPUTATIONAL METHODS

Within any given fuel category, the ratio of the quantity of dry effluent gas generated by combustion to the gross calorific value of the fuel is a constant. This ratio is known as the dry F (F_d) Factor. Values for F_d for numerous types of fuel, from coal and oil to shoe leather, have been computed and can be obtained from a table. Knowing this value, along with the heat input rate and dry oxygen concentration of the effluent gas, the volumetric flow rate is obtainable through the relationship

$$Q_{sd} = Q_H \times F_d \times \frac{20.9}{20.9 - \%O_2}$$

where

Q_{sd} = dry volumetric flow rate of stack gas, ft^3/hr
Q_H = heat input rate, 10^6 Btu/hr, and
F_d = dry F Factor for fuel being burned, $ft^3/10^6$ Btu.

The term $\frac{20.9}{20.9 - \%O_2}$ is a correction factor for excess air.

Wet effluent flow rate, Q_{sw}, can be calculated using a separate wet F Factor, F_w, and incorporating the moisture fraction in the ambient air (B_{wa}) in the excess air correction factor. The above equation then becomes

$$Q_{sw} = Q_H \times F_w \times \frac{20.9}{20.9(1 - B_{wa}) - \%O_{2\ w}} .$$

Experience has shown that these calculated flow rates are significantly lower than measured rates. Aerodynamic interferences and pitot tube misalignment are factors which can produce measured values higher than the actual flow rate. Stoichiometric calculations are quite useful, though, when instrument measurements are not possible. (4)

CONCLUSIONS

There is almost no end to the range of devices and techniques available for measuring the rate of flow of a gas stream. Of the types discussed here, each is most useful under particular conditions of flow rate, temperature, dust and moisture concentration, and so on. Many of the techniques were developed for specific applications, taking into account the peculiarities of the source to be measured, yet are applicable to other similar situations. Table 1 lists the performance characteristics of these types of low measurement devices.

TABLE 1. PERFORMANCE CHARACTERISTICS OF FLOW MEASUREMENT DEVICES

Type	Approximate range	Accuracy %	Calibration stability in dust
Venturi	100 - 500,000 cfm	1 - 2	good
Orifice	50 - 100,000 cfm	1 - 2	fair
Laminar flow	5 - 100 cfm	1 - 2	good
Hot-wire	~10 - >2,000 ft/min	~2	poor
Thermistor	~10 - ? ft/min	~1	fair
Hot-film	10 - >2,000 ft/min	~2	good
Rotating vane	<100 - >2,000 ft/min	~1	good
Swinging vane	20 - >2,000 ft/min	~3	fair - good
Drag body	5 - 100 cfm	0.5 - 2	good

With such a wide range of devices and techniques for measuring gas flow rates, plus the fact that the development of new techniques is limited only one one's ingenuity, it is virtually inconceivable that a source test should have to be abandoned due to an inability to determine the volumetric flow rate of the effluent gases. Should flows be too low for pitot tubes to provide this data, a host of alternatives are at the stack sampler's disposal.

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4. Shigehara, R.T., R.M. Neulicht, W.S. Smith, and J.W. Peeler. "Summary of F-Factor Methods for Determining Emissions from Combustion Sources". Entropy Environmentalists, Inc., Research Triangle Park, North Carolina, 1976.

SLIDE 304-0

NOTES

VELOCITY MEASUREMENT TECHNIQUES AT LOW GAS FLOWS

SLIDE 304-1

VELOCITY

- used to determine nozzle size
- used to obtain k-factor for setting isokinetics

VOLUMETRIC FLOW

- used to determine mass emissions

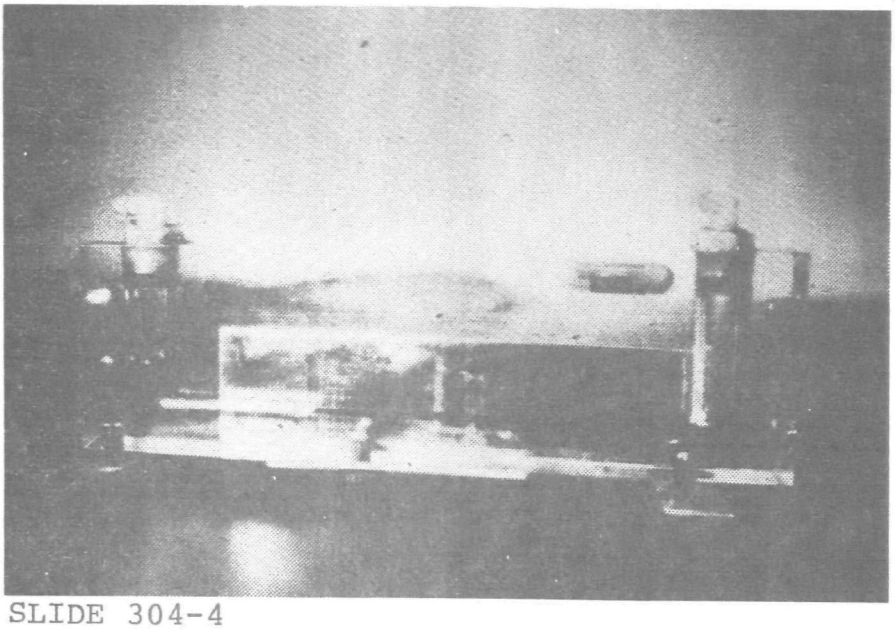
SLIDE 304-2

THE PROBLEM

- pressure differential devices insensitive below 1000 ft/min
- unreliable pitot tube accuracy below 400 ft/min

SLIDE 304-3

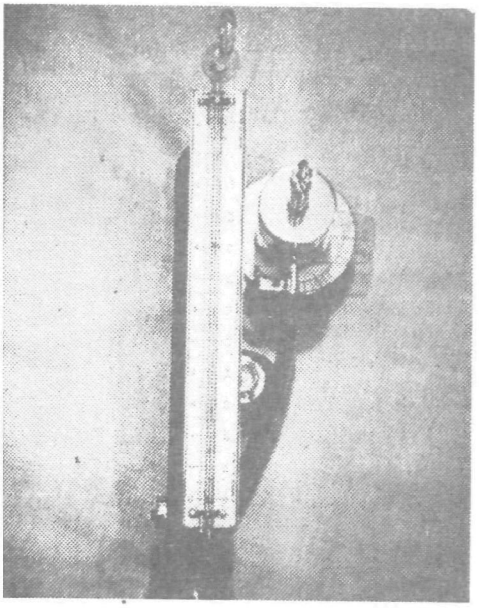
NOTES



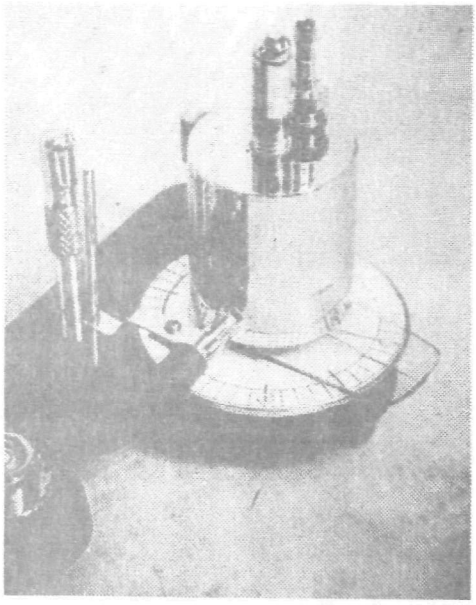
SLIDE 304-4

(picture of scale divisions of above manometer)

SLIDE 304-5



SLIDE 304-6



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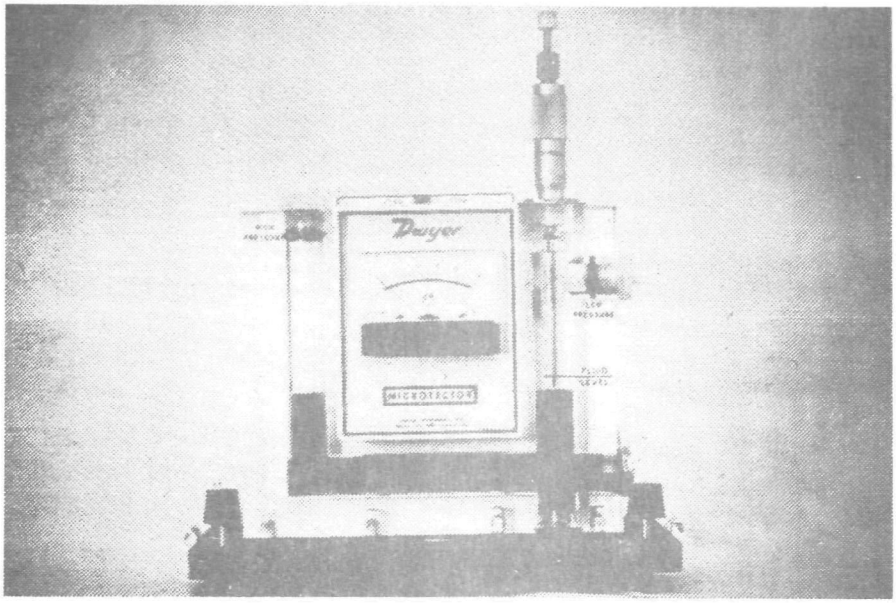
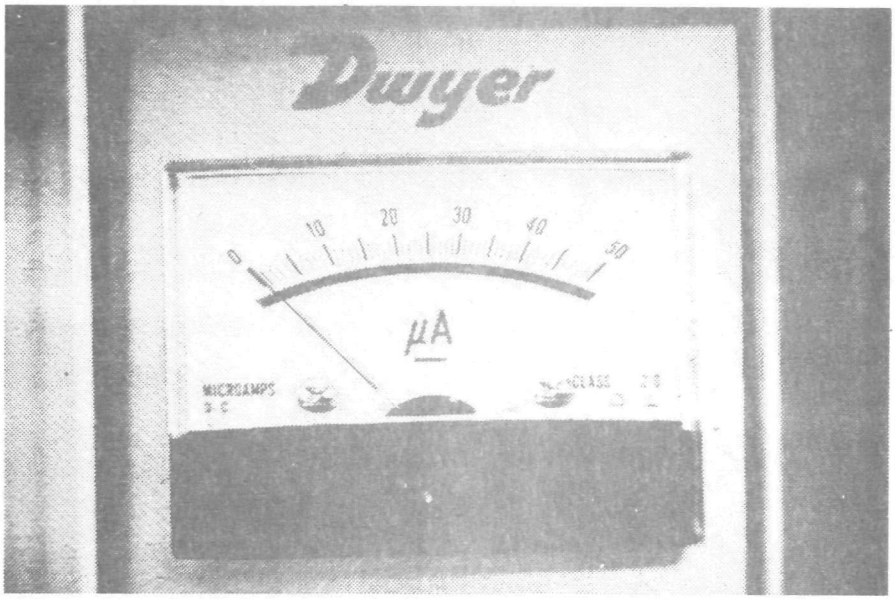
SLIDE 304-7



SLIDE 304-8



SLIDE 304-9

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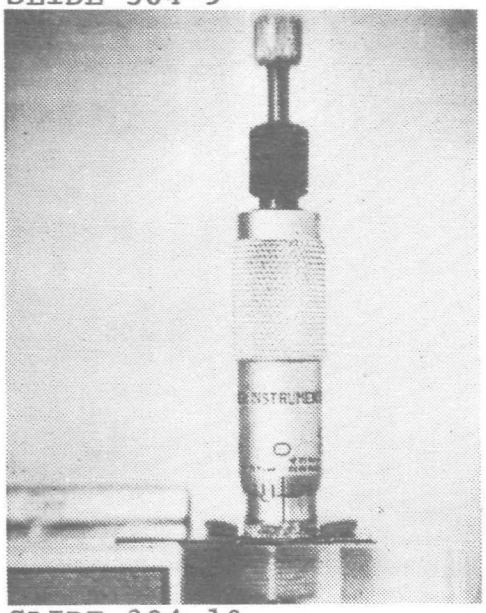


SLIDE 304-10

ALTERNATIVE APPROACHES FOR
LOW VELOCITY MEASUREMENTS

1. The use of techniques other than pitot tubes
2. Modification of the source to effect a sufficiently high velocity for using the pitot tube
3. Measure velocity at a different location and use data to calculate velocity at sampling site
4. Compute flow and velocity using process parameters

SLIDE 304-11

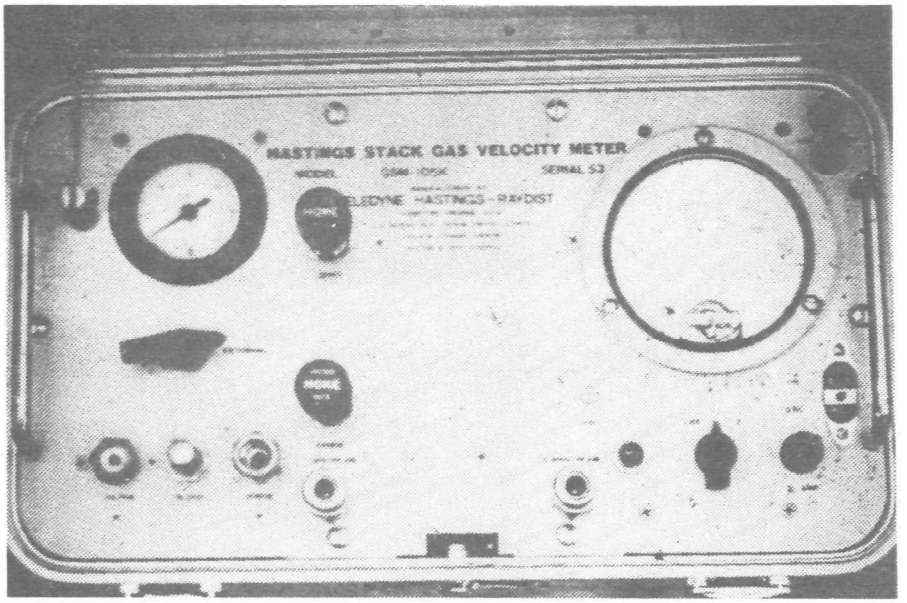
TECHNIQUES OTHER THAN
PITOT TUBES

PRESSURE DROP MEASUREMENT DEVICES

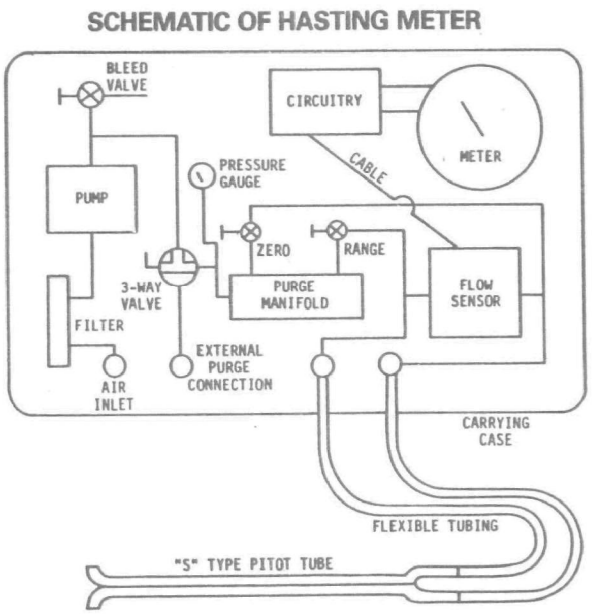
- o Venturi Meters
- o Orifice Meters
- o Mass Flow Meters

SLIDE 304-12

NOTES



SLIDE 304-13



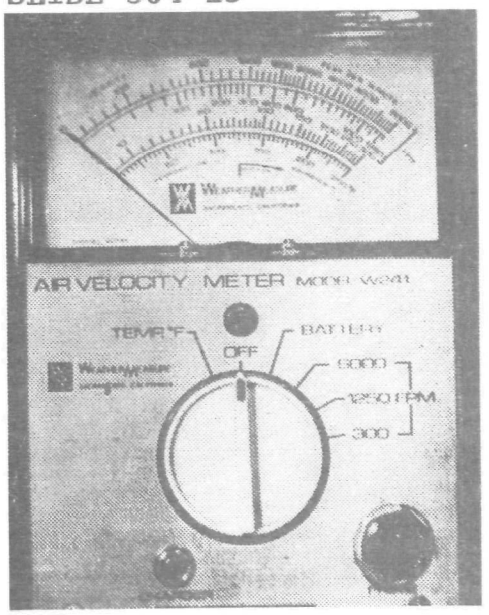
SLIDE 304-14

TEMPERATURE DIFFERENTIAL MEASUREMENT DEVICES

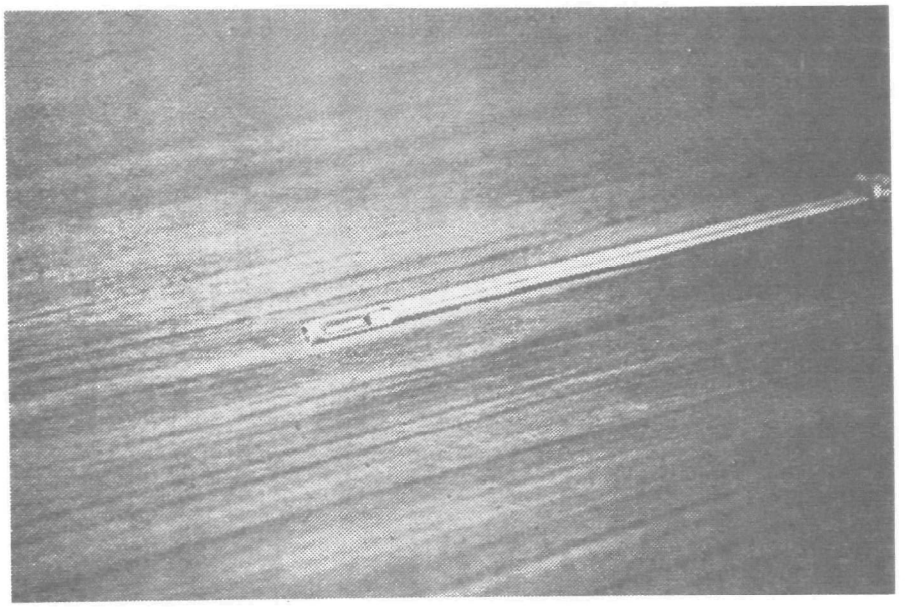
- Hot Wire Anemometer (accuracy greater than 100 FPM)
- Thermister Anemometer (velocity sensitive less than 20 FPM)
- Hot Film Anemometer

SLIDE 304-15

NOTES



SLIDE 304-16



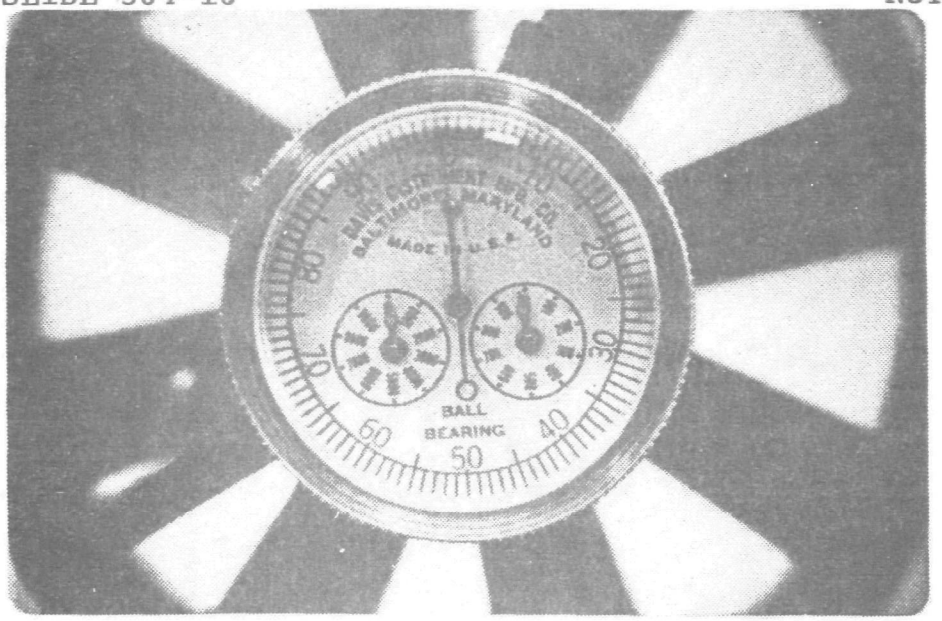
SLIDE 304-17

MECHANICAL DISPLACEMENT
MEASURING DEVICES

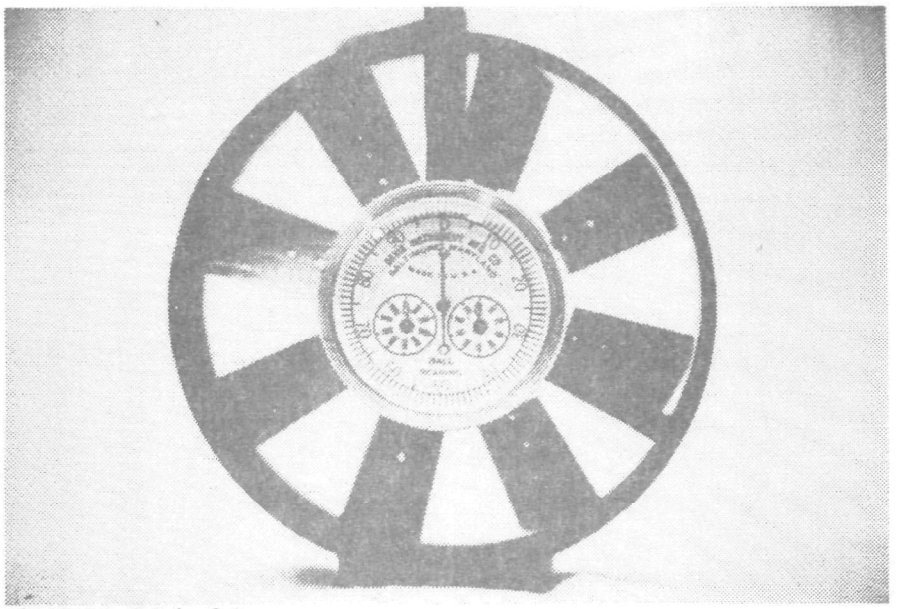
- o Rotating Vane Anemometer
- o Swinging Vane Anemometer
- o Drag Body Meters

SLIDE 304-18

NOTES



SLIDE 304-19



SLIDE 304-20

MODIFICATION OF SOURCE TO INCREASE VELOCITY

Increase velocity by reducing the cross-sectional area using stack extension

Velocity should be increased to above 600 ft/min

A lower area limit of approximately 1 ft^2 to avoid bias due to probe blockage

COMPUTATIONAL METHOD ("F" FACTOR)

o Dry "F" factor

$$Q_{sd} = Q_H \times F_d \times \frac{20.9}{20.9 - \%O_2}$$

o Wet "F" factor

$$Q_{sw} = Q_H \times F_w \times \frac{20.9}{20.9(1 - B_{wa}) - \%O_2}$$

SECTION E. CYCLONIC FLOW

ISOKINETIC PARTICULATE SAMPLING IN NON-PARALLEL FLOW SYSTEMS– CYCLONIC FLOW

by
Jim Peeler

In most stationary sources, the direction of gas flow is essentially parallel to the stack axis. Examples of non-parallel flow systems are flow immediately following a bend or turn in the ductwork, flow in a convergent or divergent section, and cyclonic (tangential) flow. Cyclonic flow most often occurs after inertial demisters following wet scrubbers, in stacks with tangential inlets, and after axial fans. Method 1–Sample and Velocity Traverses, and Method 2–Determination of Stack Gas Velocity and Volumetric Flow Rate, are not applicable to stacks with cyclonic flow. Method 1 (2.4), gives explicit instructions for determining when unacceptable flow conditions exist. In short, the angle (between the pitot orientation and the plane perpendicular to the stack axis) required to produce a null reading is measured for each sampling point. If the average of the absolute values of the angles is greater than 10°, unacceptable flow conditions exist.

In many cases, particulate sampling is required even though the appropriate reference methods are not applicable due to non-parallel flow. This situation occurs more frequently at existing sources than at new sources, since sources subject to NSPS are required to provide sampling locations which permit sampling according to the appropriate reference methods. There are three possible alternatives when unacceptable flow conditions exist:

(1) modify the sampling methodology to obtain accurate results

(2) use standard or alternate methodology which gives results biased high (in the agency's favor), or (3) modify the source to permit standard sampling procedures to be used. This paper discusses three sampling procedures which have been commonly proposed. Also, source modifications which can be employed are described. Current studies on tangential flow may provide better solutions in the future.

BACKGROUND INFORMATION

In order to determine the biases of various sampling techniques in non-parallel flow systems, it is necessary to understand the requirements of proportional sampling and the errors associated with pitot tube measurements.

Proportional Sampling - Source sampling is conducted to determine the concentration of a particular pollutant in an effluent stream. The concentration of component Z which is representative of the effluent is,

$$\bar{C}_Z = \frac{\text{volume of component Z}}{\text{total volume of effluent}} = \frac{C_Z \times V(\text{ft/sec}) \times A(\text{ft}^2) \times \theta(\text{sec})}{V(\text{ft/sec}) \times A(\text{ft2}) \times \theta(\text{sec})} \quad (1)$$

C_Z = %, if component Z is a gas

C_Z = lbs/ft^3, if component Z is particulate

For a steady state source with spatial variations in concentration and velocity, Equation (1) can be expressed as,

$$\bar{C}_z = \frac{\int_A C_Z V dA}{\int_A V dA} \quad (2)$$

Evaluation of Equation (2) requires knowledge of concentration and velocity as functions of location across the stack cross section. In practice, the integrals in Equation (2) are approximated by sampling at a finite number of points,

$$\bar{C}_Z = \frac{\sum_i C_i V_i A_i \theta_i}{\sum_i V_i A_i \theta_i} \qquad (3)$$

In the application of standard EPA methods, equal areas are sampled for equal times. Equation (3) becomes,

$$\bar{C}_Z = \frac{\sum_i C_i V_i}{\sum_i V_i} \qquad (4)$$

It is not feasible to determine the concentration (C_i) at each sampling point. However, the quantity $[\sum_i C_i V_i]$ can be evaluated by collecting a single integrated sample where the sampling rate is weighed proportionally to the stack velocity at each sampling point. This procedure of sampling at a rate which is related to the stack velocity by a constant is referred to as proportional sampling. In the preceding discussion it has been assumed that the velocity of the effluent stream is parallel to the stack axis. In non-parallel flow systems, the sampling rate should be weighted proportionally to the component of the velocity parallel to the stack axis.

When sampling for particulates it is necessary to sample isokinetically to obtain a representative sample. For sources where the velocity is parallel to the stack axis, isokinetic sampling is a special case of proportional sampling where the constant relating the sampling velocity to the stack velocity is 1.

Thus, in parallel flow systems, isokinetic sampling automatically satisfied proportional sampling requirements. For non-parallel flow systems, isokinetic sampling conditions must be based on the velocity vector, however, proportional sampling conditions must be based on the component of velocity parallel to the stack axis. This creates considerable difficulty in sampling non-parallel flow systems.

Pitot Tube Errors - Pitot tube errors arise when the pitot tube is not oreinted correctly with respect to the gas stream velocity vector. Two types of pitot tube misalignment are shown in Figure 4-4. Figures 4-5 & 4-6 show the % error in the velocity vector measurement as a function of yaw and pitch angles for a S-Type pitot. When the S-Type pitot is part of a probe assembly, the % error has even greater dependence on pitch and yaw angles.

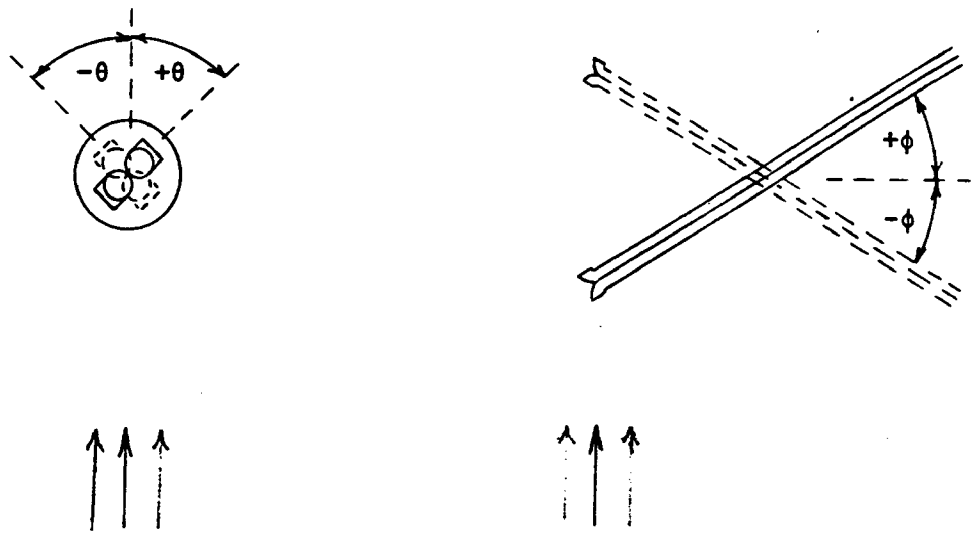


Figure 4-4. Types of Pitot Tube Misalignment

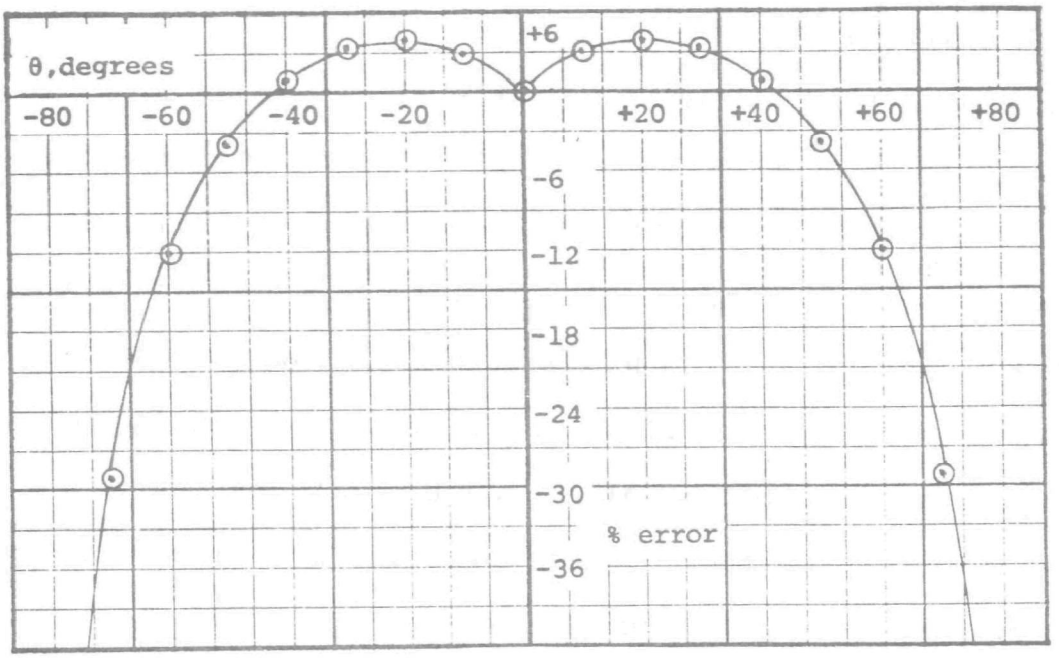


Figure 4-5 Velocity Errors from Yaw Angle Misalignment

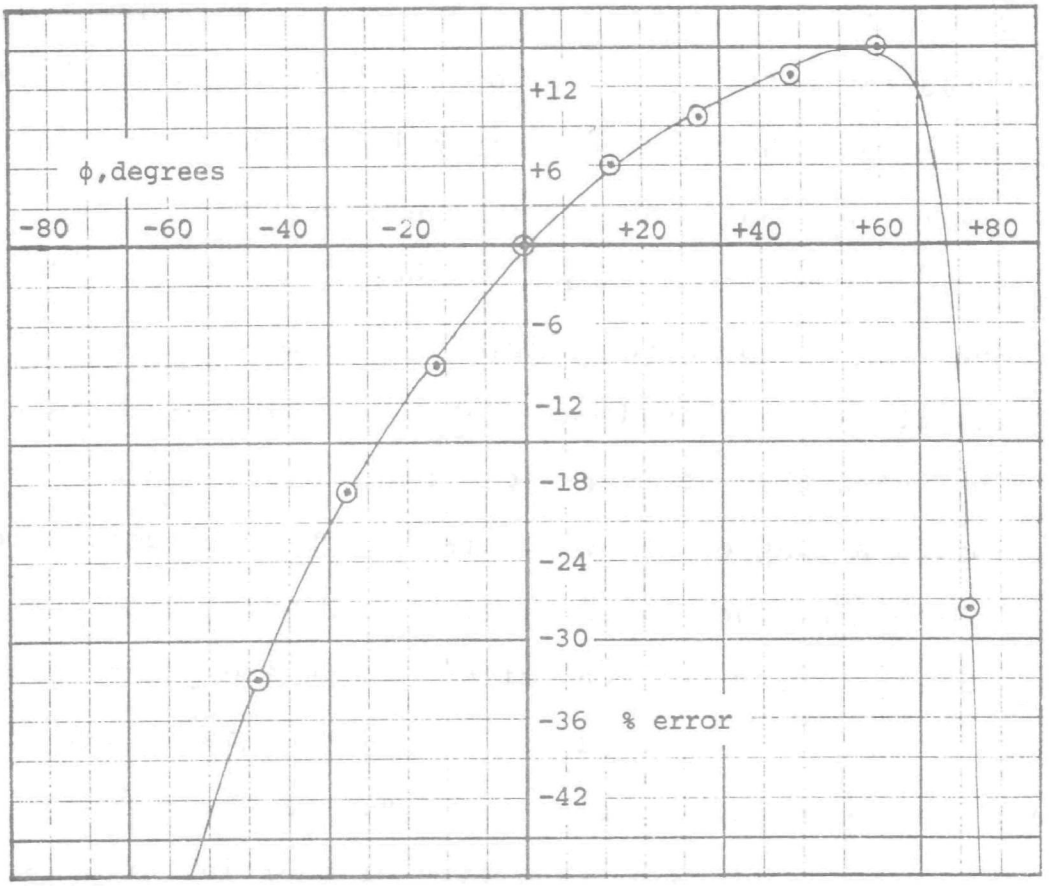


Figure 4-6 Velocity Errors from Pitch Angle Misalignment

SAMPLING TECHNIQUES FOR NON-PARALLEL FLOW SYSTEMS

When attempting to sample a source with non-parallel flow, several problems are encountered; (1) velocity measurements are subject to pitot tube errors, (2) volumetric flow rate determinations are difficult, (3) problems arise relating to the alignment between the sample nozzle and flow stream, (4) proportional sampling conditions are difficult to maintain; and (5) the inertial properties of the dust particles introduce biases of unknown magnitude. These problems are discussed as they effect three sampling techniques.

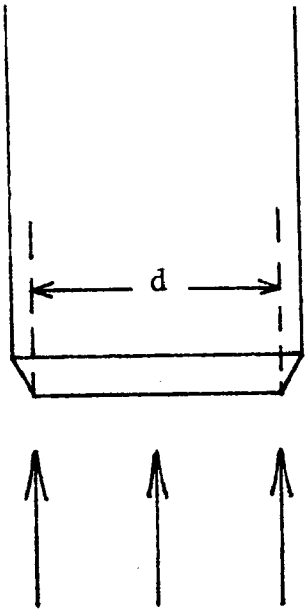
Before discussing individual sampling techniques, a bias which is common to all sampling methods for non-parallel flow systems should be considered. All of the approaches which will be described assume that a sample which is collected isokinetically and weighted proportionally to the axial velocity will accurately reflect the particulate concentration in the effluent stream. The methods for determining isokinetic and proportional sampling conditions are based on measurements of gas velocity. It should be noted that non-parallel flow systems are created by inertial forces acting on the gas stream as the effluent moves through the stack or ductwork system. Since dust particles are subject to much greater inertial affects than are gas molecules, the actual velocities of the particles and the gas stream will not be the same under cyclonic or other non-parallel flow conditions. In almost all cases, the greater inertial affects on particles will create larger angles between the particle velocities and the stack axis than between the gas velocity and the stack

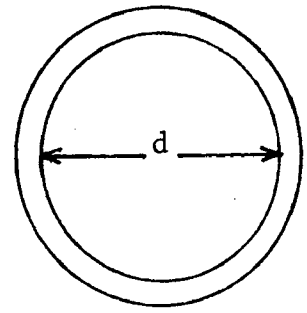
axis. This introduces a low bias of unknown magnitude in the measured concentration due to misalignment of the sampling nozzle with respect to the particle velocities. This bias increases as the particle size increases.

Criteria for determining the minimum number of sampling points and for locating the sampling points in non-parallel flow systems must be developed since Method 1 is not applicable in these cases. It is recommended that 48 sampling points (the maximum specified by Method 1) be used until applicable criteria can be developed. All of the sampling techniques which will be presented assume that sampling is conducted at points representing equal areas of the stack cross-sectional area. The procedures in Method 1 for locating sampling points should be employed.

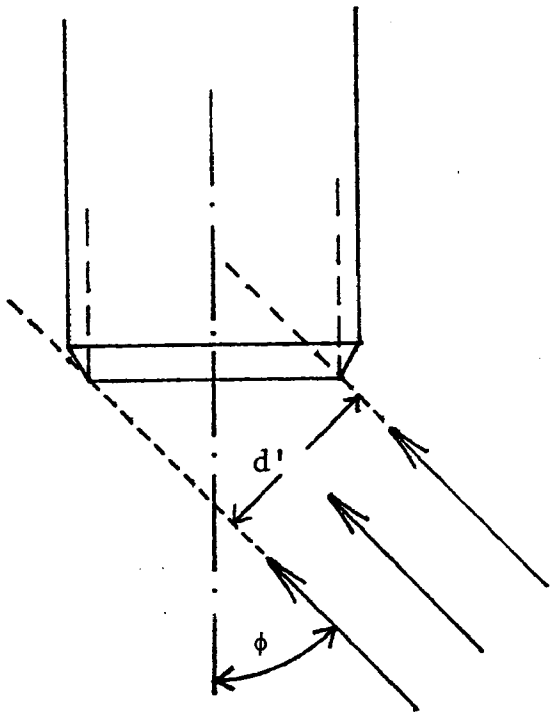
Blind Man's Approach--The blind man's approach is so named since the standard test methods are applied and the non-parallel flow situation is simply ignored. This procedure is subject to multiple biasing affects.

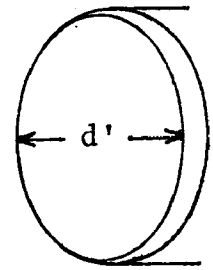
Since the nozzle is not aligned with the direction of the flow, the apparent or effective area of the nozzle opening is reduced. If the angle between the flow direction and the perpendicular to the nozzle opening is ϕ, then the area of the nozzle opening perpendicular to the flow stream is reduced by $\cos \phi$. (Figure 4-7).





actual area $A = \pi\left[\frac{d}{2}\right]^2$





effective area = A cosϕ

Figure 4-7. Reduction of effective area of nozzle not aligned with direction of flow.

In this approach, the sampler has no knowledge of the angle ϕ and therefore the sampling rate will be overisokinetic by an amount directly proportional to cos ϕ.

Figures 4-5 and 4-5 show that the pitot tube gives incorrect readings when not aligned with the flow. For all yaw angles where $-40^{o} < \theta < 40^{o}$ and for all positive pitch angles the pitot gives higher than real readings. Thus for three out of four cases of misalignment the pitot gives high readings which creates overisokinetic sampling conditions. It should be noted that the pitot readings will be further influenced when the angle of the flow is such that the pitot is effectively on the downstream side of the sampling nozzle. In this situation the nozzle disturbs the flow stream and introduces additional velocity measurement errors.

The effects of the reduced effective nozzle opening, and, in most cases, the effects of the pitot error, contribute to overisokinetic sampling. Overisokinetic sampling biases the concentration measurement low. The degree of the bias increases as the particle size increases.

In the blind man's approach, the sampling rate is weighted proportionally to the magnitude of the velocity vector. In order to meet the constraint of proportional sampling, the sampling rate should be weighted proportionally to the component of the velocity vector parallel to the stack axis. Therefore, if the angle between the velocity vector and the stack axis varies across the cross section of the stack, then proportional sampling conditions are not maintained. The bias which results from

non-proportional sampling increases as the variations in velocity and concentration across the stack increase. The direction of the bias is not easily determined.

If sampling is conducted to determine compliance with a mass emission rate standard, (lbs/hr), the total volumetric flow rate must be determined. Misalignment to the pitot with the flow results in errors in determining the magnitude of the velocity vector. A second error in determining the volumetric flow rate arises because the velocity vector is not parallel to the axis of the stack. The axial velocity vector component is equal to the velocity vector times the cos ϕ, (where ϕ is the angle between the velocity vector and the stack axis). The errors in determining the axial velocity component due to pitot misalignment error, and due to velocity direction error can be combined, and are shown in Figures 4-8 and 4-9. From these figures it is apparent that the axial velocity and thus the volumetric flow rate are overestimated. The degree of the bias cannot be estimated since, in the blind man's approach, the sampler has no knowledge of the angle between the velocity and the stack axis.

The mass emission rate is the product of the concentration measured by the sampling train and the total volumetric flow rate. The concentration is biased low and the volumetric flow rate is biased high. The two errors tend to offset each other; however, it is not possible to determine the net affect due to the unknown extent of the biases. In addition, the magnitude and direction of the bias due to non-proportional sampling is unknown.

In some stacks, negative velocities are encountered at particular sampling points. When negative velocities are

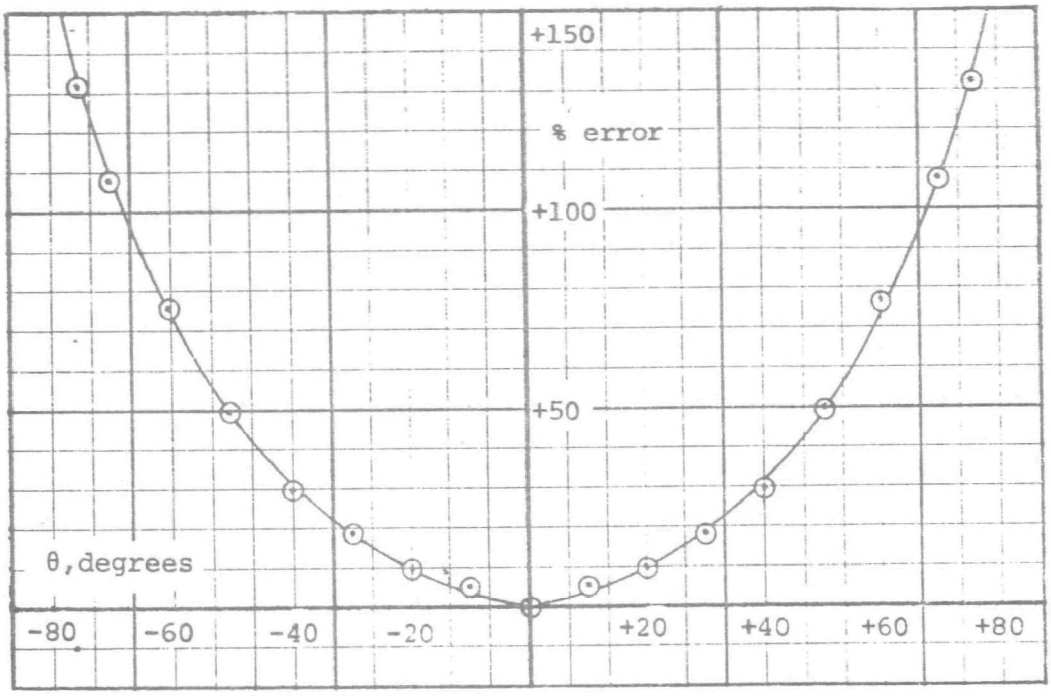


Figure 4-8. Axial Velocity Component Error due to Yaw Angle Misalignment

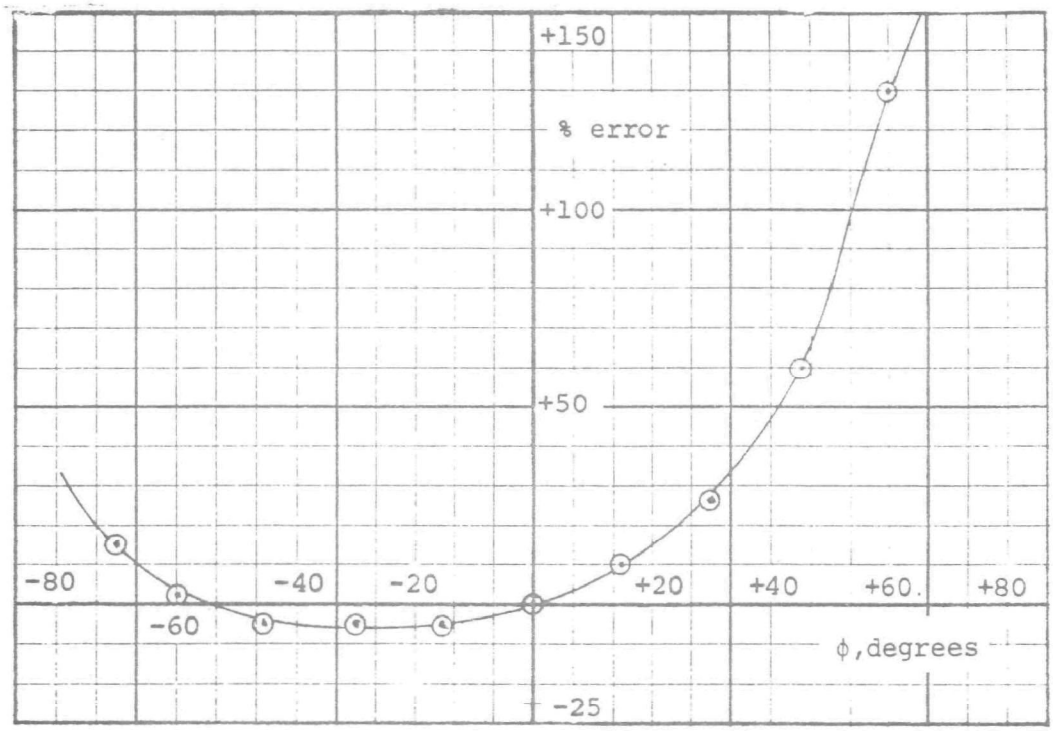


Figure 4-9. Axial Velocity Component Error due to Pitch Angle Misalignment

encountered, no sampling should be conducted. This biases the concentration determination high if the negative flow region contains any particulate material. When determining the volumetric flow rate for use in calculating a mass emission rate, the negative pitot reading(s) should be used to calculate the quantity of negative volumetric flow which should then be subtracted from the positive volumetric flow. It should be remembered that negative velocity measurements are subject to similar errors as positive velocity measurements. Neglecting the pitot errors, the mass emission rate will be biased high due to the high bias in the concentration measurement created by negative flow.

Alignment Approach--The alignment approach invloves determination of the direction of flow at each sampling point (by means of three dimensional pitot sensor or similar device). The sampling nozzle and pitot are then aligned with the flow direction at each sampling point.

For standard Method 5 particulate sampling equipment, it is easy to rotate the sampling probe for different yaw angles. However, it is not possible to align the sampling nozzle and pitot for different pitch angles. Therefore, the alignment method is not applicable to sources where pitch angle misalignment exists. Figures 4-10 and 4-11 show pitch and yaw angles for a typical stack with cyclonic flow.

In the alignment method, the sampling rate must be based on the magnitude of the velocity vector at each sampling point to maintain isokinetic sampling conditions. If the yaw angle varies

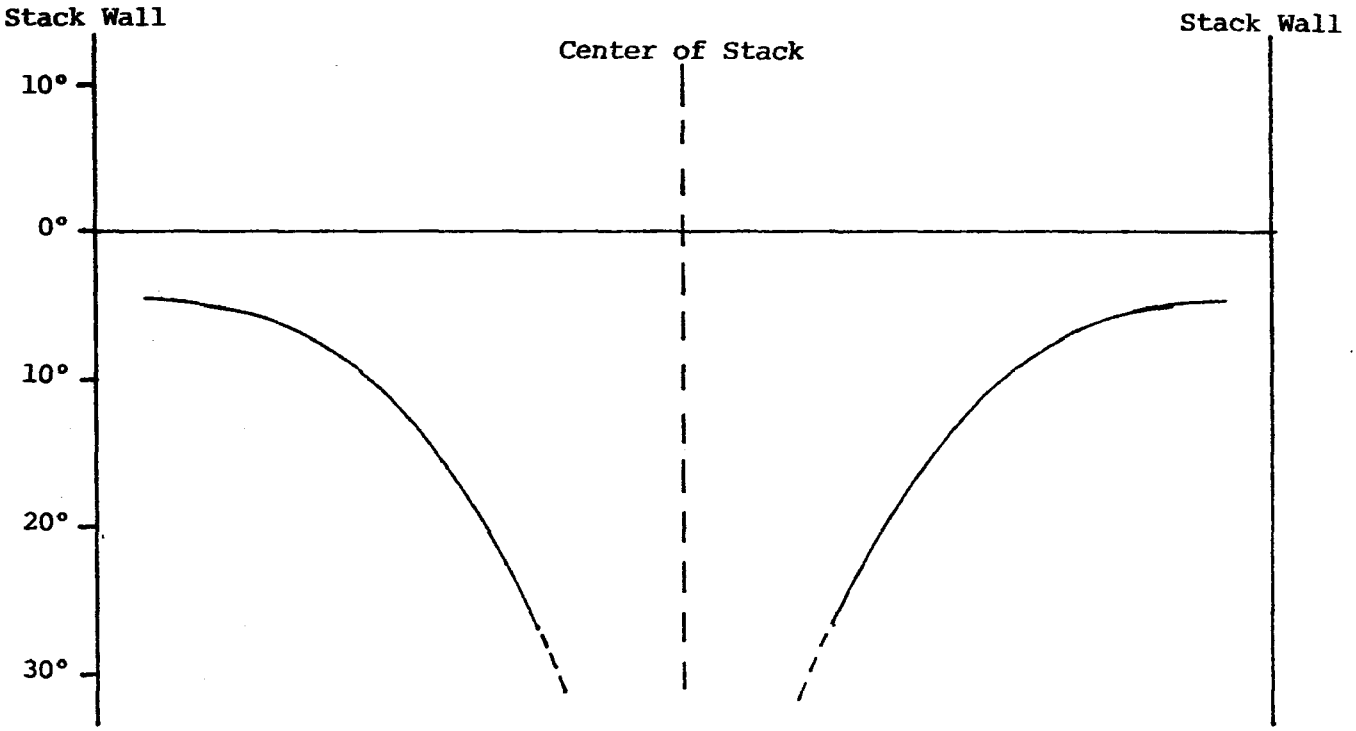


Figure 4-10. Typical Pitch Angle Profile in Stack with Cyclonic Flow. Current Data near Walls and at Center is Unreliable.

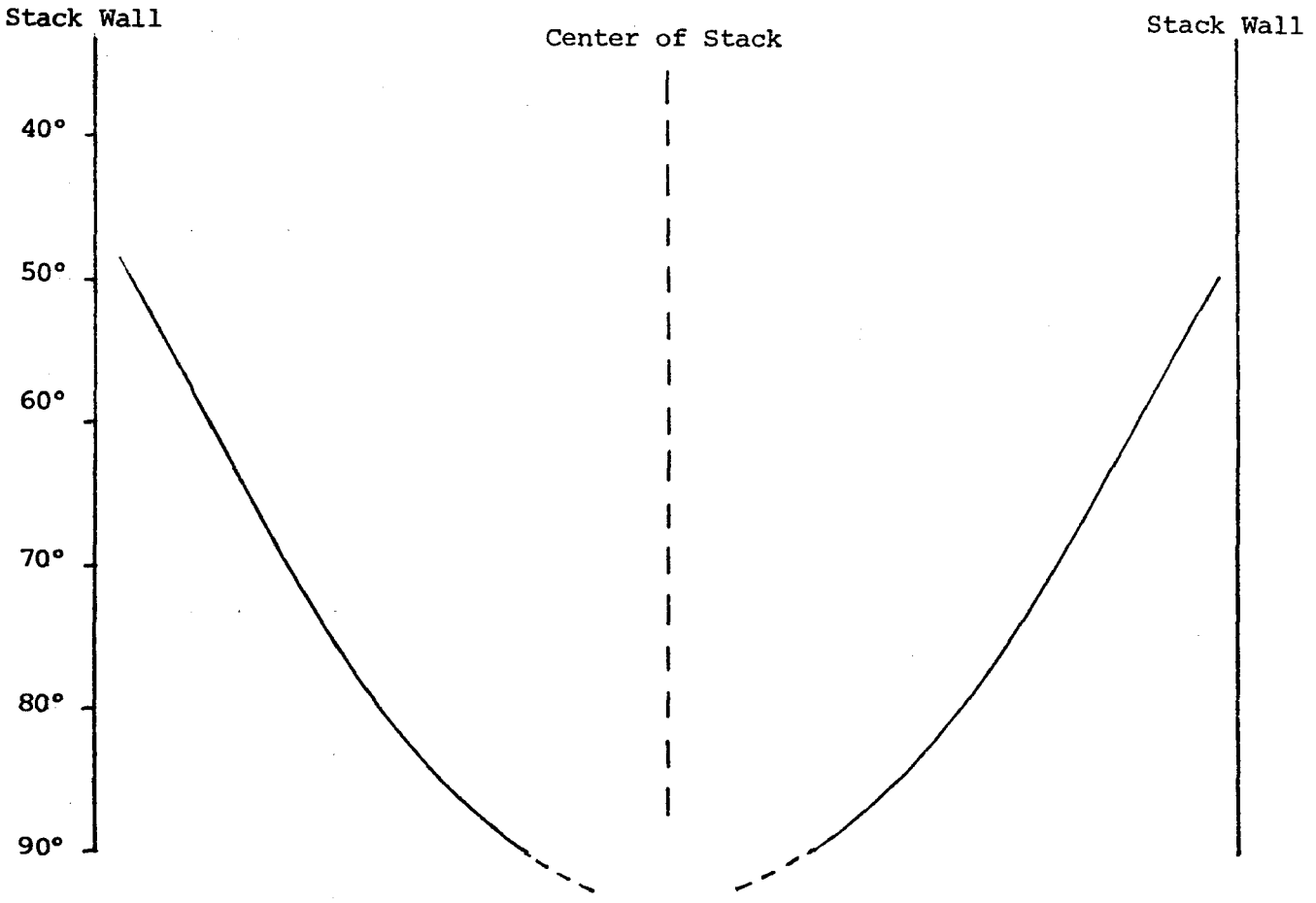


Figure 4-11. Typical Yaw Angle Profile in Stack with Cyclonic Flow. Current Data near Walls and at Center is Unreliable.

across the stack cross section, then the sampling velocity is not weighted proportionally to the axial component of the velocity vector. In this situation, proportional sampling requirements can be satisfied by adjusting the sampling time for each sampling point such that the volume of sample collected is related by a constant to the axial velocity component at each sampling point. This can be accomplished by weighting the sampling time at each point by $\cos\phi$ (where ϕ is the angle between the velocity vector and the stack axis):

$$\theta_2 = \theta_1 \cos\phi \qquad (5)$$

θ_1 = nominal sampling time per point

θ_2 = actual sampling time at a point

ϕ = misalignment angle at a point

The sampling team should be careful in selecting the nominal sampling time per point to ensure collection of the minimum required sample volume since application of Equation 5 will reduce the actual sampling time.

In sampling to determine compliance with a mass emission rate standard the volumetric flow rate must be determined. Since the angle of the velocity vector (with respect to the stack axis) must be determined to apply the alignment approach, the axial volumetric flow rate can be calculated as:

$$Q_s = K_p C_p A_s \sqrt{\frac{T_s}{P_s M_s}} \quad \frac{\sum_i^N (\sqrt{\Delta P_i} \cos\phi_i)}{N} \qquad (6)$$

where: Q_s = stack volumetric flow rate (ft^3/sec) actual conditions

K_p = 85.48

C_p = pitot tube coefficient

A_s = stack cross-sectional area (ft^2)

T_s = average stack temperature (°R)

P_s = absolute stack pressure (in. Hg)

M_s = molecular weight of stack gas, wet (lb/lb-mole)

Δ_p = pitot reading (in H_2O)

ϕ = angle between velocity vector and stack axis

N = number of sampling points

No additional biases are introduced when calculating the volumetric flow rate if the angles ϕ_i are accurately known.

No sampling should be conducted at sampling points where negative velocities are observed. There is no way to assign a negative value to the quantity C_iV_i when the velocity is negative since the sampling train obtains an integrated sample, $[\sum_i C_iV_i]$. The fact that negative flows are not sampled biases the concentration measurement high if the negative flows contain any particulate matter. When determining a mass emission rate, the negative volumetric flow rate should be calculated based on the negative axial velocity component. The net volumetric flow rate, (positive volumetric flow rate minus negative volumetric flow rate), must be used to calculate the mass emission rate. Where negative velocities are encountered, the mass emission rate will be biased high due to the bias in the concentration measurement.

Compensation Approach - The compensation approach requires determination of the direction of flow at each sampling point, (by means of a three dimensional pitot sensor or similar device), and measurement of the velocity vector at each sampling point. In the compensation approach, the sampling nozzle is aligned with the stack axis as in the blind man's approach. This method is applicable to sources with both pitch and yaw angle misalignment if a separate pitot and sampling probe are used.

The nozzle is not aligned with the flow direction; therefore the effective nozzle area is reduced by $\cos\phi$, Figure 4-12. In the compensation approach, the angle ϕ is known and the sampling rate is reduced by $\cos\phi$ to maintain isokinetic sampling conditions. The use of the nozzle area correction requires that the isokinetic sampling rate is proportional to both the velocity vector $\vec{V}$ and $\cos\phi$. Since the axial velocity component $\vec{V}_a$ is $\vec{V}\cos\phi$, the nozzle area correction also weights the sampling rate proportionally to the axial velocity. Therefore the requirements of proportional sampling are satisfied.

The compensation approach is subject to biases when the angle between the nozzle and the flow stream becomes sufficiently large. For very large angles of misalignment, the flow around the nozzle will create aerodynamic interferences with the isokinetic sampling. In general, these interferences will bias the concentration measurement low. The degree of the bias will increase as the velocity increases and as the angle of misalignment increases. Further study is required to determine at what angle these affects become significant and the extent of the biases on the sampling results.

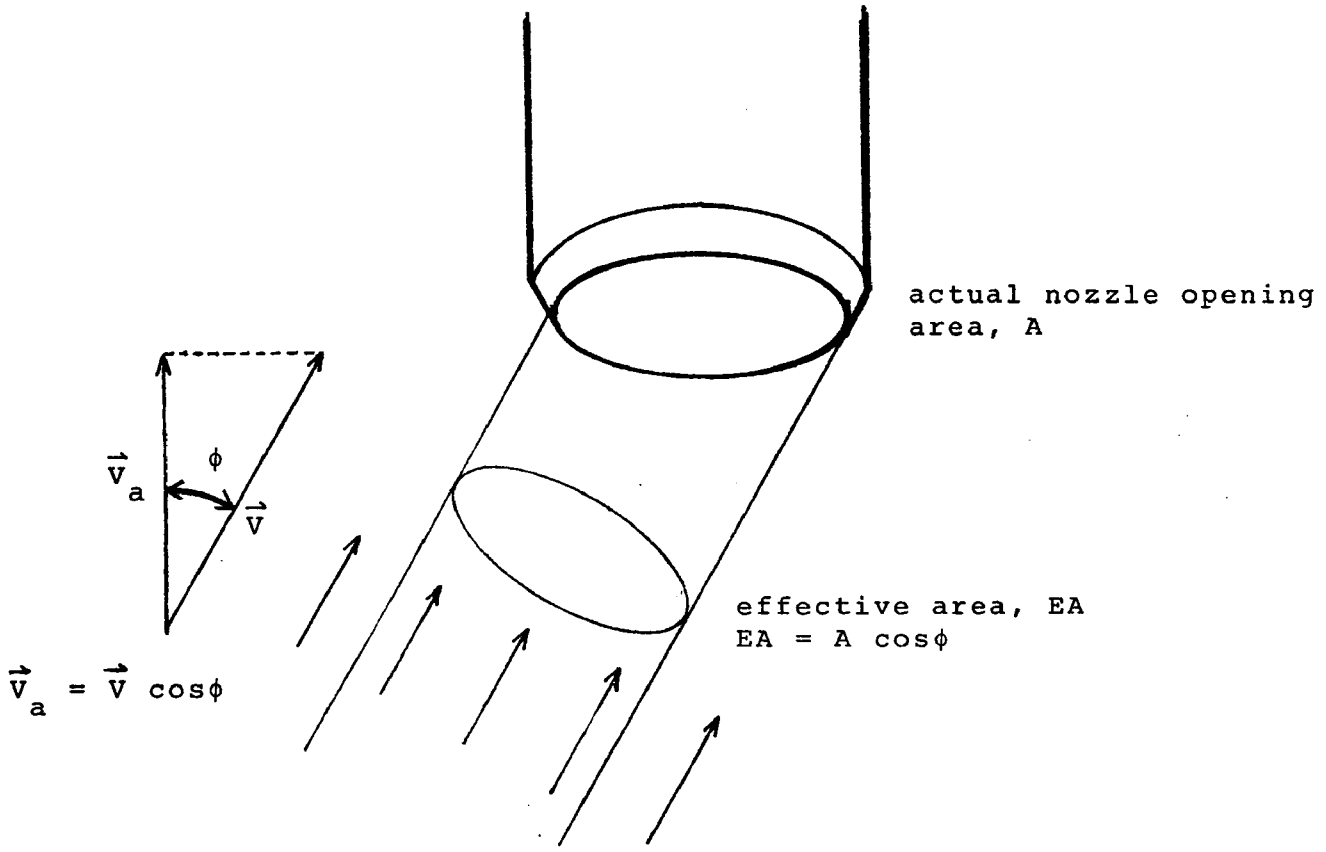


Figure 4-12. Compensation Approach

When sampling to determine a mass emission rate, the volumetric flow rate should be determined as:

$$Q = k_p C_p A_s \sqrt{\frac{T_s}{P_s M_s}} \frac{\sum_i^N (\sqrt{\Delta P_i} \cos\phi_i)}{N} \quad (7)$$

as in the alignment approach. No additional biases are introduced in calculating the volumetric flow rate if the angles are determined accurately.

As in the alignment approach, no sampling should be conducted at sampling points where negative velocities are observed. Again, this biases the concentration high if the negative flow contains particulate matter. To calculate the net volumetric flow rate where negative flows are encountered, Equation 6 can be used by adding a negative sign to $\cos\phi$ where ϕ is negative, or the negative volumetric flow can be subtracted from the positive volumetric flow. Where negative flows are encountered the mass emission rate will be biased high due to the high bias in the measured concentration.

SOURCE MODIFICATIONS

In some non-parallel flow situations, modifications to the source can be made which permit application of the standard sampling methodology. The simplest source modification is to move the sampling site to an alternative location and thereby avoid the problem altogether. This option is generally not available since anticipated non-parallel flow conditions should have been a major consideration in the selection of the origi-

nal sampling site. A second modification is to employ straightening vanes to eliminate the non-parallel flow. Straightening vanes can be fabricated of almost any material (depending on the temperature encountered). In most cases, a single vane or a pair of vanes at 90°, extending across the stack are sufficient to eliminate the flow problem. The straightening vanes should be at least 1/2 stack diameter in length, (parallel to axis of stack).

At some sources, particularly at asphalt plants, a stack with cyclonic flow functions as part of the inertial demister system for wet scrubbers. Straightening vanes employed in this situation would eliminate the stack's function as a control device and thereby greatly increase emissions. In most cases, a stack extension equippped with straightening vanes can be employed (Figure 4-13). Straightening vanes are used to create a flow disturbance which improves the flow conditions downstream at the sampling site. The flow disturbance from straightening vanes also propagates upstream to an unknown extent. It should also be noted that straightening vanes exert work on the effluent stream which is evidenced by a pressure drop across the vanes. In most cases, the straightening vanes will have little affect on the volumetric flow rate through the system since the pressure drop across the vanes is small compared to other pressure drops in the effluent handling system. Ideally, any modifications which are employed should not affect the flow pattern in stacks which function as part of the control system. Any affects on the flow pattern in the existing stack will generally reduce the cyclonic

flow and increase the emission rate. Adherence to the following criteria will minimize the affects of a stack extension and straightening vanes.

1. the stack extension should be the same diameter as the existing stack
2. the straightening vanes should be at least 1/2 stack diameter downstream from the exit of the existing stack
3. the extension must be at least 2 1/2 diameters in length after the straightening vanes.

A second type modification which can be used for stacks with cyclonic flow is essentially the addition of a tangential outlet duct (Figure 4-14). Although this type of extension is more difficult to construct, there is less affect on the flow pattern in the existing stack and straightening vanes in the extension may not be necessary. In some cases, the diameter of the extension may be smaller than the existing stack which reduces the actual length of the extension. In any case, the extension must be at least 2 1/2 diameters in length to satisfy the minimum requirements of Method 1.

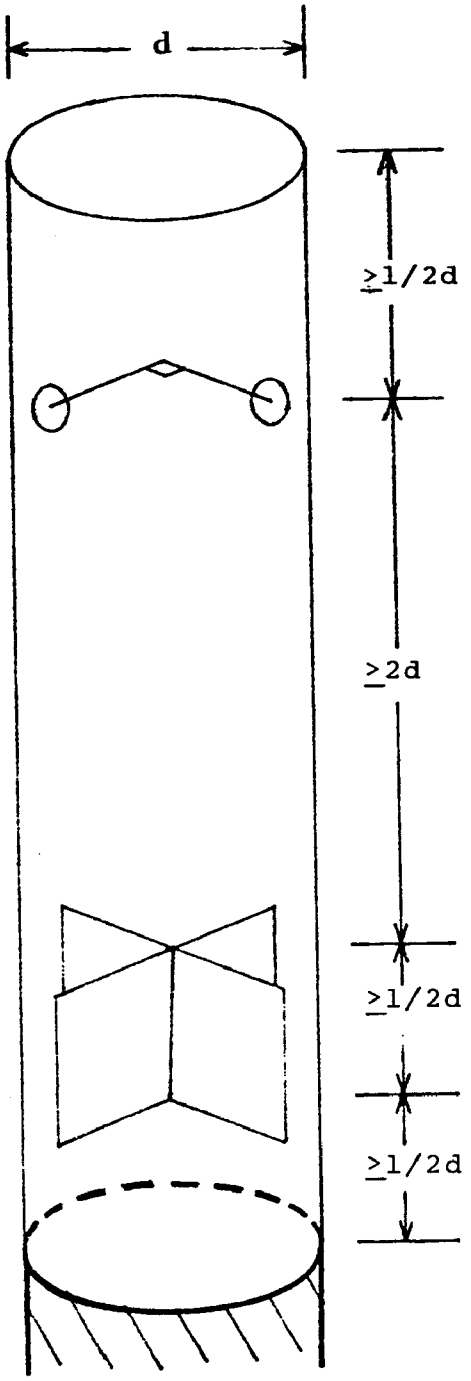


Figure 4-13. Stack Extension With Straightening Vanes

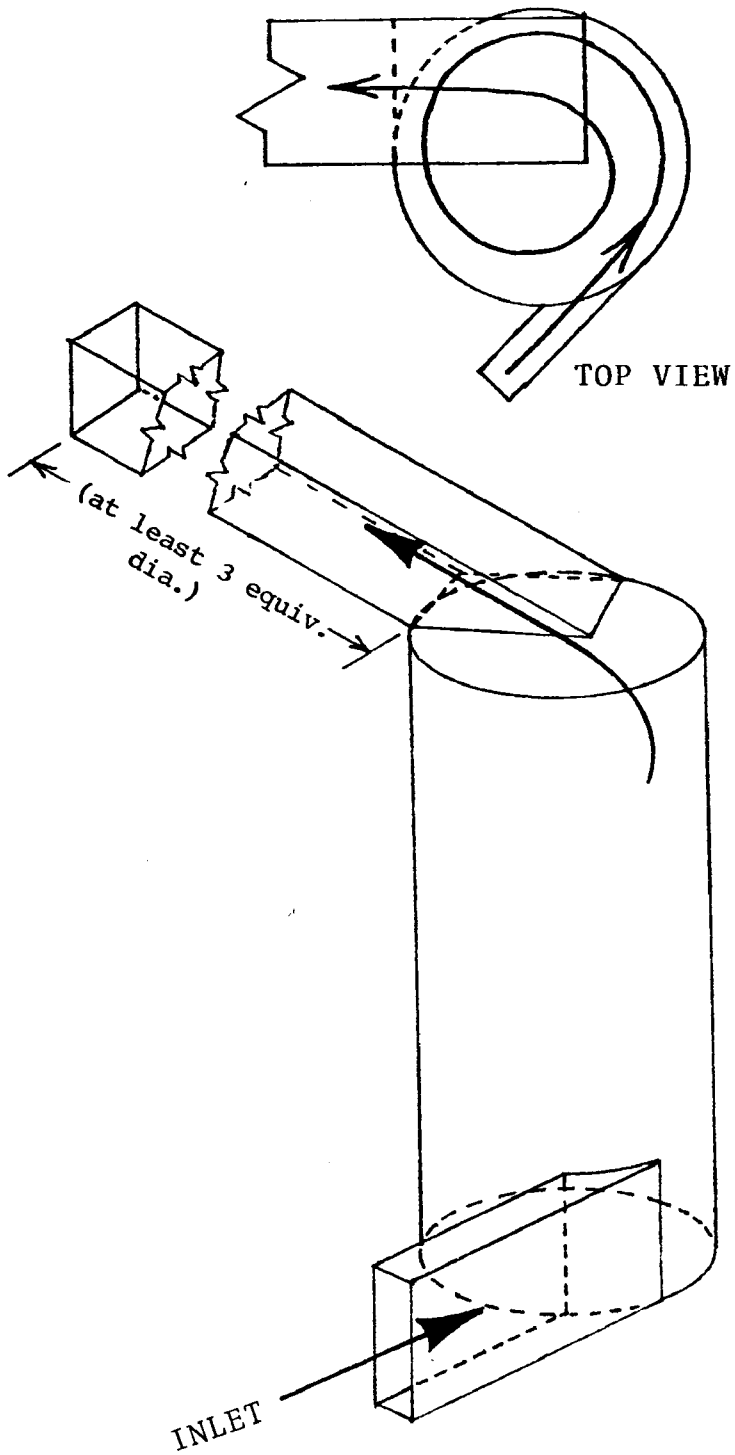


Figure 4-14. Temporary Tangential Outlet

CONCLUSIONS

When particulate sampling is required and where non-parallel flow conditions are encountered, a decision must be made to either modify the source to eliminate the unacceptable flow situation or apply one of the special sampling procedures which have been discussed. Source modifications should be employed when feasible since they will reduce the complexity and difficulty in obtaining a representative sample. Modifications to sources where stacks with cyclonic flow function as part of the control system should be carefully planned.

Where source modifications can not be employed and special sampling procedures are to be used, either the alignment approach or the compensation approach should be used. The blind man's approach should not be used due to the many problems which are encountered which result in unknown biases in the sampling results. The alignment approach is limited to non-parrallel flow situation where only yaw angle misalignment exists. The compensation method can be used in any non-parallel flow situation, however a low bias in the sampling results may occur for large angles of misalignment. Both the alignment appeoach and the compensation approach allow a particulate sample to be obtained isokinetically and both approaches satisfy the requirements of proportionally weighting the sampling relative to the stack axial volumetric flow rate. Application of either the alignment or compensation approach will require considerably more time and effort to obtain valid sampling results than is encountered in the application of standard particulate sampling procedures.

Project Summary

TECHNIQUES TO MEASURE VOLUMETRIC FLOW AND PARTICULATE CONCENTRATIONS IN STACKS WITH CYCLONIC FLOW

by

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Contract No. 68-02-3215

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ABSTRACT

The ability of a venturi to accurately measure volumetric flow in cyclonic flow situations was examined. A mathematical model, which was developed to describe the effect of the venturi on the flow, correctly predicted the intensification of the swirling motion in the venturi throat and an interesting acceleration of the axial velocity component in the core of the flow field. Experimental results showed that the venturi can accurately measure volumetric flow, even in the presence of fairly strong swirling flow. An analysis of the effect of a venturi on particulate distribution showed that, even though the venturi converging section directed particles toward the center of the venturi throat, the intense swirl present in the venturi throat quickly convected the particles back to the wall.

Both egg crate and e´toile devices were evaluated to determine their ability to straighten swirling flow. It was found that the egg crate flow straightener would effectively straighten swirling flow when the length of the straightener was equal to or greater than its cell size. It was also determined that significant energy savings could result if cyclonic flows were straightened at the base of tall stacks. Empirical equations were developed to predict the head losses for the various egg crate assemblies studied. A field study to determine the effect of an egg crate device on particulate distribution across the stack gave inconclusive results.

INTRODUCTION

Cyclonic flows are frequently encountered in the exhaust stacks of stationary sources which come under present Federal and state emissions regulations. Particles in a cyclonic flow are subject to a strong radial acceleration field and many are convected to the stack wall where they

cannot be quantitatively collected with conventional sampling techniques. It has been suggested (1) that an in-stack installed venturi by itself might straighten cyclonic flow and redistribute the particulate sufficiently to render it samplable with conventional methods such as EPA Method 5.

The initial objective of this study was to determine the validity of this theory through laboratory and field measurements. The results showed that the venturi was not adequate for this purpose. Thus, additional work was conducted to evaluate the ability of other devices such as low-pressure drop egg crates to straighten the flow and simultaneously move the particulate back towards the center of the stack.

EXPERIMENTAL

The wind tunnel shown in Figure 1 was used to investigate the effects of the venturi on cyclonic flow. Air enters this wind tunnel through a conical flow regulator, passes through a set of honeycomb straightening vanes, and then flows through a carefully calibrated Herschel-type venturi. The air then enters the suction side of a centrifugal blower. Immediately downstream from the blower the air enters a tangential admittance swirl generator, which cascades the air into the test section through four longitudinal slots externally adjustable. Hinged vanes located in these slots allow the angle of admittance to be controlled so that very intense swirling flows can be generated.

This swirl generator was also used to evaluate the ability of various low-head loss straightening vanes (Figure 2) to straighten cyclonic flow. Starting with an overall straightener length, L, of two pipe diameters, each straightening device was tested at flow rates of 7, 10, and 13 m^3/s.

At each of these flow rates, head loss data were recorded for five different swirl intensities. If the device straightened the cyclonic flow, its length was shortened and the device retested. This process continued until the flow field was no longer straightened.

After the wind tunnel studies were completed, the ability of the egg crate to straighten cyclonic flow and to redistribute the particulate was evaluated at a fertilizer plant. The stack at the plant was 76 cm in diameter and 11 m high. Stack temperature was 32 °C, moisture was 5% and the axial volumetric flow was approximately 127 m^3/min. Exhaust gases from the fertilizer blending operation entered tangentially at the base of the stack and then passed through a water spray chamber and a turning vane to produce swirling flow. The swirling flow caused particulate laden water droplets to move to the stack wall where they drained downward and exited with the scrubber water.

A galvanized steel egg crate of cell size D/4 (19 cm) and length D/2 (38 cm) was installed in the stack at a point seven pipe diameters downstream of the turning vane (four pipe diameters from the stack exit). Particulate and velocity measurements were made through sampling ports located two pipe diameters downstream and two pipe diameters upstream from the center of the egg crate. EPA Methods 1 (sampling point selection), 2 (velocity and volumetric flow), and 5 (particulate sampling) were used in the testing. Flow angle with respect to the stack longitudinal axis was measured using a United Sensor® 3-dimensional pitot tube.

RESULTS AND CONCLUSIONS

Venturi Studies

It was found that an in-stack venturi designed as described in this study will accurately measure volumetric flow in cyclonic flow situations. However,

it will not straighten cyclonic flows nor redistribute the particulate because the total angular momentum is conserved as the gas passes through the venturi throat. It was also found that the characteristic region of low axial velocity in the center of the gas stream is accelerated in the venturi throat to give a nearly rectangular velocity profile in the venturi throat, itself.

Some possible benefits of an in-stack installed venturi designed according to the specifications developed in this study are:

- Properly calibrated, a venturi can stand alone as a volume flow measuring device;
- The increased velocity in the venturi throat could make possible more accurate sampling in stacks with low velocities since most pitot tubes are inaccurate below 10 ft/s.

Flow Straightener Studies

Egg crate flow straighteners were found to be effective in removing the swirl component of the flow at lengths equal to or greater than the cell size. The straightening effectiveness was greatly reduced when the length was reduced below the cell size.

The e´toile type straightener was able to straighten swirling flow, but the overall effective length requirements were greater than for the egg crate and the head loss across the e´toile straighteners was also higher. For example, the minimum effective length for an eight-vane e´toile straightener was two stack diameters.

The field testing results were inconclusive in relation to the ability of the egg crate to redistribute the flow back towards the center of the stack. However, the egg crate did destroy the strong swirling flow present (Table 1) since the flow angle at all twenty traverse points downstream of the egg crate deviated less than 4° from the stack axis. Also, static

pressure measurements upstream and downstream of the egg crate were identical, demonstrating that the head loss was negligible. Thus, we conclude that the egg crate can be a cost-effective means to destroy cyclonic flow patterns.

In the particulate testing, eight, 60-min sampling runs were accomplished using two Method 5 trains sampling simultaneously. (Train A sampled two pipe diameters downstream of the egg crate and Train B sampled two pipe diameters upsteam.) In the first three runs, each train sampled a total of 20 points (10 points on each diameter). In these and the other five runs, Train A sampled with its nozzle and pitot tube aligned with the stack axis, while Train B sampled with its nozzle and pitot tube aligned with the direction of the gas flow at the sampling point. (Train B sampling time at each point was adjusted so that the ratio of the volume of gas collected at each point to the total axial volumetric flow in the stack remained constant.)

In the last five runs single-point sampling rather than traversing was employed. In these runs, Train A sampled at the same point - a point 58 cm in from the port hole, but Train B sampled a different point in each run, i.e., Run 4 (71 cm), Run 5 (67 cm), Run 6 (63 cm), Run 7 (58 cm), and Run 8 (49 cm). The objective of these five runs was to determine the particulate distribution upstream of the egg crate in relation to the concentration at a specific point downstream of the egg crate.

The results of the eight runs (Table 3) show that in all runs the particulate concentration determined upstream compared well with that determined downstream. Further, the close agreement between the two trains in the last five runs shows that the particulate concentration was evenly distributed upstream of the egg crate. This demonstrates that the swirling flow effectively removed large particles, i.e., the remaining particles were small enough to follow the gas flow lines. Thus, the degree of redistribution of particulate by the egg crate cannot be determined from these results. Resource limitations

and the fact that no additional sources were available for testing prevented conducting additional field tests.

REFERENCE

1. Mitchell, W. J., B. E. Blagun, D. E. Johnson, and M. R. Midgett. Angular Flow Insensitive Pitot Tube Suitable for Use With Standard Stack Testing Equipment, EPA-600/4-79-042. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1979.

TABLE 1. FLOW ANGLES MEASURED DOWNSTREAM OF THE EGG CRATE

Distance from Stack Wall (cm)	Flow Angle Port A (θ)	Flow Angle Port B (θ)
2.5	46	45
7.6	52	47
12.7	58	50
17.8	65	50
22.8	68	53
27.9	57	56
33.0	0	58
38.1	-54	-1
43.2	-52	-45
48.3	-46	-44
53.3	-40	-41
58.4	-34	-37
63.5	-28	-37
68.6	-20	-32
73.7	-20	-26

TABLE 2. COMPARISON OF PARTICULATE CONCENTRATIONS AND VOLUMETRIC FLOW UPSTREAM AND DOWNSTREAM FROM THE EGG CRATE

Run Number	Concentration (mg/m^3)		Volumetric Flow (m^3/min)	
	Upstream	Downstream	Upstream	Downstream
1	130	130	137	125
2	147	154	138	120
3	26	22	115	115
AVERAGE	101	102	130	120
4	22	18		
5	31	31		
6	103	86		
7	35	33		
8	64	55		
AVERAGE	47	45		

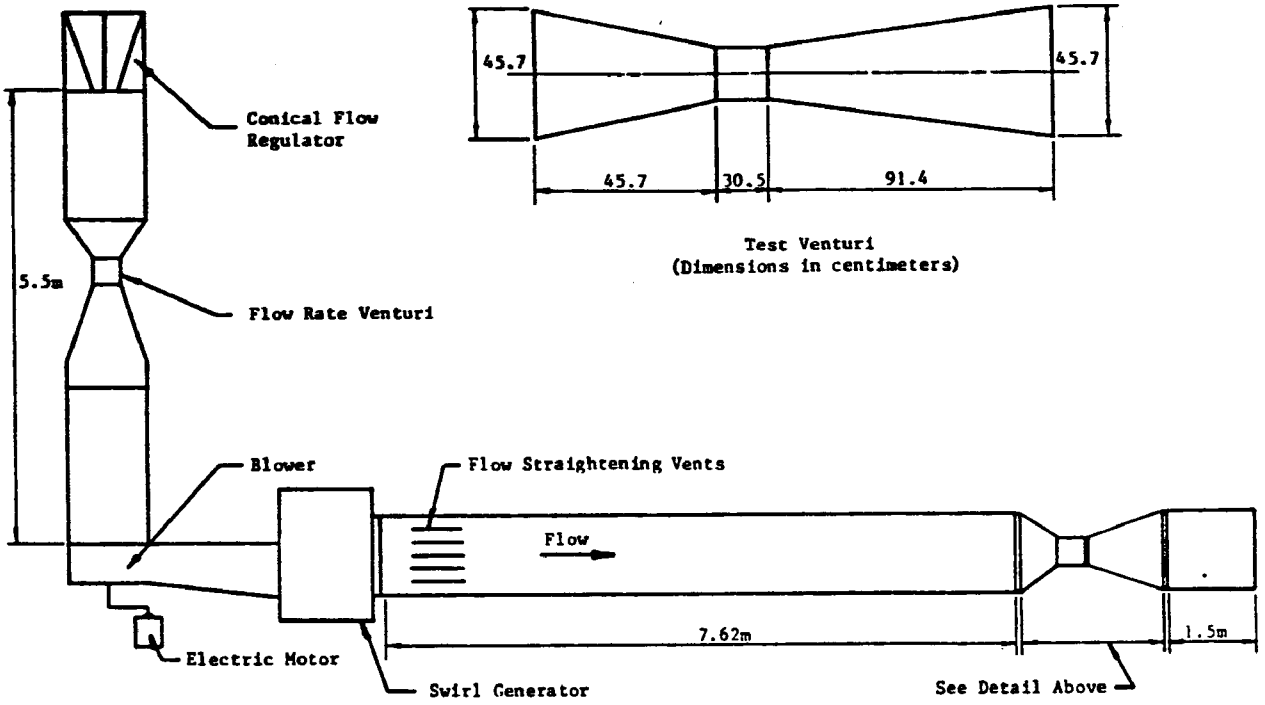


Figure 1. Experimental facility plan review.

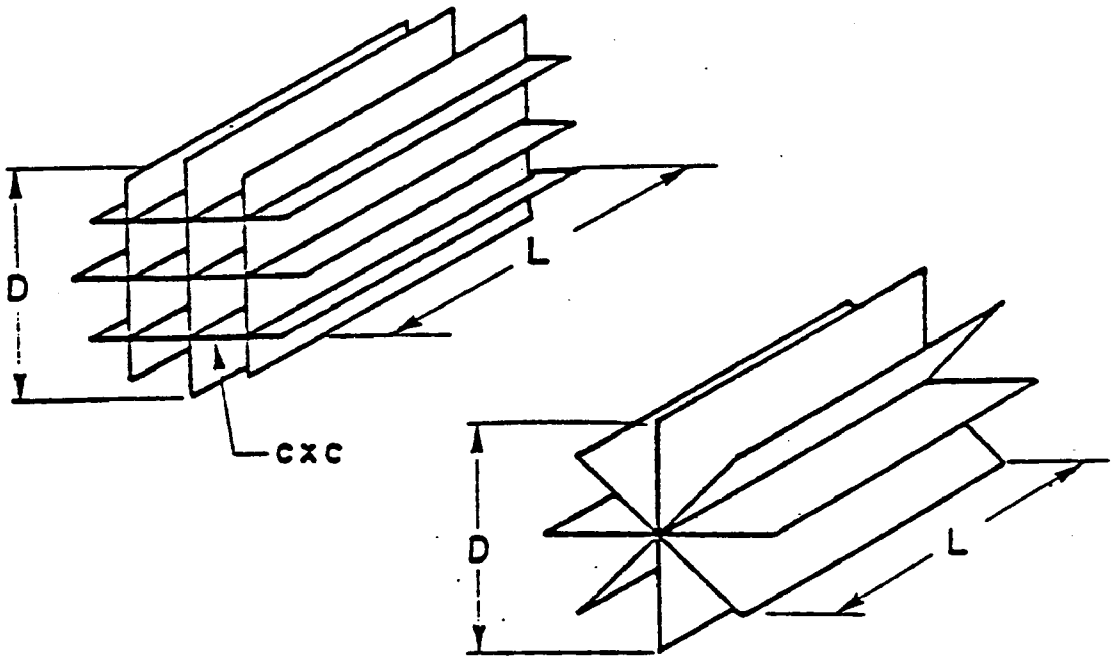


Figure 2. Egg crate and 8-vane étoile-type flow straighteners.

J. Douglas Sterrett, Allen R. Barbin, Joe W. Reece, W. Glenn Carter, and Bruce B. Ferguson are with Harmon Engineering and Testing, Inc., Auburn Industrial Park, Auburn, AL 35810

Dr. William J. Mitchell is the EPA Project Officer (see below).

The complete report, entitled "Techniques to Measure Volumetric Flow and Particulate Concentrations in Stacks with Cyclonic Flow," (Order No. PB _____; Cost: $____, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: (703) 487-4650

The EPA Project Officer can be contacted at:

Quality Assurance Division (MD-77)
Environmental Monitoring Systems Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

SLIDE 305-0

NOTES

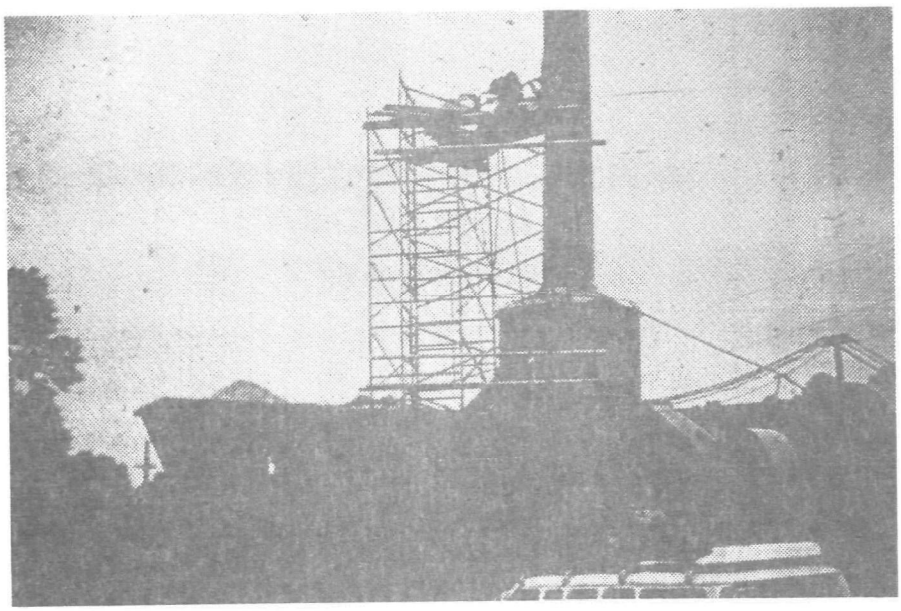
CYCLONIC
OR
NON PARALLEL FLOW

SLIDE 305-1

DEFINITION OF CYCLONIC FLOW

Cyclonic, swirling, or nonparallel flow is defined to exist in the stack when the average flow at designated sample points in the stack average greater than 10° off parallel with stack walls

SLIDE 305-2



SLIDE 305-3

NOTES

ESTABLISH A NONPARALLEL FLOW TESTING PROTOCOL

- determine whether emission regulation is a concentration or mass emission regulation
- determine if purpose of test is to prove compliance or show violation
- determine whether burden of proof is with the agency or facility
- determine suitable test method(s) to accomplish above goals
- provide facility with alternatives when a known high bias on test results is suggested by agency

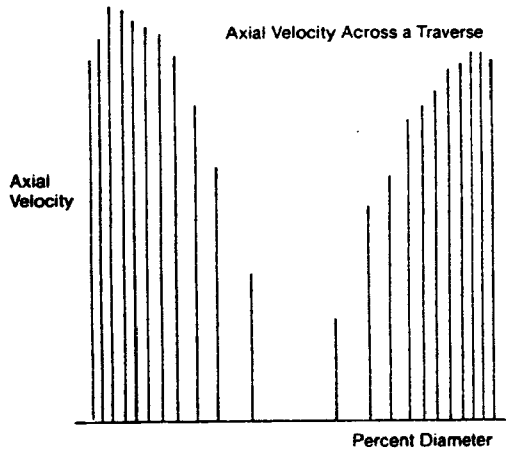
SLIDE 305-4

KNOWN FACTS WHEN SAMPLING IN NONPARALLEL FLOW

- measured particulate concentration will be biased low (less than true value); non-parallel flow does not affect measured gaseous concentration
- measured stack gas volumetric flow rate will be biased high (greater than true value)

SLIDE 305-5

EXAMPLE VELOCITY PROFILE FOR CYCLONIC FLOW



SLIDE 305-6

NOTES

SAMPLING APPROACHES FOR CYCLONIC FLOW

1. Blind Man's Approach
2. Alignment Approach
3. Compensation Approach
4. Source Modification

SLIDE 305-7

BLIND MAN'S APPROACH

PROCEDURE

- testing is performed in the normal manner and the angular flow variations and biases are ignored

RESULTS

- particulate concentration is biased low
- volumetric flow rate is biased high
- mass emission rate bias cannot be determined

SLIDE 305-8

ALIGNMENT APPROACH

PROCEDURE

- nozzle is pointed into direction of flow in an effort to compensate for angular misalignment; angle is recorded at each point
- sample time at each point is compensated for mathematically by cosine of misalignment angle
- mathematic compensation is made on flow readings using velocity pressure and alignment angle

SLIDE 305-9

NOTES

$$t' = t(\cos \theta)$$

Examples:

- **10° misalignment & 2 min./pt.**

$$t' = 2(\cos 10^0) = 1.97 \text{ min.}$$

- **45° misalignment & 2 min./pt.**

$$t' = 2(\cos 45^0) = 1.41 \text{ min.}$$

where:

t' = actual time sampled per point
t = sample time per point with no misalignment
θ = misalignment angle

SLIDE 305-10

(cont.) RESULTS

- testing is very difficult and time consuming
- particulate concentration contains less bias with two exceptions: 1) nozzle is not corrected for the angular misalignment in both planes and 2) particulate does not follow flow pattern
- flow rate will be more accurate, however, a Type S pitot tube also can only correct for the flow misalignment in one plane
- mass emission rate may contain less bias, however, readjustment of nozzle angle at every point can possibly introduce greater biases through probe breakage and sample train leakage

SLIDE 305-11

NOTES

COMPENSATION APPROACH

PROCEDURE

- testing is performed in normal manner with exception that a larger nozzle is used to correct for misalignment error and higher than true flow rate

RESULTS

- particulate concentration is less biased
- volumetric flow rate is biased high
- mass emission rate is biased high

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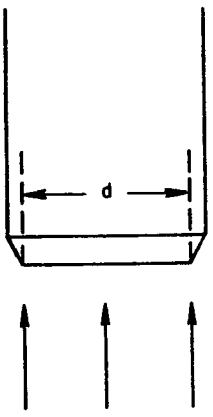
CORRECTING NOZZLE DIAMETER FOR COMPENSATION APPROACH

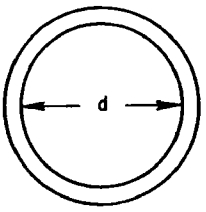
TWO ERRORS MUST BE COMPENSATED FOR

- misalignment of particulate approaching nozzle
- higher than true velocity reading

SLIDE 305-13

REDUCED EFFECTIVE NOZZLE OPENING





ACTUAL AREA $A = \pi[\frac{d}{2}]^2$

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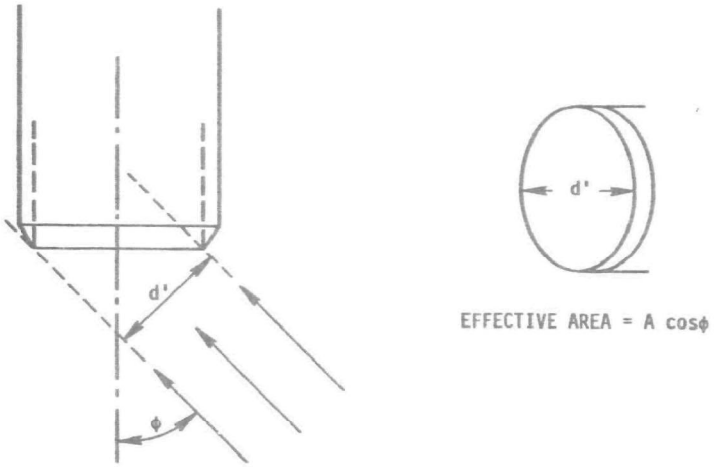
NOTES

REDUCED EFFECTIVE NOZZLE OPENING



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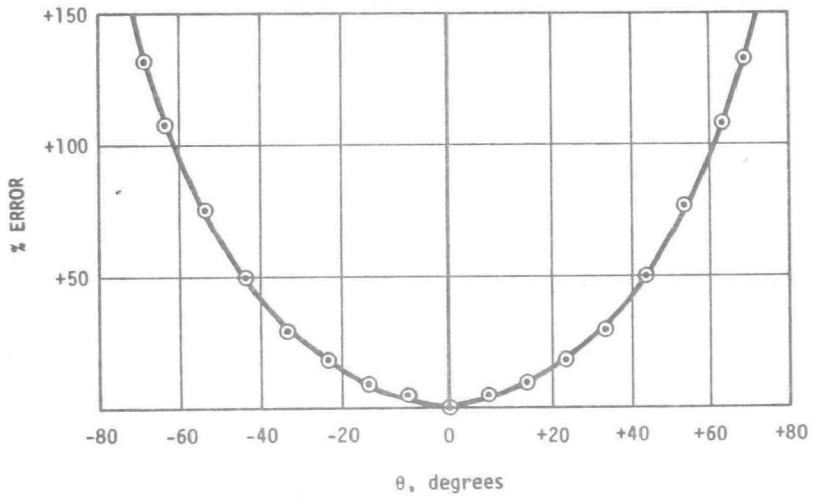
ERROR DUE TO YAW ANGLE MISALIGNMENT



SLIDE 305-16

CORRECT THE NOZZLE DIAMETER AS FOLLOWS

1. determine ideal nozzle diameter in normal manner with velocity traverse
2. record all misalignment angles during velocity traverse
3. divide ideal nozzle size by cosine of average angle of misalignment (equ. 1)
4. select nozzle that is closest to this diameter for use
5. multiply actual nozzle diameter by cosine of average angle of misalignment and use calculated value on data sheet for isokinetic calculations and to set nomograph (equ. 2)

SLIDE 305-17

NOTES

$$n_i' = \frac{n_i}{(\cos \theta)} \qquad \text{(equ. 1)}$$

Examples:

- 10° misalignment & 0.29" diameter nozzle

$$n_i' = \frac{0.29}{(\cos 10°)} = 0.294"$$

- 45° misalignment & 0.29" diameter nozzle

$$n_i' = \frac{0.29}{(\cos 45°)} = 0.410"$$

where:

n_i' = adjusted ideal nozzle diameter used to select actual nozzle for compensation method sampling

n_i = ideal nozzle diameter determined using average velocity pressure with type "S" pitot tube oriented normally (parallel to stack walls)

θ = average or maximum misalignment angle

SLIDE 305-18

$$n' = n_a(\cos \theta) \qquad \text{(equ. 2)}$$

Examples:

- 10° misalignment & 0.375" diameter nozzle

$n_i' = (0.375)(\cos 10°) = 0.369"$

- 45° misalignment & 0.375" diameter nozzle

$n_i' = (0.375)(\cos 45°) = 0.265"$

where:

n' = nozzle size used for setting nomograph and calculating isokinetic rate

n_a = actual nozzle diameter used on sampling train

θ = average or maximum misalignment angle

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NOTES

SOURCE MODIFICATION
OPTION 1

Procedure:

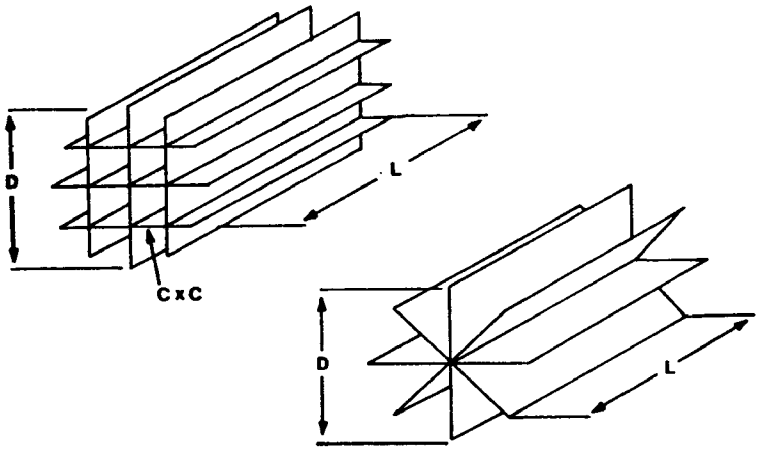
- place a flow straightening device in stack to interrupt cyclonic flow
- test in normal manner on parallel flow

Results:

- particulate concentration should be accurate representation
- flow rate should be more accurate

Note: flow straighteners can cause the source to emit more particulate emissions due to lack of cyclonic separation

SLIDE 305-20



FLOW STRAIGHTENERS

SLIDE 305-21

SOURCE MODIFICATION
OPTION 2

Procedure:

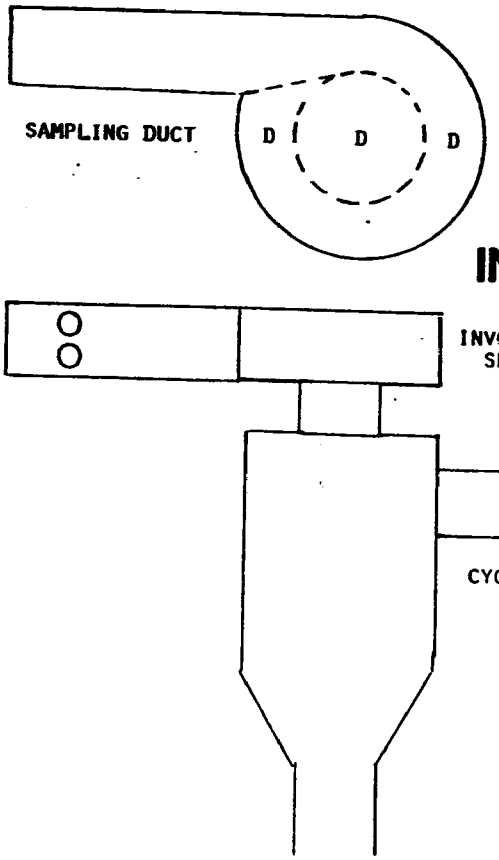
- place an involute or exit duct on top of a small stack; sample involute duct in normal manner

Results:

- particulate concentration, volumetric flow rate and mass emission rate will all be accurate

SLIDE 305-22

NOTES



INVOLUTE SYSTEM

SLIDE 305-23

CONCLUSIONS

RANKING OF APPROACHES FOR
FACILITY TESTED SOURCES

- use flow straighteners or involute system if source will not be affected and approach is feasible
- use compensation method for concentration emissions regulation
- use blind man's approach for mass emission regulation

SLIDE 305-24

(cont.) RANKING OF APPROACHES FOR AGENCY TESTED SOURCES

- use source modification when it is certain that source will not be affected and approach is feasible
- use blind man's approach for concentration emission regulations
- use blind man's approach for particulate concentration measurement and measure volumetric flow at a more accurate location for mass emission regulation

SECTION F. CONDENSIBLES

CONDENSIBLES, REACTIVE COMPOUNDS, AND EFFECT OF SAMPLING TRAIN CONFIGURATION

by

Guy Oldaker

As source sampling technology has changed over the years, the definition of what constitutes "particulate matter" has been revised to reflect these changes. This definition is crucial to the determination of what pollutants are controllable and are thus subject to study and possible regulation.

A by-product of this situation is the problem of establishing sampling and analytical procedures which will reliably collect those pollutants once they have been defined. Several factors enter into the determination of exactly what kind of data a given stack test will produce. These include the temperature of the stack gas at the moment of filtration, the location of the filter in the sampling train, and the analytical methods used to retrieve the sample from the train for quantification. The existence of condensible and reactive particulate has had a major part in determining the methodology used for particulate sampling for NSPS sources and in state regulations for existing sources. With the establishment of sampling train design parameters, and analytical procedures begins the argument of the "representativeness" of the captured sample.

DEFINITION OF A PARTICULATE

The typical definition of particulate matter in most state regulations reads something like "Any solid or liquid emission except uncombined water at standard conditions." In most states

EPA Method 5 is the predominant sampling method for determining particulate emission rates from sources. Method 5 defines particulate as that which is captured by the probe and filter at 120°C. Thus, many states use a Method that is inconsistent with their legal definition of particulate.

On the Federal level, in the NSPS regulations concerning particulate matter, the emission levels acceptable, and the methods used to determine emission levels, are consistent with another definition: "any finely divided solid or liquid material other than uncombined water as measured by Method 5 or any equivalent or alternative method." This avoids legal inconsistencies.

The question of inclusion of condensible material, and the problems created by reactive particulate matter, have influenced the development of the Reference Methods for use on NSPS sources. As proposed in the Federal Register, August 17, 1971, for three affected NSPS source classifications, the full EPA Method 5 train (front and back half) would have been used to determine particulate emission rates. Proposed allowable emission limits were based on the results from use of the full EPA Method 5 drain.

The response to the proposed regulations challenged the 'representativeness' of the particulate sample captured in the impingers. The full EPA Method 5 train was designed to attempt to capture particulate as was defined at that time (particulate existing @ 20°C and later). Questions were raised regarding oxidation and condensation of sulfates as well as reaction of sulfates on the filter and in the impingers, with respect to whether these same reactions occur after dispersion into ambient air.

As noted, factors such as filter type, placement and temperature, and sample recovery techniques influence the quantity of particulate captured. The development of the Method 5 train reflected an attempt to have a sampling method consistent with the definition of particulate at that time. However, the arguments put forward against back-half analysis carried a considerable amount of weight when coupled with the lack of studies on reaction and dispersion characteristics of particulates upon exiting the stack. The EPA engineers determined that the material collected in the impingers was usually (though not in every case) a consistent fraction of the total particulate catch. In fossil-fueled steam generators this fraction was approximately 50 percent, while in the case of incinerators 20 to 30 percent of the total particulate catch was found in the impingers. The EPA chose to use only the front half of the Method 5 train to determine the particulate emission rate, making a corresponding reduction in the allowable emission limit.

BACK-HALF ANALYSIS

As noted, a considerable amount of thought has gone into what constitutes a "particulate" and whether the captured sample is representative of what the control equipment sees or what occurs at ambient condition after dilution and cooling. The full EPA train (front and back-half) seems to represent sampling conditions consistent with many state regulations. Eleven states allow for the reporting a back-half analysis in some form.

Going to the CRC Handbook of Chemistry and Physics, one can find some 180 inorganic and organometallic compounds which boil or sublime above 20°C but below 120°C. Though these compounds would be included in the legal definition of"particulate" in 48 states, they will pass through the heated filter of a standard Method 5 train.

The two major compound groups which are most discussed when considering back-half analysis are sulfates and organics. The degree to which these groups condense or react in the impingers appears to be dependent upon the source. However, in each source category the percentage of the total particulate tends to be consistent. The condensation and reaction of SO_x compounds has been a subject of much discussion. EPA engineers have determined for NSPS sources this reaction does not necessarily play a large part in the back-half catch. Hydrocarbons (organics) play a larger role at sources such as wood veneer plants, coffee roasters, and some asphalt plants. Back-half catch may account for 50% or more or the total catch. Clearly, this is a significant fraction. (See Table 6.1).

Analysis procedures are important when back-half catch is desired. Simple boil-down of the impinger water would result in the loss of these organic compounds. The usual procedure would be an ether-chloroform extraction with a boil-down at ambient conditions. The remaining inorganic salts and acids could be boiled down as usual. In the source categories noted above, the organic catch will have a greater impact of the total catch than the inorganics.

Back-half analysis raises the possibility that results could be biased slightly high through inclusion of dissolved or hydrated gases (HCl readily combines with impinger water) which, by themselves, are gaseous at room temperatures. Sulfates may be formed as a pseudo-particulate by reaction in the impinger water such as:

$$NH_3 + SO_2 + H_2O \rightarrow (NH_4)_2SO_3 \quad (1)$$

or

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad (2)$$

(unbalanced equations)

The question of these reactions affecting the total particulate catch is still unanswered. However, these biases will tend to be insignificant when compared to the amount of genuine particulate caught.

The central question in dealing with condensibles and reactive compounds is defining what constitutes a particulate. In the majority of states there is an inconsistency between the legal definition and the particulate sampling methodology. The particulate catch depends on the sample train configuration and sampling temperature.

In the NSPS regulations, particulate is defined by the methodology used. By specifying Method 5 @ 120°C (160°C for fossil-fuel-fired steam generators) a common basis is drawn for comparison of allowable emission levels with particulate sampling data. (The current Method 5 is front-half analysis only.)

The cost of controlling the particulates which exit at standard conditions could be prohibitive. In setting NSPS emission

levels, the best available control technology (considering cost) must be taken into consideration by the EPA administrator. By selecting sampling methodology and emission levels that demonstrate the level achievable by this control technology, the EPA avoids the problem of considering the representativeness of the samples when condensibles and reactive compounds are excluded. The questions about the reactions which occur in the back-half, and whether these take place beyond the stack exit, still exist and are a subject of further research.

Table 6-1

Source Category	% of Total Catch Collected in Back Half
Fossil Fuel Fired Steam Gen.	≃ 50%
Incinerator	≃ 20-30%
Conventional	
Asphalt Hot Mix overall	41-48%-86%
w/ scrubber	4 -29 - 56
w/ Baghouse	30-66 - 86
Drum-Mix (Preliminary)	
Uncontrolled	≃ 26%
Venturi control (Scrubber)	≃ 9%
Wet Scrubber Fan	≃ 17%
Asphalt Roofing ?	
Petroleum Refineries	36- 56 - 83
Lead Smelter	36- 77- 83
Secondary Brass and Bronze	17- 38 - 58
BOF (Steel and Iron)	14- 30 - 40
Electric Arc	
Inlet Baghouse	1- 2 - 4
Outlet Baghouse	40- 57 - 76

13

Effects of Sampling Train Configuration and Analytical Procedures on Particulate Catch

BY

Walter S. Smith

Robert A. Estes

As source sampling technology has changed over the years, the definition of what constitutes "particulate matter" has been revised constantly to keep up with those changes. This definition is crucial to the determination of what pollutants are controllable and are thus subject to study and possible regulation.

A by-product of this situation is the problem of establishing sampling and analytical procedures which will reliably collect those pollutants once they have been defined. Several factors enter into the determination of exactly what kind of data a given stack test will produce. These include the temperature of the stack gas at the moment of filtration, the location of the filter in the sampling train, and the analytical methods used to retrieve the sample from the train for quantification. The effects of these factors on the particulate catch warrant close examination.

Defining a Particulate

In the beginning, definitions of particulate matter were largely empirical. "Solids, in the form of dust or fume, which pass with the gases through a flue or stack"[1] seemed reasonable enough in 1920. By 1957, the American Society of Mechanical Engineers was using "particles of gas-borne solid matter larger than one micron mean diameter,"[2] which, if anything, is less comprehensive than its predecessor.

As concern of the quality of the environment escalated during the past decade, an attempt was made to extend the scope of source sampling beyond an evaluation of the best available control equipment toward complete emissions inventories. Correspondingly, there was a general broadening of the definition of particulates by state agencies. A definition similar to "any material, except uncombined water, which exists in a finely divided form as a liquid or solid at standard conditions"[3] currently appears in the regulations of all but two states.

In the Federal Register, June 14, 1974, EPA states that "particulate matter means any finely divided solid or liquid, other than uncombined water, as measured by Method 5... or an equivalent or alternative method."[4] In other words, a particulate is now anything which is caught by the sampling apparatus used, and then detected by the analytical methods employed.

Sampling Train Development

As noted, different sampling trains and analytical methods can yield different results. A major variable is the configuration of the sampling train. The location of the collection filter, the temperature at which it is maintained during a test, and the selective inclusion or exclusion of elements of the sample train in total catch analysis are important factors in ascertaining particulate catch.

Early methods of determination of dust concentration in gas streams, notably Western Precipitation Company's WP-50 (1920) and the ASME's Power Test Code 21 (1941) employed instack filters

for particulate collection (Figure 1). One such filter, the Alundum Thimble, is a relatively coarse filter medium which is maintained in the stack at stack temperature. Penetration of particulate through the thimble was at that time considered to be a negligible problem.

As particulate collection devices such as electrostatic precipitators, became widely used, the importance of catching smaller particles increased. A more comprehensive sample than was provided by a heated filtration medium was also desired.

In 1963, the Los Angeles Air Pollution Control District devised a sampling train in an effort to achieve a complete emissions inventory. Three Greenberg-Smith impingers in series, the first two prefilled with 100 ml. distilled water and the third dry, serve as particulate collectors. Normally, the impinger train is backed up by a single thickness paper extraction thimble in order to collect any particulate matter that may have passed through the impingers (Figure 2). If particulate wetting is undesirable, an Alundum Thimble, substituted for the paper thimble, may precede the impingers (Figure 3). In all cases, analysis of the impinger water by extraction, boil-down and weighing is specified. This method will hereafter be referred to as the LA Method.

Eight years later, the Method 5 sampling system guidelines were promulgated by the EPA. Method 5 retained the concept of out-of-stack filtration introduced in the LA Method, but in a different format (Figure 4). A glass mat filter was placed

before the impinger train, and the filter maintained at about 250°F. Heating of the probe was also specified, such that the temperature of the gas sample would not fall below 250° prior to filtration. Impinger water analysis was retained as a part of the sample recovery procedure.

In the Method 5 train, as originally proposed, effluents which condense above 250°F should be caught on the heated filter; those which condense between 250°F and 70°F should be caught in the condensers. The filter catch is then determined gravimetrically, and the water in the condensers is analyzed for particulate content. These determinations, taken together, comprise a sample which attempts to include all substances which are particulate standard conditions.

Back Half Analysis

Method 5 currently calls for removing particulates from sample - exposed surfaces ahead of the filter frit with an acetone rinse. The acetone is then evaporated at ambient temperature and pressure, desiccated, and weighed. This defines particulate catch at the temperature of the filter during sampling or at room temperature, whichever is higher. However, some water of hydration might be included in that catch.

Since most stack temperatures are well above room temperature, the practical problem of excessive drying time leads many to dry the sample at the temperature at which the filter was maintained during the test. This should not affect results, as long as drying temperature does not exceed the sampling temperature.

Analysis of the impinger water, as noted previously, is necessary to account for any effluents which are gaseous at the filter temperature but which condense at the temperature of the impingers. At present, eleven states require analysis of the impinger catch, though the methods of analysis vary. Federal regulations currently omit the back half entirely.

According to the CRC Handbook of Chemistry and Physics there are some 180 inorganic and organometallic compounds which boil or sublimate above standard temperature but below 250°F. Though these compounds would be included in the legal definition of "particulate" in 48 states, they will pass through the heated filter of a standard Method 5 train.

Simple boiling down of the water would result in the loss of those effluents that volatilize at the temperature employed. Simple extraction will remove some of the volatiles, yet solubles are left behind. Therefore, the reasonable procedures would be extraction with a solvent (e.g., ether-chlorofom), followed by boil-down. This procedure would remove most everything, depending on the solubility of the volatiles in extraction. For trains with the filter after the impingers (Figure 2), filtration is needed to remove solids in the impinger water prior to extraction.

Back half analysis raises the possibility that results could be biased slightly on the high side through the inclusion of dissolved and hydrated gases which, by themselves, are gaseous at room temperature. An example would be hydrated HCl

derived from HCl gas and the water in the impingers. Additional positive error can be introduced through the formation of pseudo-particulates in the impinger water, e.g.,:

$$NH_3 + SO_2 + H_2O \rightarrow (NH_4)_2SO_3 .$$

This particular action ultimately takes place in the atmosphere, but whether or not it should be included in the particulate catch is a question as yet unanswered.

Nevertheless, any such positive bias will likely be insignificant relative to the amount of genuine particulate which is caught by the impingers. With the collection filter maintained at 250°F during a test, the amount of particulate matter in the impinger water will certainly be significant and should not be overlooked.

Filter Location and Temperature

In-stack filtration methods, by maintaining the filter medium at the temperature of the stack gas, define particulates as substances which are solid or liquid at that temperature. This data, while useful for control equipment design, is of little value in the context of environmental impact assessment. Since emissions caught by the filter consist only of substances which are particulates at the stack temperature, these emissions will change from source to source, perhaps even fron run to run, as the definition of particulate varies with fluctuations in stack gas temperature.

Whereas in-stack filters define particulates at stack temperature, Method 5 defines particulates at the temperature of the

out-of-stack filter. This temperature is nominally 250°F, but regulations allow for a range of ±25°F, and temperatures up to 320°F are permitted in the case of fossil-fuel fired steam generators.

Effluents emitting from high-temperature sources may not cool to 250°F before filtering, depending on such factors as ambient temperature, wind speed, and probe length. On the other hand, effluents which enter the probe at less than 250°F will be heated to some extent prior to reaching the filter medium.

Another angle to consider, though minor, is what might happen if the probe were not as hot as the filter, causing the stack gas sample to be cooled and then reheated. Should this occur, there is the possibility that some substances which are gases at the filter temperature would cool enough to form particulate in the probe. These may not evolve back into the gaseous state upon reheating.

To avoid heating a sample above its stack temperature, maintaining the filter at 250°F or stack temperature, whichever is lower, is sometimes proposed. This broadens somewhat the definition of a particulate in the case of effluents at less than 250°F, but reintroduces the original problem of having the definition of the particulate collected based on a variable.

While the temperature of the heated box can be maintained in the neighborhood of 250°F, or any other arbitray figure, the crucial factor, namely the temperature of the sample at the moment of filter penetration, remains difficult to monitor and control with current Method 5 hardware.

Placement of the filter after the impingers, as in the LA Method or in EPA Method 13 (Figure 5), leaves all of the problems involved in back half analysis unsolved, while introducing additional ones. Collection of basic materials in the impinger water increases the likelihood of trapping acid gases. In addition, the fact that carbon does not wet poses clean-up problems.

In a few instances the use of filters in both places is specified (Figure 6). Experience has indicated, however, that the use of filters both before and after the impinger train does not yield results significantly different from those obtained by an unmodified Method 5 train (Figure 4).

As to the actual sampling train, then, it can be said that the Method 5 system as originally proposed, is, if not perfect, the most effective method devised to date. Ideally, all substances in the effluent stream which are solid or liquid at standard conditions are caught on the filter or in the water impingers. This arrangement comes close to catching particulates as defined at standard conditions.

Keep in mind the difference between what the train actually catches, and what is retrieved from the train and reported as the particulate catch. How the results of a test are analyzed determines how accurately the reported catch represents the actual catch.

Conclusions

Total assessment of environmental impact was close to reality with the original Method 5 system. Economic factors entered the picture at this point, however. Arguing that the cost of total control technology would be prohibitive at this point, industries campaigned for removal of the condenser, or back half, analysis from the total catch. This eliminates, for example, measurement of SO_3 emitted by fossil-fuel fired installations.

So it has come to pass that Method 5 currently ignores the back half catch in its determination of particulate emissions. The consequences of ignoring this part of the train are significant, since the nature of the catch--and thus the working definition of a particulate--now rests solely upon what is caught by the heated filter. All states currently accept EPA Method 5 particulate data in some applications; most accept this data for all particulate emissions tests. As we have seen, a disparity exists between the nature of particulates collected by Method 5 and the nature of particulates as defined by law in no less than 48 states. By accepting data produced by the current Method 5 those states are, in effect, contradicting their own statues.

Thus, inclusion or exclusion of the back half analysis, in conjunction with the temperature at which the filter is maintained during sampling, unquestionably affect the results obtained during a particulate test. If the back half is ignored, as is currently the case with Method 5, the operating temperature of the front half of the train becomes very significant in

determining what is caught by the heated filter and thus perceived as particulate emissions.

Method 5 is now specified as the procedure to be used when making particulate mass emission measurements for compliance with performance standards. These standards have been formulated bearing in mind "the degree of emission reduction which (taking into account the cost of achieving such reduction), the Administrator determined has been adequately demonstrated."[5]

In other words, despite the advances in stack sampling technology in recent years, we are still evaluating the best available control technology. Testing and regulation of total environment impact of effluent gases is not yet a reality.

FIGURE 2

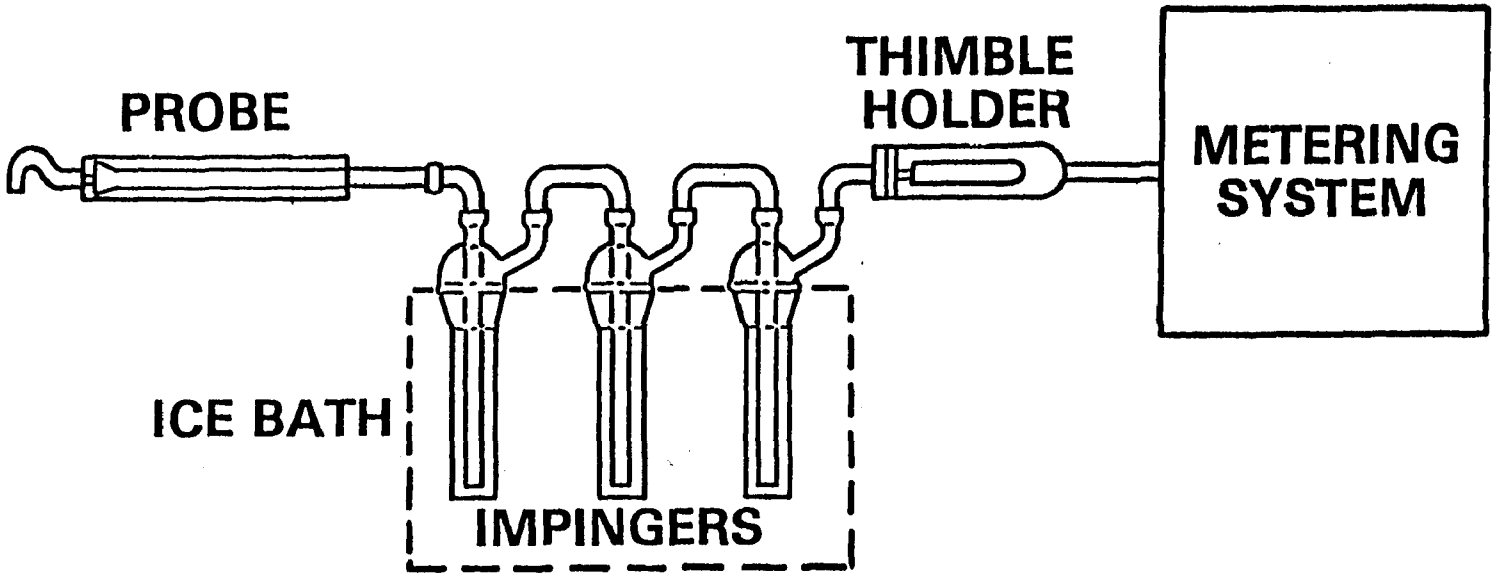


Figure 2. L.A. method particulate train with paper thimble after water impingers.

FIGURE 3

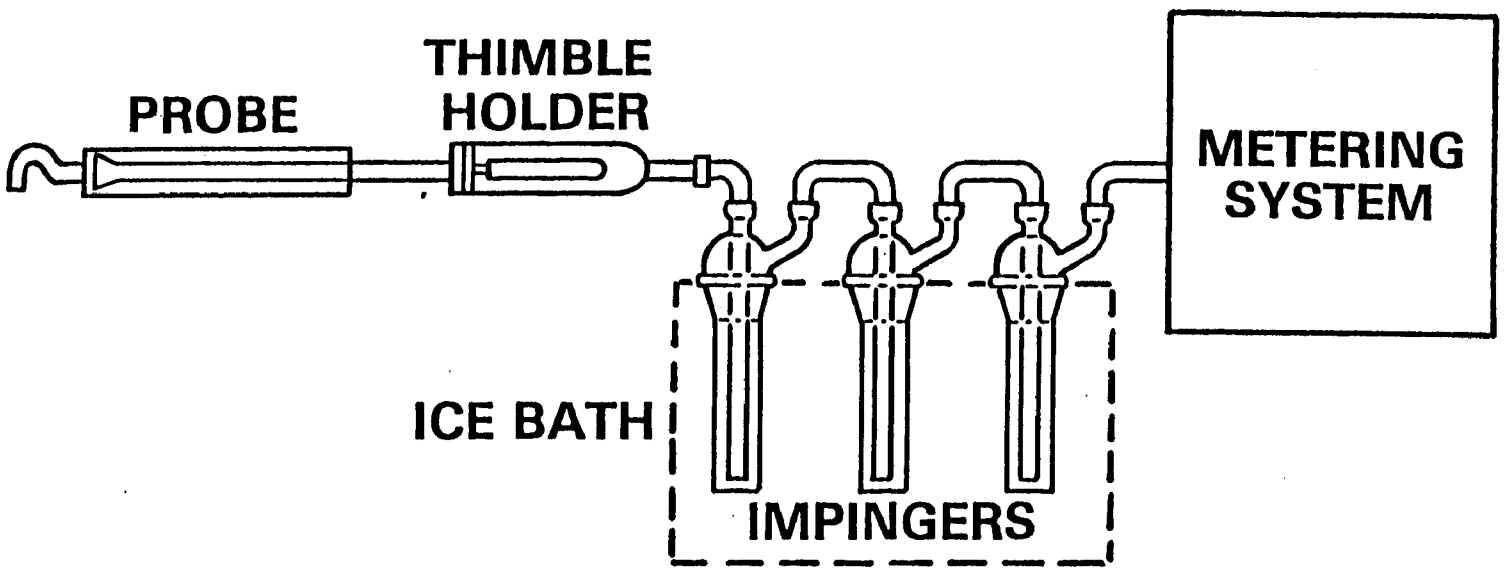


Figure 3. L.A. Method particulate train with ceramic thimble preceding water impinger.

FIGURE 4

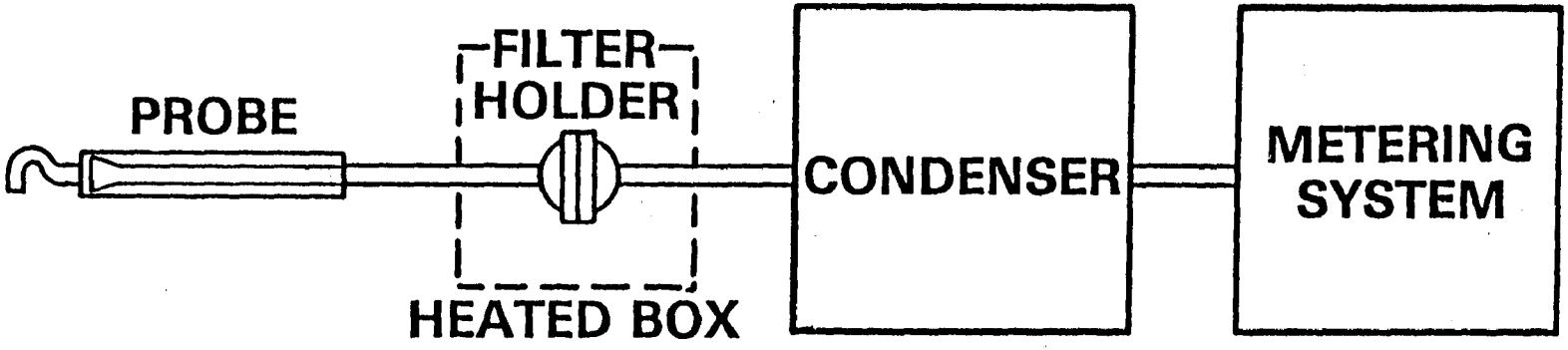


Figure 4. EPA Method 5 particulate train with heated glass mat filter preceding condenser.

FIGURE 5

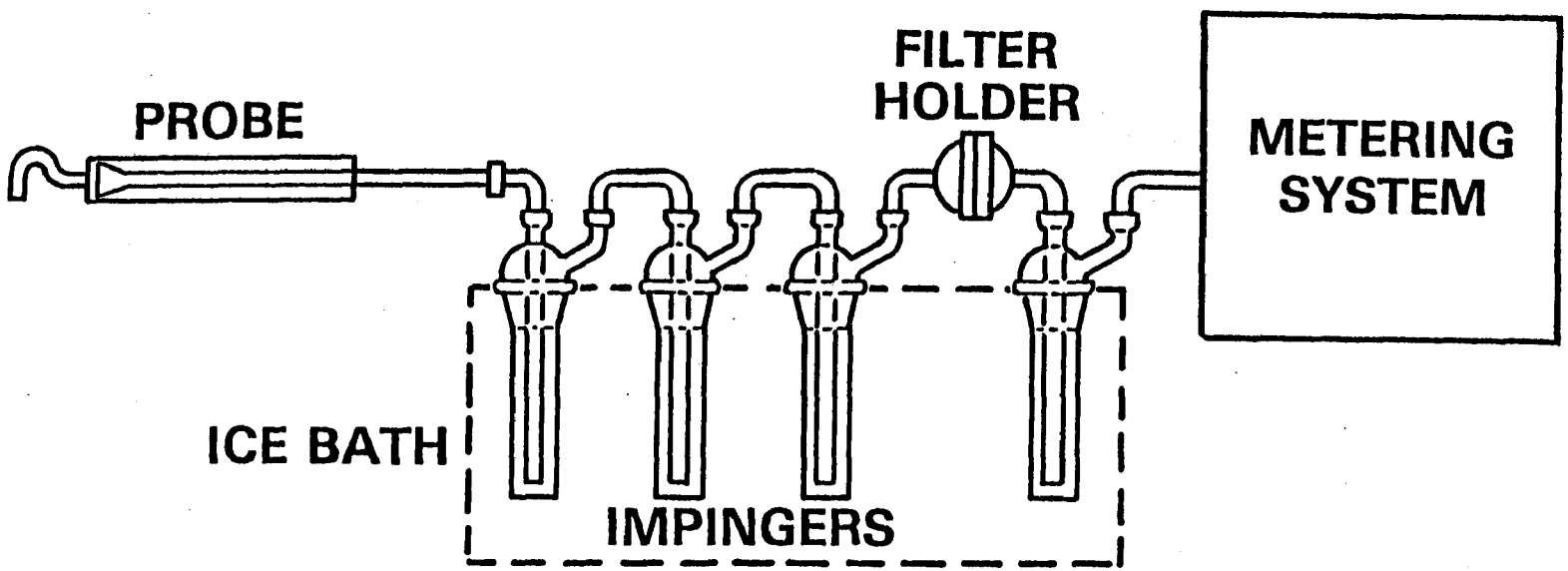


Figure 5. EPA Method 13 train with glass mat filter following impingers.

FIGURE 6

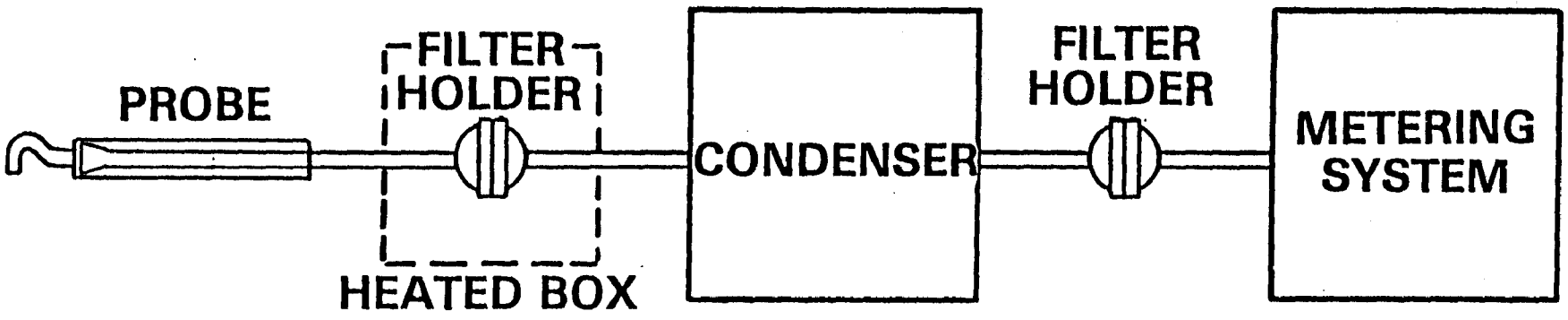


Figure 6. Particulate train with glass mat filters before and after condenser.

FIGURE 7

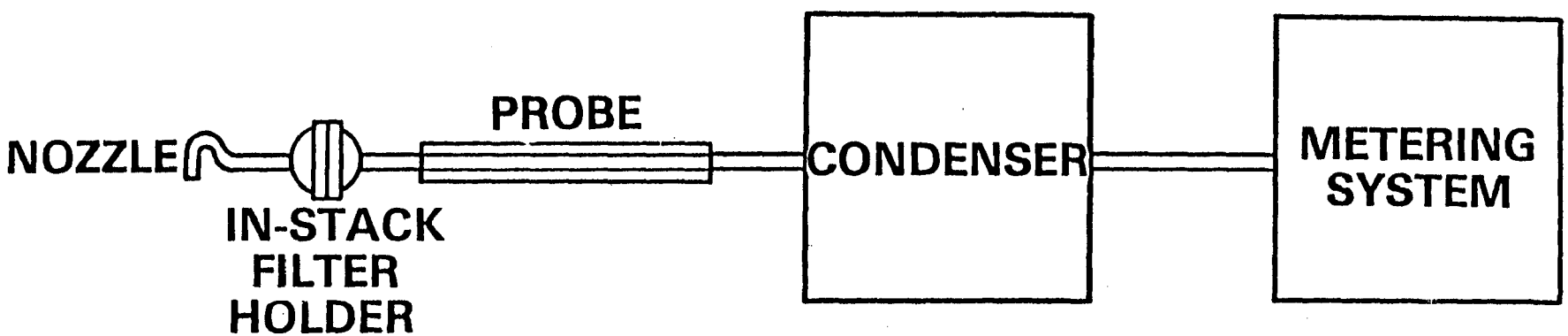


Figure 7. In-stack particulate sampling train.

SLIDE 306-0

NOTES

CONDENSIBLE MATTER

SLIDE 306-1

DEFINITION OF CONDENSIBLE MATTER

Condensible matter or condensible particulate is usually defined as any matter that is in gaseous phase at stack temperature

SLIDE 306-2

BIASES FROM CONDENSIBLES

POSITIVE

Some condensibles that are not intended to be regulated condense below stack temperature and are collected on heated filter

NEGATIVE

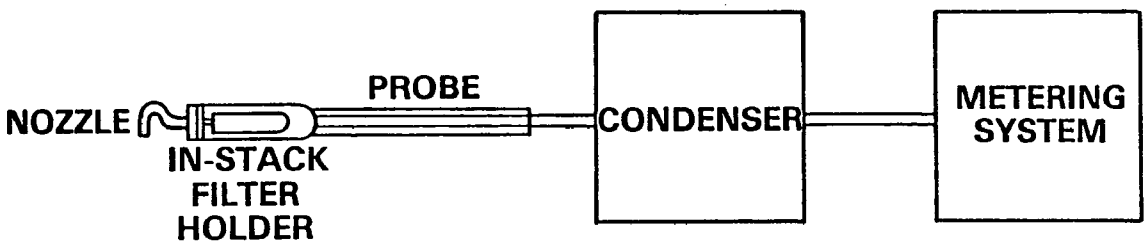
Some condensibles that are to be regulated do not condense at filter temperature and pass through filter

SLIDE 306-3 NOTES

CONDENSIBLE MATTER

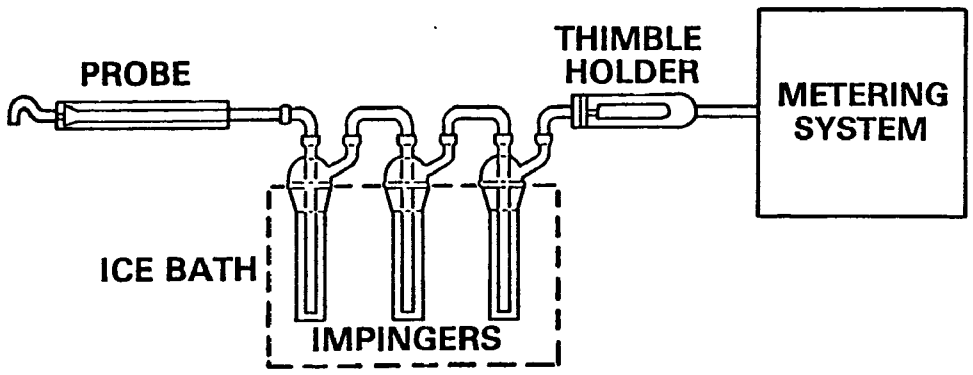
SOURCE CATEGORY:	% OF TOTAL CATCH IN BACK HALF:
• fossil fuel fired gen.	≈ 50
• incinerator	20 - 30
• asphalt plant	40 - 85
• smelters	35 - 85

SLIDE 306-4



FIRST GENERATION L.A. SAMPLE TRAIN

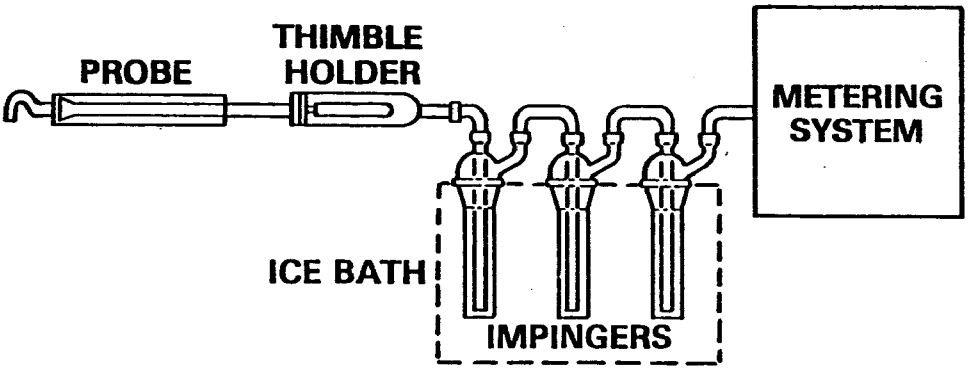
SLIDE 306-5



SECOND GENERATION L.A. SAMPLE TRAIN

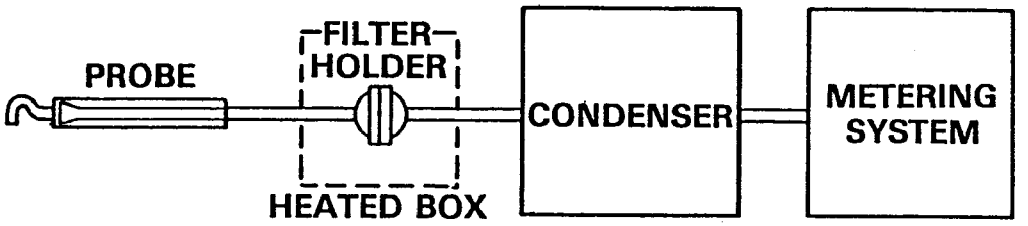
SLIDE 306-6

NOTES



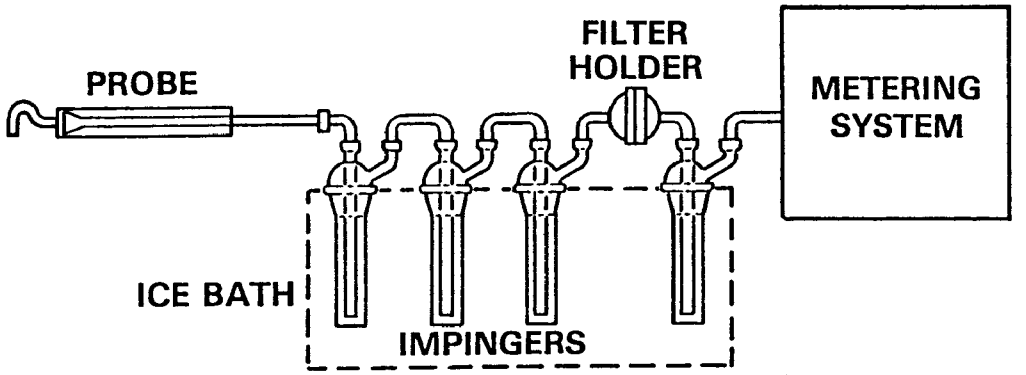
THIRD GENERATION L.A. SAMPLE TRAIN

SLIDE 306-7



EPA METHOD 5 SAMPLE TRAIN

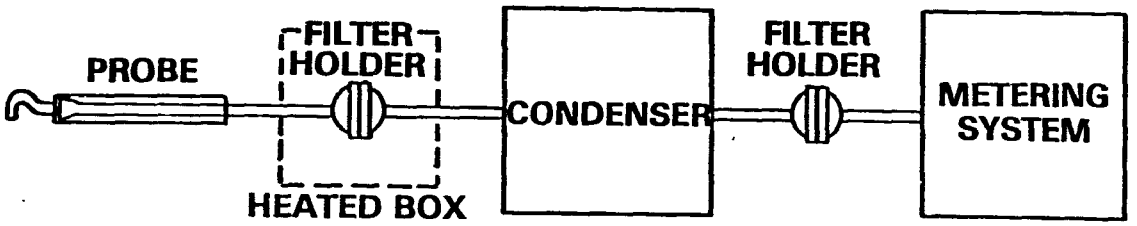
SLIDE 306-8



EPA METHOD 13 SAMPLE TRAIN

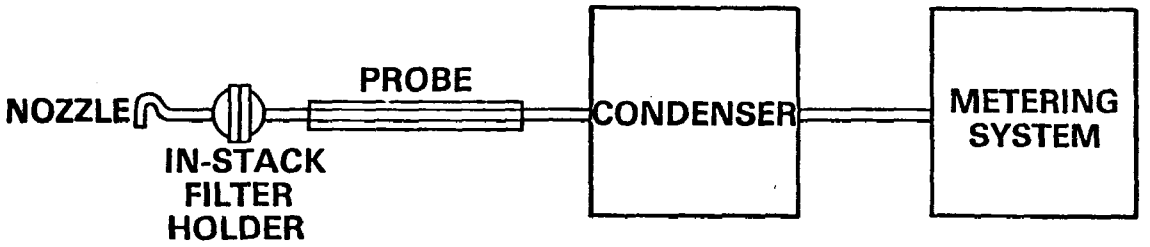
SLIDE 306-9

NOTES



EPA METHOD 13 SAMPLE TRAIN

SLIDE 306-10



EPA METHOD 17 SAMPLE TRAIN

SLIDE 306-11

STEPS TO HANDLE CONDENSIBLES

- determine if condensibles are to be regulated by applicable emissions regulations
- design proper sampling and analytical procedures to match intention of the regulation

SLIDE 306-12

NOTES

REMOVAL OF SULFATE CONDENSIBLE FROM THE PARTICULATE CATCH

- heat sample train filter and probe above sulfate dewpoint
- heat recovered sample to a specified temperature (i.e., 320°F, 450°F) for 4 hours in a furnace
- IPA rinse recovered sample and titrate for free acid ($H_2SO_4 \cdot 2H_2O$)
- water rinse recovered sample and titrate for acid and sulfates ($H_2SO_4 \cdot 2H_2O$)

SLIDE 306-13

INCLUSION OF SULFATE WITH PARTICULATE EMISSIONS

OPTION 1

- ensure probe and filter temperature do not exceed specified temperature (i.e., 250°F, 320°F)
- do not allow any posttest heating of the recovered sample

OPTION 2

- use Methods 5 and 8 sampling trains
- remove all sulfates from Method 5 sample as previously cited and then add sulfate results from Method 8 train

SLIDE 306-14

EXCLUSION OF OTHER INORGANIC CONDENSIBLES FROM PARTICULATE CATCH

OPTION 1

- use an in stack filter sample train

OPTION 2

- maintain probe and filter temperature above dewpoint of condensibles during testing

OPTION 3

- determine exact amount of condensible in sample by analytical means and subtract from catch

SLIDE 306-15

NOTES

USE OF IMPINGERS TO COLLECT CONDENSIBLES
ETHER-CHLOROFORM EXTRACTION TECHNIQUE

Problems with technique:

- pseudoparticulates may be formed in the impingers
- ether-chloroform extraction can be highly dependent on pH of sample

SLIDE 306-16

(cont.) Elimination of problems with technique:

- allow source to determine and subtract any pseudo-particulates
- standardize pH for extraction when non-extractables are not to be included
- have published procedures that are applied uniformly

SLIDE 306-17

CAUTIONS ON CONDENSIBLE SAMPLING TECHNIQUES

- EPA Reference Method 5 sample box temperature may not be an accurate indication of sample gas temperature
- condensed particulate matter may change its chemical composition after condensation
- although temperature is major parameter for collection of condensibles, several other factors can greatly affect condensibles, i.e., moisture content, dilution air, presence of other compounds

SECTION G. FLUCTUATING VELOCITY

SLIDE 307-0

NOTES

FLUCTUATING VELOCITY

SLIDE 307-1

TYPES OF FLUCTUATING VELOCITY

- o minor variations at short time intervals (seconds)
- o major variations at short time intervals (seconds)
- o minor variations at long time intervals (minutes)
- o major variations at long time intervals (minutes)

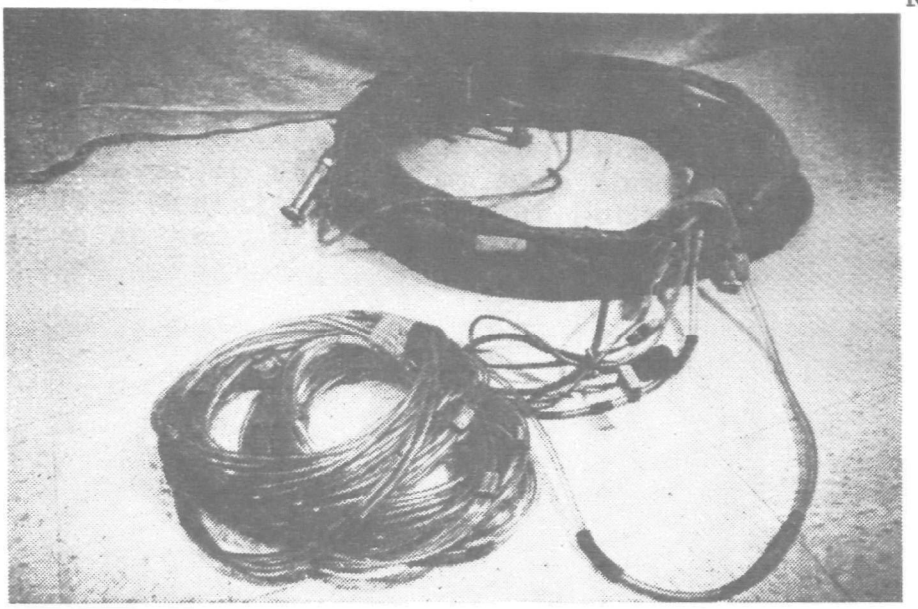
SLIDE 307-2

MINOR VARIATIONS AT SHORT TIME INTERVALS

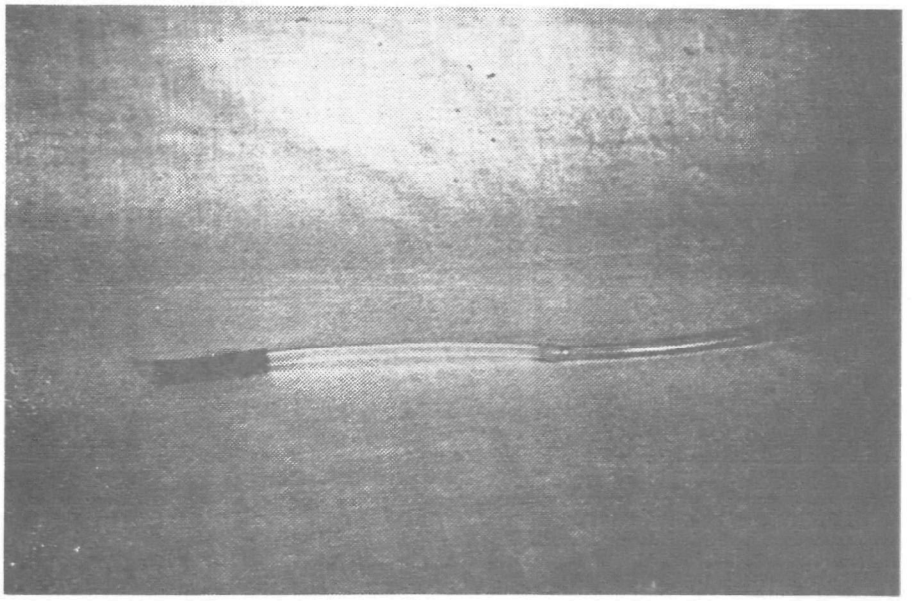
- o add extra lengths of tubing (i.e., 100 ft) to pitot tube lines
- o add capillary tube to impact line

SLIDE 307-3

NOTES



SLIDE 307-4



SLIDE 307-5

MAJOR VARIATIONS AT
SHORT TIME INTERVALS

1. Add extra length of pitot tube lines
2. Make flow adjustments at 2 minute intervals and ignore at other times
3. Calculate the impact of variation with preliminary velocity traverse and make appropriate adjustments in isokinetic rates

SLIDE 307-6

NOTES

MINOR VARIATIONS AT LONG TIME INTERVALS

- change isokinetic sampling rate whenever Δp changes by more than 20%. Mentally time weight both the Δp and ΔH and record their time weighted readings

SLIDE 307-7

MAJOR VARIATIONS AT LONG TIME INTERVALS

- change isokinetic sampling rate whenever Δp changes by more than 20%. Mentally time weight both the Δp and ΔH and record their weighted readings
- allow testing to proceed if the large variation in Δp forces the train out of its range of maintaining isokinetic
- do not change nozzles during a sample run

SECTION H. SOOT BLOWING

PARTICULATE SOURCE SAMPLING AT STEAM GENERATORS WITH INTERMITTENT SOOT BLOWING

OCTOBER 1, 1978

PREPARED FOR:
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DIVISION STATIONARY SOURCE ENFORCEMENT

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PARTICULATE SOURCE SAMPLING AT STEAM GENERATORS WITH INTERMITTENT SOOT BLOWING

Introduction

At fossil-fuel fired steam generators which utilize intermittent soot blowing practices, a major contribution to the total particulate emissions from the facility often occurs during relatively short duration soot blowing periods. Since emissions during soot blowing periods can be quite significant, a procedure is needed for conducting performance tests and weighting the test results in a manner which will accurately reflects the total emissions from the source. The major problem areas encountered in developing such a procedure include: (1) establishing a workable definition of "representative" emission values which is directly comparable to the applicable emissions standard; (2) determining representative source operation conditions for conducting the performance test, (both for normal operating conditions and soot blowing conditions); and (3) collecting particulate samples which accurately reflect the emissions for both source operating modes. This paper discusses these problem areas and outlines methods which may be employed to determine representative emission values for fossil-fuel fired steam generators with intermittent soot blowing. It should be noted that some control agencies enforce emission standards which are effectively "never to exceed" emission limitations. In this situation, sources must comply with the emission standards during soot blowing and testing must be conducted to reflect the maximum emissions from the source. Other control agencies may exclude soot blowing from all performance tests as a non-representative operating condition. This paper does not attempt to address either of these issues.

Soot Blowing Practices / Effluent Characteristics

Soot blowing practices are highly variable between sources and are subject to change both with time and with operating conditions at any specific source. The frequency and duration of soot blowing periods is dependent on many factors including: boiler design, firing method, furnace operating conditions, combustion efficiency, type of fuel, ash content of fuel, operating load, and the frequency/magnitude of load fluctuations. Soot blowing may be conducted as a regularly scheduled intervals or may be initiated as necessary when indicated by operating parameters such as increased pressure drop across the furnace and heat exchanger surfaces, or decreased heat transfer efficiency. Some modern large scale generators blow soot continuously. For steam generators with intermittent soot blowing, the frequency of the cleaning periods ranges from once per 24 hours to nearly continuously. Both manual and automatic soot blowing systems are used at steam generators.

The soot blowing process employs a number of lances to remove accumulated material from the heat exchange surfaces in the furnace, boiler, superheater, and air preheater while the boiler is operating. The lances travel across the heat exchange surfaces and remove the deposits by means of high pressure jets of steam or air. The effectiveness of the lances is dependent on (1) spacing of the lances, (2) nozzle design and angle of attack, (3) air or steam pressure, (4) lance-to-tube speed, (5) frequency and duration of operation, and (6) the nature of the deposits on the tube surfaces.

The particulate concentration of the uncontrolled effluent stream is subject to large temporal variations during the soot blowing period due to the nature of the tube cleaning process. For a specific lance, most of the accumulated material is removed from the tube surfaces on the instroke of the lance. The remaining deposits are removed as the lance is retracted. In addition, the cleaning process is usually initiated at the heat

exchange surfaces nearest the burners and moves downstream, finally cleaning the air preheater. Since deposits on the various heat exchange surfaces are generally not uniform, this method of cleaning adds to the temporal variations in the uncontrolled particulate concentration during the soot blowing period. The variations in the particulate concentration during soot blowing may be minimized or "smoothed" to some extent by the particulate control device and effluent handling system.

For the purposes of conducting particulate emission performance tests, steam generators utilizing intermittent soot blowing practices should be treated as cyclic or batch processes where each cycle consists of a period of normal operation and a period of soot blowing. The normal operation period is characterized by steady-state source operation and relatively constant emission levels over the duration of the performance tests. In contrast, the soot blowing period is characterized by increased particulate emissions and large fluctuations in the emission values over a relatively short time period.

Representative Emission Values

Isokinetic sampling for particulate matter automatically integrates or averages the particulate concentration of the effluent stream over the duration of the sampling run. Thus, at most sources, the time period for averaging emission values is indirectly defined by the duration of the sampling run. Three sample runs are averaged to determine the performance test results. For steam generators with intermittent soot blowing, the fluctuations in particulate concentration are relatively large and the interval between soot blowing periods may be considerably greater than the duration of the sampling runs. Therefore, at these sources, alternate sampling procedures and alternate averaging or weighting procedures must be employed to determine representative emission values.

For the purposes of this discussion, "representative" emissions are considered to be the emission values which would be measured if, for a given time period, the entire effluent stream could be

collected, well mixed, and then sampled. Employing this definition, the representative emission rate for a steam generator with intermittent soot blowing is equivalent to the emission rate from a steady-state source which would produce the same net pollutant mass emissions over the time period being considered.

Consider the simplest case where independent sampling runs are conducted to determine the pollutant mass rate at normal operating conditions and during soot blowing. If multiple sampling runs are performed at either operating condition, then the averages of the samples at each operating condition should be used to determine the representative emission rate. The pollutant mass emission rate which is representative of the emissions from the source, ($\overline{pmr}$), may be calculated from the following equation:

$$\overline{pmr} = (pmr_1 t_1 + pmr_2 t_2) \times 100 \qquad (1)$$

where: pmr_1 = average pollutant mass rate of samples at normal operating conditions

pmr_2 = average pollutant mass rate of samples during soot blowing

t_1 = percent of source operation time at normal operating conditions

t_2 = percent of source operation time blowing soot

The volumetric flow rate, (dry, standard conditions) and percent excess air are not expected to vary significantly between periods of normal operation and periods of soot blowing. Therefore, a representative mass concentration, ($\overline{C}$), or representative specific emission rate, ($\overline{E}$, lbs/10^6Btu), may also be determined by simply time weighting the measurements at each condition;

$$\overline{C} = (C_1 t_1 + C_2 t_2) \times 100 \quad (2)$$

$$\overline{E} = F(C_1 t_1 + C_2 t_2) \times 100 \times \left(\frac{20.9}{20.9 - \%O_2} \right) \quad (3)$$

where: C_1 = average particulate concentration of samples at normal operating conditions

C_2 = average particulate concentration of samples during soot blowing

It should be emphasized that if the volumetric flow rate varies significantly between normal operation and soot blowing periods, then alternate equations should be employed to determine representative particulate concentrations and representative specific emission rates. In addition, if the percent excess air varies significantly between the two source operating modes, then alternate equations must be employed to determine representative specific emission rates. These equations are derived in Appendix A of this paper.

As an alternate to conducting independent sampling runs during normal operations and soot blowing periods, a representative emission rate may be determined if sampling runs are conducted at normal operating conditions and additional sampling runs are conducted which include both normal operation and soot blowing. In this case, the representative pollutant mass rate may be calculated as:

$$\overline{pmr} = pmr_1 \left(t_1 - \frac{B}{A} t_2\right) + pmr_x \left(\frac{A+B}{A}\right) t_2 \times 100 \quad *(4)$$

where:

pmr_1 = average pmr of sample(s) at normal operating conditions

pmr_x = average pmr of sample(s) containing soot blowing

*This equation was developed by C. L. Goerner of the Texas Air Control Board. See Appendix B for details.

t_1 = percent of source operating time at normal operating conditions

t_2 = percent of source operating time blowing soot

A = hours of soot blowing during sample(s)

B = hours not soot blowing during sample(s) containing soot blowing

The above equation may be employed to determine a representative particulate concentration, ($\overline{C}$) or representative specific emission rate, ($\overline{E}$) provided that the volumetric flow rate remains constant, and in the case of the specific emission rate, the excess air also remains constant. It should be noted that Equation 4 may be employed even when independent sampling runs are conducted at normal operating conditions and during soot blowing. In this situation, B=0 and $pmr_x = pmr_2$. Thus Equation 4 reduces to Equation 1.

Sampling Strategies

Due to the variability of both operating conditions and soot blowing practices between sources, an appropriate sampling strategy should be devised for each source based on the source - specific conditions encountered. It is essential that the source operating conditions and soot blowing practices are clearly understood and well documented in order to conduct performance tests which are representative of emissions from the source. Factors such as normal maximum operating load, frequency of soot blowing periods, duration of soot blowing periods, and methods or parameters employed to initiate soot blowing should be considered. Data from installed transmissometers may provide the most useful information for establishing the conditions at which the source should operate during the performance tests. The source should note all periods of soot blowing on the permanent data record of the transmissometer measurements. A comparison of the plant production rate records and transmissometer data will then provide a simple means for determining both the frequency and duration of typical soot blowing periods while the source is operating at the maximum normal production rate or other conditions which the con-

trol agency may specify as representative conditions for conducting the performance tests. In addition, assuming that a linear correlation between the optical density and mass concentration of the effluent exists, it provides a rough estimate of the relative particulate emissions levels during soot blowing. Such an estimate is useful in evaluating the significance of temporal variations during the soot blowing period and in determining the level of effort which should be expended in sampling the soot blowing.[1] For example, if the transmissometer data indicates that the particulate concentration is much greater during soot blowing and if soot blowing constitutes a significant fraction of the total source operating time, then more emphasis should be placed on sampling the soot blowing period than would be expended in sampling soot blowing periods at a source where the apparent particulate concentration is not drastically increased during cleaning, or where the cleaning periods are infrequent or of short duration.

For sources where the interval between soot blowing periods is relatively short, performance tests should be conducted such that each sampling run spans an entire cycle of normal operation and soot blowing. Each sample traverse should be intitated at either a different sampling point or at a different time in the operating cycle so that the composite sampling during the soot blowing periods is representative of the effluent across the entire stack or duct cross section. The agency should not allow the source to schedule sampling such that sampling at a point of minimum velocity or minimum particulate concentration is always coincident with the soot blowing portion of the plant cycle. The average of three sampling runs should provide a representative emission value.

For sources where the interval between soot blowing periods is too long to permit sampling runs to be conducted over the entire operating cycle, two options are available: (1) separate sampling runs may be conducted during normal operation and during soot blowing to determine the parameters required for calculation of representative emission values; or (2) sampling runs may be conducted at normal operating conditions and additional runs may be conducted which include both normal operation and soot blowing to allow

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[1] "Use of In-stack Transmissometer in Manual Source Sampling for Particulate Mass Concentration Measurements", K.Foster, N.White, Presented at East Central Section, APCA Annual Meeting, Dayton, Ohio, September 17-19, 1975.

calculation of a representative emission value according to Equation 4. The number of sampling runs used to determine values for the appropriate parameters directly affects the accuracy of the calculated emission rates. At a minimum, two runs should be conducted during normal operating conditions and one run should be conducted during or containing soot blowing. For sources where soot blowing constitutes a very significant portion of the total emissions from the source, it may be necessary to conduct more than one sampling run during or containing soot blowing. Essentially, the number of runs conducted at each operating condition should be directly dependent on the fraction of emissions arising during each operating condition. Sampling runs conducted during soot blowing should span the entire blowing period due to the existence of temporal variations in the effluent particulate concentration over the cleaning cycle.

If independent sampling run(s) are to be conducted during the soot blowing period, the short duration of typical soot blowing periods will usually prohibit completion of a full sampling traverse during the cleaning cycle. When a short duration soot blowing period requires a reduced number of sampling points, all of the sampling points should lie on the same stack or duct diameter to allow continuous sampling during the blowing period without interruption of sampling to change ports. Ideally, the sampling points which are selected would be representative of both the average particulate concentration and average volumetric flow rate in the stack or duct. However, the sampler and agency observer have no prior knowledge regarding the particulate concentration variation across the stack with the exception of those cases with obvious flow disturbances. Sampling sites where the velocity profile is fully developed and where the particulate concentration is relatively uniform reduce the significance of measurement errors arising from traversing only a portion of the stack. Single point particulate sampling should always be avoided but may be necessitated at sources with very short duration soot blowing periods. A point of representative velocity should be selected when single point sampling is required. When this situation is encountered the errors in the

calculated emission rate due to sampling at a single point will be minimized due to the relatively small fraction of the total emissions occurring during the short soot blowing period. If more than one soot blowing period is to be sampled, the sample traverses should be initiated at different sampling points, (or conducted at different sampling points for single point sampling) to minimize the effects of concurrent spatial and temporal variations. The effluent velocity must be measured at the point(s) sampled during soot blowing runs in order to maintain isokinetic sampling conditions. These velocity measurments should be compared to the values measured at the same points during normal operation sampling runs to check the validity of assumptions regarding constant volumetric flow rate during both operational conditions. For sources subject to specific emission standards, (mass per unit of heat input) measurements of $\%CO_2$ and/or $\%O_2$ during soot blowing periods should be used to determine if the excess air varies significantly between soot blowing and normal operation. The equations in Appendix A should be employed to determine representative specific emission values for sources where significant variations in the percent excess air are encountered.

APPENDIX A

It should be noted that the method for determining a representative emission value is in some cases dependent on the applicable emission standard, (i.e., mass emission rate, concentration, or specific emissions standard - lbs/10^6 Btu). Each case is considered separately in the following sections. The following nomenclature is employed.

C_1 - effluent particulate concentration during normal operating conditions, (dry standard conditions)

C_2 - effluent particulate concentration during soot blowing, (dry standard conditions)

Q_1 - effluent volumetric flow rate during normal operating conditions, (dry, standard conditions)

Q_2 - effluent volumetric flow rate during soot blowing (dry, standard conditions)

pmr_1 - pollutant mass rate during normal operating conditions

pmr_2 - pollutant mass rate during soot blowing

T_1 - amount of time source operates at normal operating conditions

T_2 - amount of time source blows soot

Case I - Representative Mass Emission Rate, $\overline{pmr}$

$$\overline{pmr} = \frac{\text{total mass emissions}}{\text{total time}} \qquad \text{A-1}$$

The general equation for N operating modes is;

$$\overline{pmr} = \frac{\sum_{i=1}^{N} pmr_i \; t_i}{\sum_{i=1}^{N} t_i} = \frac{\sum_{i=1}^{N} c_i Q_i t_i}{\sum_{i=1}^{N} t_i} \qquad \text{A-2}$$

For a FFFSG with intermittent soot blowing, N = 2, then;

$$\overline{pmr} = \frac{pmr_1 \; T_1 + pmr_2 \; T_2}{T_1 + T_2} = \frac{C_1 Q_1 T_1 + C_2 Q_2 T_2}{T_1 + T_2} \qquad \text{A-3}$$

If the volumetric flow rate does not change during soot blowing, then;

$$\overline{pmr} = \frac{(C_1 T_1 + C_2 T_2) Q}{T_1 + T_2} \qquad Q = \text{constant} \qquad \text{A-4}$$

Case II - Representative Concentration, $\overline{C}$

$$\overline{C} = \frac{\text{total mass emissions}}{\text{total volume of effluent}} \qquad \text{A-5}$$

The general equation for N operating modes is,

$$\overline{C} = \frac{\sum_{i=1}^{N} pmr_i t_i}{\sum_{i=1}^{N} Q_i t_i} = \frac{\sum_{i=1}^{N} C_i Q_i t_i}{\sum_{i=1}^{N} Q_i t_i} \qquad \text{A-6}$$

For a FFFSG with intermittent soot blowing, N = 2, then;

$$\overline{C} = \frac{pmr_1 T_1 + pmr_2 T_2}{Q_1 T_1 + Q_2 T_2} = \frac{C_1 Q_1 T_1 + C_2 Q_2 T_2}{Q_1 T_1 + Q_2 T_2} \qquad \text{A-7}$$

If the volumetric flow rate does not change during soot blowing, then;

$$\overline{C} = \frac{C_1 T_1 + C_2 T_2}{T_1 + T_2} \qquad Q = \text{constant} \qquad \text{A-8}$$

Case III - Representative $\bar{E}$, (lbs/10^6 btu)

$$\bar{E} = \frac{\text{total mass emissions}}{\text{total heat input}} \qquad \text{A-9}$$

$$\bar{E} = \frac{\sum_{i=1}^{N} pmr_i \, t_i}{\sum_{i=1}^{N} H_i \, t_i} \qquad \text{A-10}$$

where: H = heat input rate

Since considerable difficulty is encountered in attempting to measure heat input rates and/or total heat input, the F-factor method is usually employed. Therefore, a different approach should be used to determine $\bar{E}$, based on the parameters which are actually measured.

$$E = C \, F \left(\frac{20.9}{20.9 - \%O_2} \right) \qquad \text{A-11}$$

Define Z such that equation 11 can be written in generalized form,

$$E \ (\text{lbs}/10^6 \text{ Btu}) = C\left(\frac{\text{lbs}}{\text{ft}^3}\right) \quad F\left(\frac{\text{ft}^3 \text{ stoich.}}{10^6 \text{ Btu}}\right) \quad Z\left(\frac{\text{ft}^3}{\text{ft}^3 \text{ stoich.}}\right) \qquad \text{A-12}$$

Since F is a constant, equation 10 can be written as;

$$\bar{E} = F \left[\overline{CZ} \left(\frac{\text{total mass emissions}}{\text{total stoichiometric effluent volume}} \right) \right] \qquad \text{A-13}$$

Note that $\frac{Q}{Z} = Q_s$

where Q_s = stoichiometric volume flow rate

A general equation for N operating modes can be written as;

$$\bar{E} = F \, \frac{\sum_{i=1}^{N} C_i Q_i t_i}{\sum_{i=1}^{N} \frac{Q_i}{Z_i} t_i} \quad \text{or} = \quad F \, \frac{\sum_{i=1}^{N} C_i Z_i Q_s t_i}{\sum_{i=1}^{N} Q_{si} t_i} \qquad \text{A-14}$$

For a FFFSG with intermittent soot blowing, N = 2

$$\bar{E} = F\left[\frac{C_1Q_1T_1 + C_2Q_2T_2}{\frac{Q_1T_1}{Z_1} + \frac{Q_2T_2}{Z_2}}\right] \qquad \text{A-15}$$

If the volumetric flow rate does not change during soot blowing, then,

$$\bar{E} = F\left[\frac{C_1T_1 + C_2T_2}{\frac{T_1}{Z_1} + \frac{T_2}{Z_2}}\right] \qquad Q = \text{constant} \qquad \text{A-16}$$

If the excess air does not change during soot blowing, then

$$\bar{E} = FZ\left[\frac{C_1Q_1T_1 + C_2Q_2T_2}{Q_1T_1 + Q_2T_2}\right] \qquad Z = \text{constant} \qquad \text{A-17}$$

If both the volumetric flow rate and excess air do not change during soot blowing, then;

$$\bar{E} = FZ\left[\frac{C_1T_1 + C_2T_2}{T_1 + T_2}\right] \qquad \begin{matrix} Q = \text{constant} \\ Z = \text{constant} \end{matrix} \qquad \text{A-18}$$

For almost all steam generators with intermittent soot blowing practices, the volumetric flow rate (dry standard basis) and the quantity of excess air are not expected to vary between periods of normal operation and periods of soot blowing. Therefore, simply time weighting the emission values can be employed to determine the representative pollutant mass rate (eq. 4), representative concentration (eq. 8), and the representative specific emission rate, E (eq. 18). Where the volumetric flow rate, and in the case of the specific emission rate E, the quantity of excess air vary significantly during soot blowing,the general form of the equations should be employed to determine representative emission values.

APPENDIX B

TEXAS AIR CONTROL BOARD

8520 SHOAL CREEK BOULEVARD
AUSTIN, TEXAS 78758
512/451-5711

June 12, 1978

Mr. Quirino Wong
Surveillance & Analysis Branch
Environmental Protection Agency
Region VI
1201 Elm Street
First International Building
Dallas, Texas 75270

Dear Quirino:

As you know, we have had some problems with the recent EPA determination concerning soot blowing in stack sampling calculations. As suggested by yourself and Kirk Foster, we would like to present our ideas for consideration.

The accompanying equation uses the pollutant mass rate (PMR) basis but should readily adjust to a concentration basis. It yields a time averaged pollutant mass rate averaged over the daily operating time. Although spikes are included in the average, the equation has no penalty for spikes of emissions above average (such as while blowing soot).

Development of the equation is included for the record.

$$PMR_{AVG} = PMR_{SBR} \frac{(A+B)\ S}{AR} + PMR_{NOSB} \left(\frac{R-S}{R} - \frac{BS}{AR}\right)$$

PMR = Pollutant Mass Rate (lb/hr)
PMR_{AVG} = Average PMR for daily operating time
PMR_{SBR} = Average PMR of sample(s) containing soot blowing
PMR_{NOSB} = Average PMR of sample(s) with no soot blowing
A = Hours soot blowing during sample(s)
B = Hours not soot blowing during sample(s) containing soot blowing
R = Average hours of operation per 24 hours
S = Average hours of soot blowing per 24 hours

At least one sample must contain soot blowing and at least one sample must contain no soot blowing.

Sincerely,

CLGoerner PE

Charlie L. Goerner, P.E.
Source Evaluation Section

Averaging Soot Blowing in Stack Samples

$$PMR_{AVG}(R) = PMR_{SB}(S) + PMR_{NOSB}(R-S) \quad (1)$$

$$PMR_{SBR}(A+B) = PMR_{SB}(A) + PMR_{NOSB}(B) \quad (2)$$

Solving equation (2) for PMR_{SB};

$$PMR_{SB} = [PMR_{SBR}(A + B) - PMR_{NOSB}(B)] / A \quad (3)$$

Substitute equation (3) into equation (1) yields;

$$PMR_{AVG}(R) = [PMR_{SBR}(A + B) - PMR_{NOSB}(B)] \frac{S}{A} + PMR_{NOSB}(R-S) \quad (4)$$

Collecting terms yields;

$$PMR_{AVG}(R) = PMR_{SBR}(A + B)\frac{S}{A} + PMR_{NOSB}(R-S-\frac{BS}{A}) \quad (5a)$$

or;

$$PMR_{AVG} = PMR_{SBR} \frac{(A+B)S}{AR} + PMR_{NOSB} (\frac{R-S}{R} - \frac{BS}{AR}) \quad (5b)$$

PMR = Pollutant Mass Rate (lb/hr)

PMR_{AVG} = Average PMR for daily operating time

PMR_{SB} = PMR while blowing soot

PMR_{NOSB} = Average PMR of sample(s) with no soot blowing

PMR_{SBR} = Average PMR of sample(s) containing soot blowing

A = Hours soot blowing during sample(s)

B = Hours not soot blowing during sample(s) containing soot blowing

R = Average hours of operation per 24 hours

S = Average hours of soot blowing per 24 hours

SLIDE 308-0

NOTES

INTERMITTENT SOOT BLOWING

SLIDE 308-1

DETERMINE TYPE OF EMISSIONS REGULATION

THE REGULATION MAY REQUIRE

- addition of soot blowing on a daily basis since it is a normal part of operation
- testing at worst case since the regulation is never to exceed limitation
- the exclusion of soot blowing from the regulated emission

SLIDE 308-2

INTERMITTENT SOOT BLOWING
DAILY AVERAGING TECHNIQUE

1. Determine normal cycle and duration of the soot blowing.
2. Determine the locations of soot blowing
   - boiler tubes
   - superheater tubes
   - air preheater

Note: All boilers do not contain all of these heat exchangers

SLIDE 308-3

NOTES

SOOT BLOWING TEST PROTOCOL

- A separate run should be performed during soot blowing.
- The run should be conducted for the same length of time as the normal soot blowing.
- The run should be made as nearly as possible to the correct soot blowing interval cycle.
- The criteria for minimum points and sample volume should be waived.

Note: The "separate run" may be the third run or the agency may require a fourth run.

SLIDE 308-4

SOOT BLOWING AVERAGING TECHNIQUES

MASS EMISSION RATE BASIS

$$pmr = (pmr_1 t_1 + pmr_2 t_2) \times 100$$

where

pmr_1 = average pollutant mass rate of samples at normal operating conditions

pmr_2 = average pollutant mass rate of samples during soot blowing

t_1 = percent of source operation time at normal operating conditions

t_2 = percent of source operation time blowing soot

SLIDE 308-5

AVERAGING TECHNIQUE FOR lb/10^6 Btu

Convert to an Emission Rate Basis:

$$pmr = \frac{E}{F} Q_{s_{std}} \left(\frac{20.9 - \%O_2}{20.9} \right) (60)$$

where

pmr = pollutant mass rate, lb/hr

E = lb/10^6 Btu

$Q_{s_{std}}$ = flue gas flow rate, scfm

F = F factor used to determine lb/10^6 Btu

$\%O_2$ = percent oxygen during sample run

SLIDE 308-6

NOTES

The resulting mass emission rates from Equation 2 along with their corresponding time can be averaged using Equation 1. The results will be on a mass emission rate basis.

SLIDE 308-7

AVERAGE TECHNIQUE USING MEASURED CONCENTRATION (C) TO CONVERT TO lb/10^6 Btu ($\bar{E}$)

$$\bar{E} = F \frac{\sum_{i=1}^{N} C_1 Q_1 T_1}{\sum_{i=1}^{N} \frac{Q_1}{Z_1} t_1}$$

where:

$\bar{E}$ = lb/10^6 Btu
C = concentration, lb/dscf
Q = flue gas flow rate, dscfh
Z = excess air correction
t = percentage of time during day
F = F factor

SLIDE 308-8

AVERAGING TECHNIQUE USING 1b/10^6 Btu (E)

$$\bar{E} = \frac{\sum_{i=1}^{N} E_i \frac{Q_i}{Z_i} t}{\sum_{i=1}^{N} \frac{Q_i}{Z_i} t}$$

where

E = 1b/10^6 Btu
Q = flue gas flow rate, dscfh
Z = excess air correction
t = percent of time

SLIDE 308-9

NOTES

LET'S TAKE AN EXAMPLE

Run 1	0.095 lb/10^6 Btu	3,650,000 scfh	10.2	$\%O_2$
Run 2	0.087 lb/10^6 Btu	3,540,000 scfh	8.9	$\%O_2$
Run 3	0.091 lb/10^6 Btu	3,930,000 scfh	9.3	$\%O_2$
Run 4	0.330 lb/10^6 Btu	3,810,000 scfh	10.8	$\%O_2$

Soot blowing = 45 minutes each for 3 times a day

SLIDE 308-10

CALCULATE PERCENT OF TIME (t)

$$\text{Soot blowing} = \frac{3(45)}{(60)(24)}(100) = 9.375\% = t_4$$

$$\text{Sample Runs} = \left[\frac{100 - 9.375}{3}\right] = 30.2\% = t_1, t_2, \& \ t_3$$

SLIDE 308-11

CALCULATE STOICHIOMETRIC VOLUMETRIC FLOW (Q_s)

$$Q_{s_1} = \frac{Q_1}{Z_1} = \frac{(3{,}650{,}000)(20.9 - 10.2)}{20.9} = 1{,}869{,}000 \text{ scfh}$$

Q_{s_2} = 2,033,000 scfh
Q_{s_3} = 2,181,000 scfh
Q_{s_4} = 1,841,000 scfh

SLIDE 308-12

NOTES

CALCULATE AVERAGE $\bar{E}$

$$\bar{E} = \frac{\sum_{i=1}^{N} E_i Q_{s_i t_i}}{\sum_{i=1}^{N} Q_{s_i t_i}}$$

SLIDE 308-13

CALCULATE AVERAGE $\bar{E}$

$$\bar{E} = \frac{(0.095)(1.869)(30.2) + (0.087)(2.033)(30.2) + (0.091)(2.181)(30.2) + (0.33)(1.841)(9.375)}{(1.869)(30.2) + (2.033)(30.2) + (2.181)(30.2) + (1.841)(9.375)}$$

$\bar{E} = 0.111$ lb/10^6 Btu

Note: All flue gas flow rates have been divided by 1,000,000 to allow the data to be more easily placed on one slide

SLIDE 308-14

NOTES

APPROXIMATING AVERAGING TECHNIQUE

When Q_{sd} and $\%O_2$ are fairly constant:

$$\overline{C} = (C_1t_1 + C_2t_2) \times 100$$

$$\overline{E} = F(C_1t_1 + C_2t_2) \times 100 \times \left(\frac{20.9}{20.9 - \%O_2}\right)$$

where

C_1 = average particulate concentration of samples at normal operating conditions

C_2 = average particulate concentration of samples during soot blowing

SLIDE 308-15

CONCLUSIONS

- determine how soot blowing should be handled for emission regulation
- establish soot blowing testing protocol
- evaluate the testing results to ensure a correct representation of soot blowing data

SECTION I. SAMPLING PORT LOCATION

ACCESS PROBLEMS

by

Walt Smith

In general terms, "access" as it applies to source sampling means everything of a physical nature that the tester requires of the source in order that a valid test may be performed. This includes:

1) being physically able to get necessary men and equipment to the sampling port location;
2) having enough room and freedom from obstructions for safe performance and observation of a valid test;
3) having necessary support items (e.g. electricity);
4) not being denied use of any of the above.

The question of access should be covered at the pre-test meeting, if such a meeting is held, so that these items will be available at the time testing is to be done. Not all situations can be anticipated at the pre-test meeting, and some questions that are "answered" (proper number and location of sampling ports) may still cause a problem (port caps frozen by rust) on the date of the test. Nonetheless, it is important that certain points be covered prior to the test. The pre-test meeting provides the best opportunity for this, since all parties are represented and the sampling site is (presumable) available for inspection. If no pre-test meeting has been held, these items must be covered immediately prior to the test.

The general requirements that the tester makes of the source in order to satisfy the predetermined test protocol will depend on the type of source, the tester and his equipment, and the protocol. The inspector should know what to look for as

indicators that these requirements will be met on the test date. A comprehensive site inspection, conducted by the inspector in conjunction with representatives of the source and the testing firm, takes only a short time and substantially diminishes the chance of access problems interfering with the execution of test protocol.

Items to be inspected or discussed fall into three basic categories. The first and most extensive inspection is of the sampling site, to determine whether a valid test can be performed there. The observer should then discuss with the testing firm representative the nature of his equipment and his plans for adapting, if necessary, to unusual sampling site configurations. Finally, all potential safety problems should be covered. The source representative should be able to relay all safety rules relevant to the areas of the plant where personnel involved in the testing effort will be working. OSHA regulations should also be considered. These will pertain to ladders, platforms, hand rails, and so forth. Following is a detailed discussion of what to look for in each of these areas during the pre-test inspection.

THE SAMPLING SITE

As the agency observer, the tester, and the source representative approach the sampling site, the tester may be looking for such things as vehicular access, unloading area, and means for transporting sampling equipment from his vehicle to the sampling site. The source representative will aid him in working

out these matters of logistics; you needn't worry about such problems.

Upon arriving at the actual sampling site, a few preliminary observations are in order. (If you are not familiar with the requirements for an acceptable sampling site, go back and review EPA Method 1). Make certain that there are at least two equivalent duct diameters form the sampling port location to the nearest disturbance upstream, and at least one-half diameter downstream to the nearest disturbance or the stack exit. These distances are absolute minima. A test performed at a site which does not meet both of these requirements will not be considered an acceptable demonstration of compliance or violation. Ideally, there should be eight diameters upstream and two diameters downstream of straight, undisturbed flow.

SAMPLING PORTS

After establishing the straight-run distances upstream and downstream of the port location, determine the number of sampling points needed according to the Method 1 formulae. See that there are enough sampling ports provided, and they are installed in the proper locations, to enable this particular requirement of Method 1 to be met.

(NOTE: Reference methods 1-8 have been revised since the December 1971 promulgation. In particular, the requirements for point locations in a rectangular cross-section have been changed, as have minimum stack diameter requirements. The inspector should be familiar with the most recent versions, promulgated on August 18, 1977, of the reference methods.)

If the sampling site and/or port locations do not meet the requirements of method 1, you may require the source to make necessary modifications. In borderline cases, consider that working with a cooperative source will be helpful on the test date, before demanding costly modifications. Make sure that the requests you make of the source are reasonable in light of the goal of meeting the testing objectives.

Having located all ports, make sure each can be opened. A typical sampling port consists of a 4-inch hole in the duct wall, a 4-inch diameter pipe extension (nipple) generally between four and 24 inches in length, and a threaded metal cap which screws onto the nipple to seal the port when it is not in use. Frequently, these caps will become frozen in place by rust; this is particularly true if the ports have not been opened for some time. Try to get all ports open--this will save time on the day of the test. If one or more caps will not come off with a pipe wrench, try the following measures:

- Slip a length of 2-inch pipe over the wrench handle to increase the length of the lever arm.
- Beat on the sides of the cap with a hammer or other heavy object, to break the threads free.
- Heat the cap (but not the nipple) with a torch; it may expand enough to loosen.

If these measures succeed, coat the threads with an anti-seize compound before replacing the cap. If the cap still refuses to loosen, more drastic measures are called for:

- Cast metal caps can be broken apart by repeated blows with a hammer.

·Use a cutting torch to cut off the nipple around the base of the cap.

·If feasible, cut a new port (this is the very last resort).

Bear in mind that these remedies preclude resealing the port with the cap. It may be desirable to wait until the test date before destroying or altering a port.

After locating and opening each port, check with the tester to be sure the ports are of sufficient diameter to accommodate whatever instruments will be placed in the stack. This will rarely be a problem, as most sampling equipment is designed to fit ports as small as 3 inches in diameter. Check to be sure that the nipples are flush with the inside wall of the duct. If the pipe extends even a fraction of an inch into the duct, a flow disturbance has been introduced which will affect any sampling points near the duct wall. Also, measuring the depth of the nipple along its inner surface and assuming that the inner end of the nipple is flush with the stack wall will yield an erroneous value for the duct diameter, dislocating the sampling points calculated from that value.

Often, sampling ports will have deposits of some sort along their inner surfaces. This may be in the form of loose particulate, hard cake, or rust and scale. Suggested that the source deposits from all ports. This procedure may have to be repeated at the time of the test, but clearing the ports now will eliminate delays later in cases where deposits are difficult to remove.

It is desirable to minimize the length of the sampling traverse as much as possible. This is the distance from a sampling

port to the most distant sampling point that must be reached from that port. The reason for this stipulation is that sampling probes will sag noticeably when the length of probe extended into the stack exceeds ten feet or so. If an in-stack filter assembly (or other heavy attachment) is affixed to the probe tip, the sagging will be more pronounced.

At existing sampling sites, the ports are fixed in number and arrangement and not easily or cheaply relocated. However, be sure that existing ports are used in the most efficient way. On round ducts of large diameter, access through four ports spaced 90^{o} apart reduces the needed probe length to less than half the duct diameter (there are no sampling points in the middle 20% or more of the diameter). If such a duct has four accessible ports installed, suggest use of all four. Rectangular ducts less than eight feet in the short dimension are best sampled using ports along the long dimension. If both dimensions exceed 8 feet, access from opposite sides will help.

Generally, the sampling team will have to adapt to whatever port arrangement is provided. The observer should be aware of the likelihood of probe sag when the sampling traverse exceeds eight or ten feet. If the direction of probe sag is upstream, the pitot velocity readings will be higher than real. If the direction of probe sag is downstream, the velocity readings will be low. If the probe sags across the streamlines, the readings may be correct, but the probe tip will not be at the sampling point. Sagging would have to cause a misalignment of more than 30^{o} in the first case, and more than 15^{o} in the second case before the velocity error exceeded ten percent.

Errors in the velocity measurements create anisokinetic sampling conditions. Higher than real pitot readings create overisokinetic sampling conditions which bias the concentration measurement low. Similarly, lower than real pitot readings create underisokinetic sampling which biases the measured concentration high. Errors in velocity measurements introduce an additional bias when mass emission rates are calculated, due to the error in the volumetric flow rate, a determination also based on pitot velocity measurements.

DUCTWORK

The tester will probably want to measure certain duct dimensions in order to determine what sort of equipment he will need to bring to perform the test. He will be measuring the traverse distance, the distance from a given port to the opposite duct wall. This dimension is used to calculate the sampling point locations and to determine the probe length necessary to reach all of those points.

If the duct is circular, suggest that the tester measure two perpendicular diameters. Should they differ by more than 5%, two different sets of sampling points should be used, each determined by one of the diameters. (If four ports will be used, one set of points will suffice.) If the cross-sectional area of the duct must be determined (the applicable standard is in terms of pollutant mass rate rather than pollutant concentration), measure the circumference in the plane of the sampling points and calculate the area based on the assumption that the duct is circular. The calculated area will thus be equal to or greater

than the actual area; any bias introduced by the stack being out of round will favor the agency, not the source.

For rectangular ducts, particularly at steam generators, remember to consider the thickness of insulating material when computing the internal dimensions from measurements of external dimensions. Measurement of two adjacent sides will suffice unless the duct is noticeably asymmetrical. As with round ducts, assuming the cross-section is rectangular and calculating the area accordingly will bias pollutant mass rates in favor of the agency, if at all.

Should a source representative challenge the assumption of roundness or rectangularity, ask him for his figure for the cross-sectional area. He should be able to support this figure to your satisfaction before it is used in further calculations.

The newly promulgated (August 18, 1977) Reference Method 1 prohibits use of the method in ducts of less than 0.071 m^2 (113 $inches^2$) cross-sectional area. This corresponds to a circular duct of 0.30 m (12 inch) diameter. Do not allow velocity measurements or particulate sampling in ducts which do not meet this minimum size requirement without consulting Chapter 3.

Inspect the ductwork in the area of the sampling ports visually, checking the condition of the wall material. In particular, look for possible leaks. Deteriorated duct walls indicate a possibility of leakage which could compromise the validity of the test. This is most important in cases where the duct is under a negative pressure, since leaks will cause ambient air to be drawn into the gas stream, diluting the sample

and disrupting stream lines. If positive pressure exists in the duct, leakage will be in the form of stack gases escaping into the ambient environment. This probably will not effect the samples, unless a significant percentage of the stream is escaping. Be aware of the possibility of toxic or noxious fumes in the work area (see section on Safety below).

Any duct which carries a particulate-laden or corrosive gas stream will probably have deposits along its inner surfaces. In vertical ducts or stacks, deposits may be limited to rust or scale. Loose particulate may build up in ports, on ledges, or at any other irregularity in the walls. In horizontal ducts, the problem of particulate deposition may be severe, amounting to a considerable percentage of the cross-sectional area.

Ask the source representative to see that the internal surfaces of ducts to be sampled are lanced (cleaned with an air jet) not less than 24 hours before the testing is to be done. It is the responsibility of the source to see that this is done. Be absolutely sure, before testing starts, that deposits in the bottom of horizontal ducts have been removed. These deposits are sometimes so deep that a probe (inserted from either the side or the top of the duct) may plow into the dust layer, vacuuming up large quantities of particulate and instantly ruining the sample. Merely taking care to avoid getting the nozzle in the dust layer is insufficient precaution. Re- entrainment of particulate at the boundary between dust layer and moving gas stream will create higher-than-real particulate concentrations near the top of the dust layer. Although the bias thus introduced

will be in the agency's favor, its magnitude is unpredictable and potentially great.

Internal obstructions, if they are present, can affect test results by introducing flow disturbances. Checking for these obstructions can be difficult, but there are a few approaches. Scan the outside of the duct for evidence of structures which may pass through the walls to the inside. A good example of this would be an in-situ gas monitor, which has a tube permanently mounted across the stack. Ask the source representative for engineering drawings of the duct. These may indicate straightening vanes, dampers, structural members, etc. inside the duct. Finally, if a light is available, look into the ports and inspect visually the interior of the duct for as far as you are able to see.

If the tester has brought along the proper instruments, or if gauges are mounted on the duct, record the temperature and the static pressure of the gases. These will be of use on the date of the test, when they may be compared against the conditions in the stack at that time.

WORK AREA

For the purposes of this section, "work area" means the immediate vicinity of the sampling ports, from which the testing and observing personnel and their equipment will be operating. This includes platforms, scaffolds, the outer wall of the duct or stack, and any nearby areas which may be used for such purposes as sample recovery and equipment storage.

In general, see that there is room for all personnel to do their jobs effectively. The tester will determine his needs in terms of his men and equipment. The observer should see that he will have access to both the port area and the meter box location, taking into consideration the amount of "elbow room" needed by the testing crew.

The observer should also make sure that there are no features of the site which will jeopardize the fulfillment of the test objectives as set forth in the protocol. Check for obstructions in front of the sampling ports. Most particulate sampling equipment, with the probe connected to the sample box (containing the heated filter compartment and the impinger ice bath), requires a clearance of about one foot beyond the probe length. This clearance is measured from the outer end of the nipple perpendicularly from the stack wall to the nearest obstruction. The tester will be able to determine if there are any clearance problems, based on his knowledge of his equipment.

Have the source representative point out the nearest source of 110v, 60-cycle electricity. With his assistance and that of the tester, locate a suitable clean-up area, where particulate-laden filters may be transferred to storage containers with a minimum danger of sample loss. (Many testers perform clean-up procedures in their van or truck, with the doors closed to deflect wind.) If testing is expected to take more than one day, suggest that the tester and the source representative work out procedures and locations for overnight storage of the sampling equipment.

RIGGING

The term "rigging," as it is used in this section, means the physical apparatus used to support and maintain the sample box-pitobe assembly at the proper locations and attitudes for execution of a valid test. Support for the pitobe and sample box typically consists of an overhead monorail from which the sample box is suspended at one or two points by rollers. The most common alternative is placement of the sample box on a table of some sort.

Rigging set-ups will vary as widely as do site configurations, and are not limited to standard equipment and procedures. The ingenuity of the test crew is often called upon, and the results are often unique. Whatever the rigging arrangements, the set-up should:

1) allow positioning of the nozzle at each sampling point and perpendicular to the gas stream lines
2) provide stability during sampling
3) minimize opportunities for sample loss or contamination
4) not hinder the test team (or observer) in the performance of their duties
5) not introduce unsafe conditions (see section on safety)

In most sampling situations, the probe is in a horizontal position. For this reason, most sample box-pitobe assemblies are designed for use in this configuration. Vertical traversing requires some degree of adaptation; this situation will be discussed later.

Determine the alignment of the sampling traverses as dictated by the sampling port locations. Make sure that probe supports

can properly be attached to the stack, or that a table or tray can be placed in front of each port at the proper height. The tester will be able to make these determinations based on his familiarity with his particular equipment. Whatever means of support is proposed, ensure that the nozzle opening can be positioned at each sampling point with reasonable accuracy; that the plane of the nozzle opening will be perpendicular to the gas stream lines; and that support will be steady, such that there is no tendency toward deviation from either of these criteria, even if the sample box-pitobe assembly is left unattended during sampling.

When sampling a rectangular duct which runs horizontally, the ports may be across the top or bottom of the duct rather than down the side. Sampling downward from the top of a duct poses few problems, assuming that the sampling equipment being used is adaptable to this type of traverse (this is not always the case). The main consideration again is the probability of particulate deposits in the bottom of the duct.

Sampling upward from the bottom of a duct poses more serious problems. Most sampling equipment cannot be modified for this type of traverse. Even if it can, there are more problems. In a typical sampling probe, the glass (or stainless steel) liner is held in place by the gasket and ferrules at the nozzle end and by the filter glassware connections at the sample box end. When the probe is inserted in the duct, heat expansion will cause the metal ferrules to ease their grip on a glass liner. With the probe in a horizontal or nozzle-downward position, the only danger

in this is the possible loss of seal between nozzle and liner. When the probe is used nozzle-upward, however, ferrule expansion may cause the liner to become completely unseated from the nozzle, and possibly to fall out of the probe altogether. Sampling upward should be avoided if at all possible; if such traverses are unavoidable, some means will have to be devised to prevent the liner from coming unseated as the ferrules expand.

Ocassionally, a horizontal duct may be encountered which is circular. If ports are not already installed, or if new ports are easily cut, have them situated as shown in Figure 2-1. This arrangement eliminates the need for disconnecting and reconnecting the probe from the sample box in the middle of a run. (This maneuver should be avoided in any sampling situation if at all possible, as it introduces a high probability of sample loss.) Ask the tester if his sample box will function properly when situated with the probe angled 45^{o} downward. As a bonus, this sampling configuration will greatly reduce the possibility of dipping the nozzle in deposits of loose particulate which may exist in the bottom of the duct.

SAFETY

Source testing is, by nature, a potentially hazardous undertaking. Work is typically conducted at elevated locations, often upon temporary platforms or scaffolding. Electrically-powered equipment will be in use. Testers may be exposed to noxious gases, dust, loud noise, hot objects, and weather. By working at industrial sites, stack samplers are also subject to the safety hazards of the particular facilities to which their

job may take them. Despite these aspects of source testing, almost any job can be done in safety if it is carefully planned and conscientiously executed.

Unsafe conditions will be generally related to one of two areas: the sampling site and its environs, and the testing equipment and procedures. Potential hazards that arise from conditions at the plant or sampling site should be corrected by plant personnel. They will possess the necessary knowledge of the plant and the process. Neither source testers nor agency observers are empowered with the the authority to single-handedly effect alterations or modifications to someone else's plant or process.

Factors associated with working at elevated sites perhaps constitute the most evident safety problems. Access ladders, stairways, and the work area should comply with OSHA standards. There are specifications for ladders and ladder cages, safety belts, steps, railings and footplates along stairways and around platforms, and for temporary scaffolding. These and other related standards may be found in 29 CFR Part 1910, available at nominal cost from your state's Department of Labor.

Care should be exercised when working at elevated sites to avoid dropping objects, or causing them to fall. Recommend that the tester minimize the amount of equipment hoisted to an elevated platform. Spare parts, back-up equipment, clean-up materials, etc. could be left in the truck. Platforms cluttered with unnecessary equipment are crowded, and chances are increased of someone tripping over something, thus breaking equipment, injuring himself, or knocking objects over the side.

Testing personnel should see that all items of testing epuipment at the site are placed in secure positions. Heavy boxes should not be placed where they can fall over, glass should be protected from accidental breakage, and rigging should support their intended loads with a considerable margin for safety. Ropes and chains should be visually inspected before use.

Meter boxes, thermocouples, pumps, and other items of sampling equipment require 110-volt electric current. Be sure all electric lines and equipment are grounded. Exercise particular care when wet areas are encountered at a sampling site.

Before sampling is commenced, the locations of any adjacent power lines should be determined and relayed to all personnel. A minimum clearance of at least ten feet must be allowed between power lines and any equipment. Assume all power lines are "hot"; do not take anyone's word that a wire is not live.

Placement of a metal probe into a moving gas stream will often generate a substantial static charge in the probe. If the gas stream has just exited an electrostatic precipitator, the charging effect will be particularly strong. Probe sheaths should be grounded to prevent static buildup. This grounding will also prevent shocking in case the heater wires inside the probe short out against the sheath.

The problem of electric shocks, particularly static shocks, may not appear to be serious. Remember that not only is there danger from the shocks themselves, but also from the involuntary reactions shocks will cause. Such a reaction may result in dropped objects, and possibly a serious fall.

Noxious gases and dust should be anticipated at all sampling sites. This is particularly true when the duct being sampled is under a positive pressure. Ports should be opened only when necessary, and carefully sealed around instruments placed in them. If the work area is inclosed, make provisions for ventilation. Remember that the sampling train exhaust (in the meter box) will be a source of stack gas fumes. If high concentrations of toxic gases are expected, frequent spot checks with detector tubes or other detection equipment should be made. If high concentrations are found, appropriate masks or respirators should be worn by all personnel who will be continuously in the work area. In all cases, when such symptoms as dizziness, headache, eye irritation, nausea, or breathing difficulty occur, assume the presence of gaseous toxicants and take appropriate action. Should dust be an air comtaminant of concern, eye protection and masks should be available for use at personal discretion.

Heat is a frequently encountered sampling safety problem which manifests itself in two ways. First, sampling probes are always hot to some degree, and hottest when just removed from a heated gas stream. Care should be taken when handling probes to avoid burns. A more serious problem is that of elevated ambient temperatures in the work area. If hot summer weather, heat radiating from duct surfaces, or a combination of these factors can be expected, be sure to have an adequate supply of drinking fluids on hand. Salt tablets are also useful. If possible, have plant personnel arrange to ventilate the site. One small fan can make a large difference in comfort.

Noise is another environmental irritant which can manifest itself in two ways. Many sampling sites are constantly noisy, due to proximity to fans or other loud equipment. Ear protection should be a part of each man's personal safety gear. Nearby sources of sudden noises, such as sirens, whistles, and relief valves, should be pointed out by plant personnel. Activation of these devices could cause at least an involuntary reaction, and at worst hearing damage.

All personnel-testers and observers-should always be wearing hard hats and steel-toed boots. Additional safety gear, such as goggles, ear protection, respirators, etc., should be carried along in case they become necessary. Follow plant rules and the recommendations of the source representative at all times. Most plants have learned from experience what types of safety equipment and procedures should be followed. Specialized safety gear, such as safety belts for climbing, grounding straps, or chemically-resistant clothing, will usually be provided by the plant.

Have the source representative point out the locations of nearby safety equipment. This equipment includes eye baths, safety showers, fire-fighting equipment, and first-aid equipment. The meaning of emergency signals employed by the plant should be understood by all parties involved in the testing.

Most test teams will carry their own first-aid kit; an agency representative frequently employed in observing source tests should also consider carrying along his own personal kit. It should go without saying that a thorough familiarity with the kit's contents and use is a must.

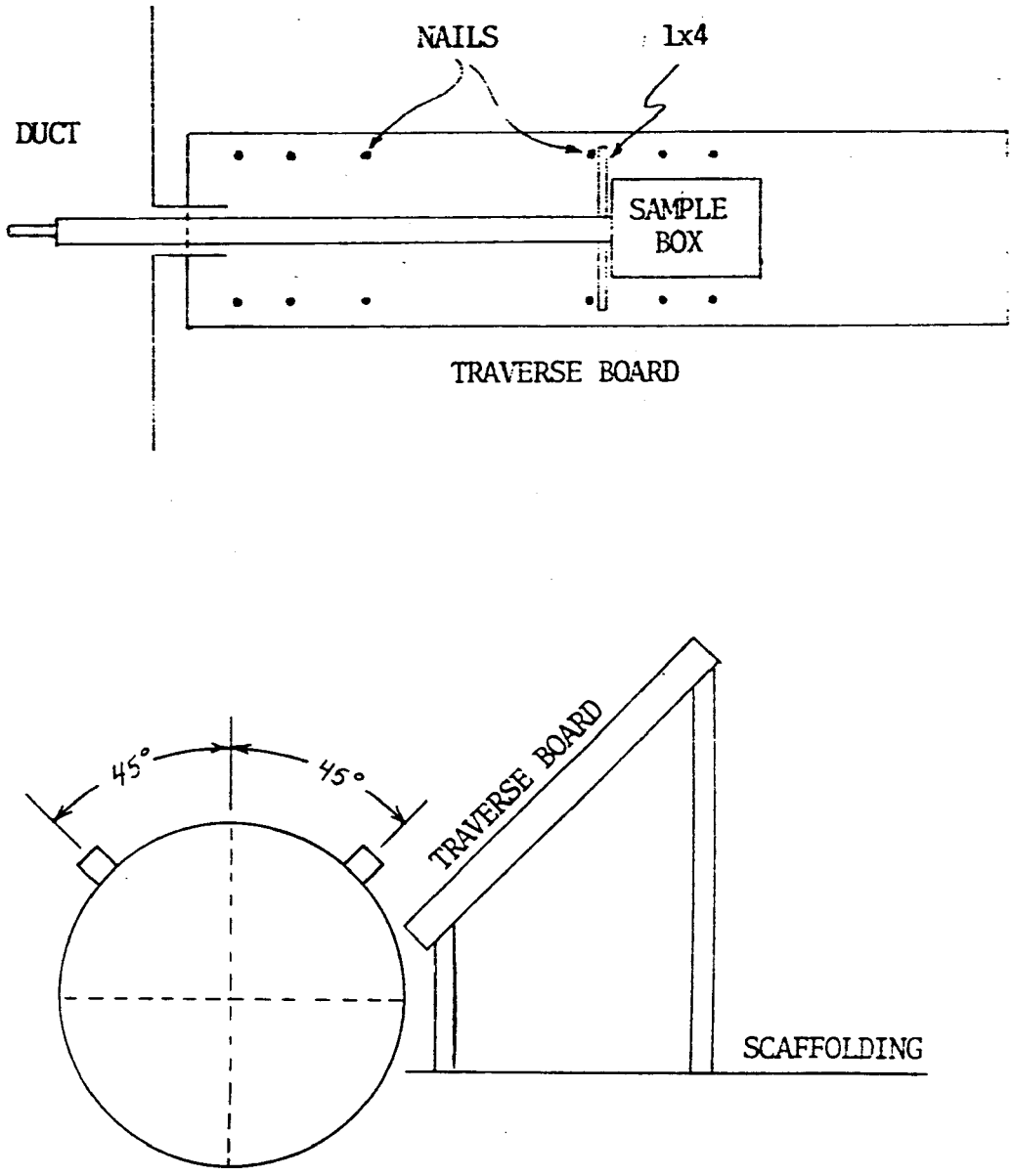


Figure 2-1. Suggested Port Location in Horizontal Round Ducts

ESTABLISHING SAMPLING POINT LOCATIONS IN DUCTS WITH ECCENTRIC CROSS-SECTIONS

by

Giuseppe J. Schiappa

In the vast majority of stack sampling situations, the duct carrying the effluent to be sampled is circular or rectangular in cross-section. Reference Method 1 is written on the assumption that all ducts to be sampled will be circular or rectangular; the possibility that a duct may have a cross-section of some other shape is not considered. Field experience has shown that eccentric-shaped cross-sections, though rare, are encountered on occasion. In these cases, Method 1 guidelines do not specify precisely how to determine the optimum sampling location, the number of traverse points needed, or the cross-sectional layout of these points. Strategies for making these determinations will have to be developed for each eccentric duct encountered in light of the particular shape of the duct cross-section. These strategies should embody the principle and intent of Method 1, extending them beyond circular and rectangular ducts to encompass the particulars of the sampling situation at hand.

DETERMINATION OF OPTIMUM SAMPLING LOCATION

Method 1 guidelines with regard to selection of the optimum sampling site location in a duct can be applied directly to the case of eccentric ducts. The sampling site ideally should be at least eight equivalent diameters downstream and two equivalent diameters upstream from the nearest flow disturbances. In no case should the site be less than two diameters downstream or one-half diameter upstream from disturbances. Simply stated, the procedure

for determining the optimum sampling site location in a given duct is to find the largest accessible section of straight run between any two flow disturbances, and to locate the sampling ports in that section such that 80% of the straight run is on the upstream side, and 20% is on the downstream side of the ports.

A problem arises in determining the "equivalent diameter" of a duct with an irregular cross-section, so that the distances to the upstream and downstream disturbances may be expressed in terms of duct diameters. If the cross-section is an aberration of a circle, calculate a mean diameter. If the cross-section is trapezoidal or polygonal, the equivalent diameter is determined by the equation:

$$D_e = 4 \left(\frac{A}{P}\right)$$

where

D_e = equivalent diameter
A^e = cross-sectional area
P = perimeter

The perimeter should be determined by measurement, and the area may be calculated using appropriate geometric formulas.

Having established the distances from the chosen measurement site to the nearest upstream and downstream disturbances, the minimum number of traverse points may be determined according to Section 2.2 of Method 1.

CROSS-SECTIONAL LAYOUT AND LOCATION OF TRAVERSE POINTS

In mapping out a given number of equal areas within an eccentric-shaped cross-section, one's ingenuity will frequently be called upon. The more irregular the shape encountered, the

more subjective the process of laying out the equal areas. There is often more than one acceptable way to divide up a duct cross-section. What is offered here are guidelines, first for aberrated circular ducts (ellipsoidal), and then for trapezoids and polygons.

For ducts whose cross-sections are variations on a circle, treat the duct as circular for purposes of locating traverse points. If ports are not installed, have them located one-quarter of the duct circumference apart. One should be in the plane of the greatest expected concentration variation. Extend axes from each port through the geometric center of the cross-section. Use the length of each of these axes to determine a set of point locations, using Table 1-2 in Method 1. If the axes are of different lengths, this will yield two separate sets of traverse point markings. Be sure to keep track of which set of points applies to which port.

If the cross-section in question is a trapezoid or other irregular polygon, a graphic method of point distribution should be employed. Draw the duct cross-section to scale on graph paper, and determine the total number of squares covered. Dividing this number by the minimum number of sample points required yields the number of squares to be covered by each equal area. Remember that more than the minimum number of sampling points may be used.

The layout of these equal areas will be dictated by several factors. The locations of the sampling ports, if they are already present, must be taken into consideration. Extend a line from the center of each port, perpendicular to the wall in which the port is located, to the opposite side of the duct. The areas should be

arranged such that as many sampling points as possible lie along these lines. (Pivoting of the probe from side to side to reach sampling points should be avoided as much as possible, due to the inherent inaccuracies in locating the nozzle near a point using this method.) Figures 3-1 & 3-2 are examples of this graphic method. Figure 3-1 is of an ammonium nitrate prilling tower. The "duct" cross-section is a metal grating across the top of the tower, which is square. Testing personnel were able to enter the tower and walk around on the grating; hence, access to the points was not difficult. The dark circle in the center is the spray head location, an area which could not be sampled at the grating level. In Figure 3-2, a trapezoid, note that every point is on or near a perpendicular drawn through a port.

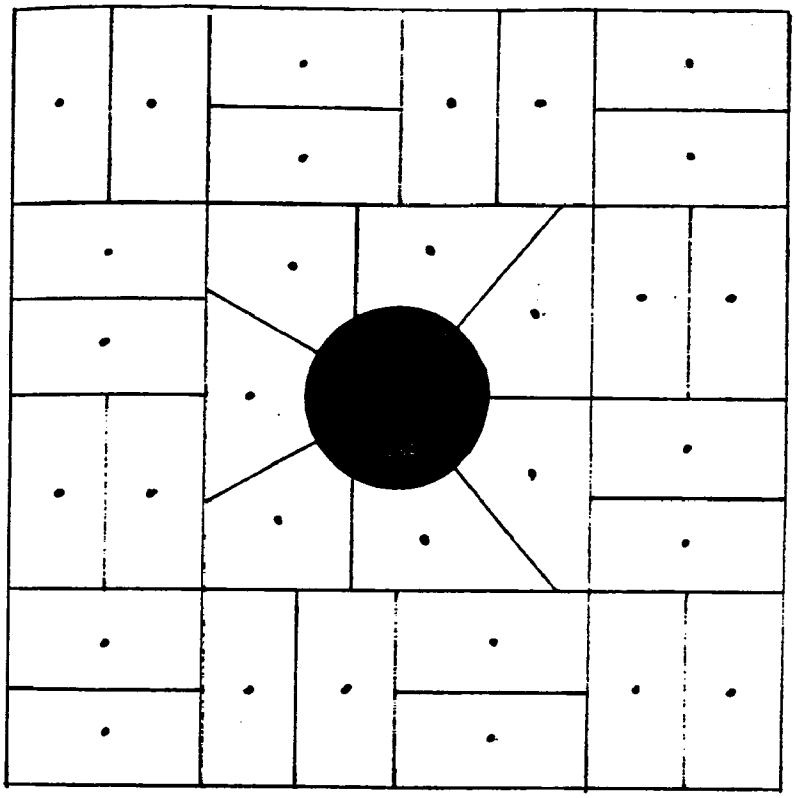


Figure 3-1.

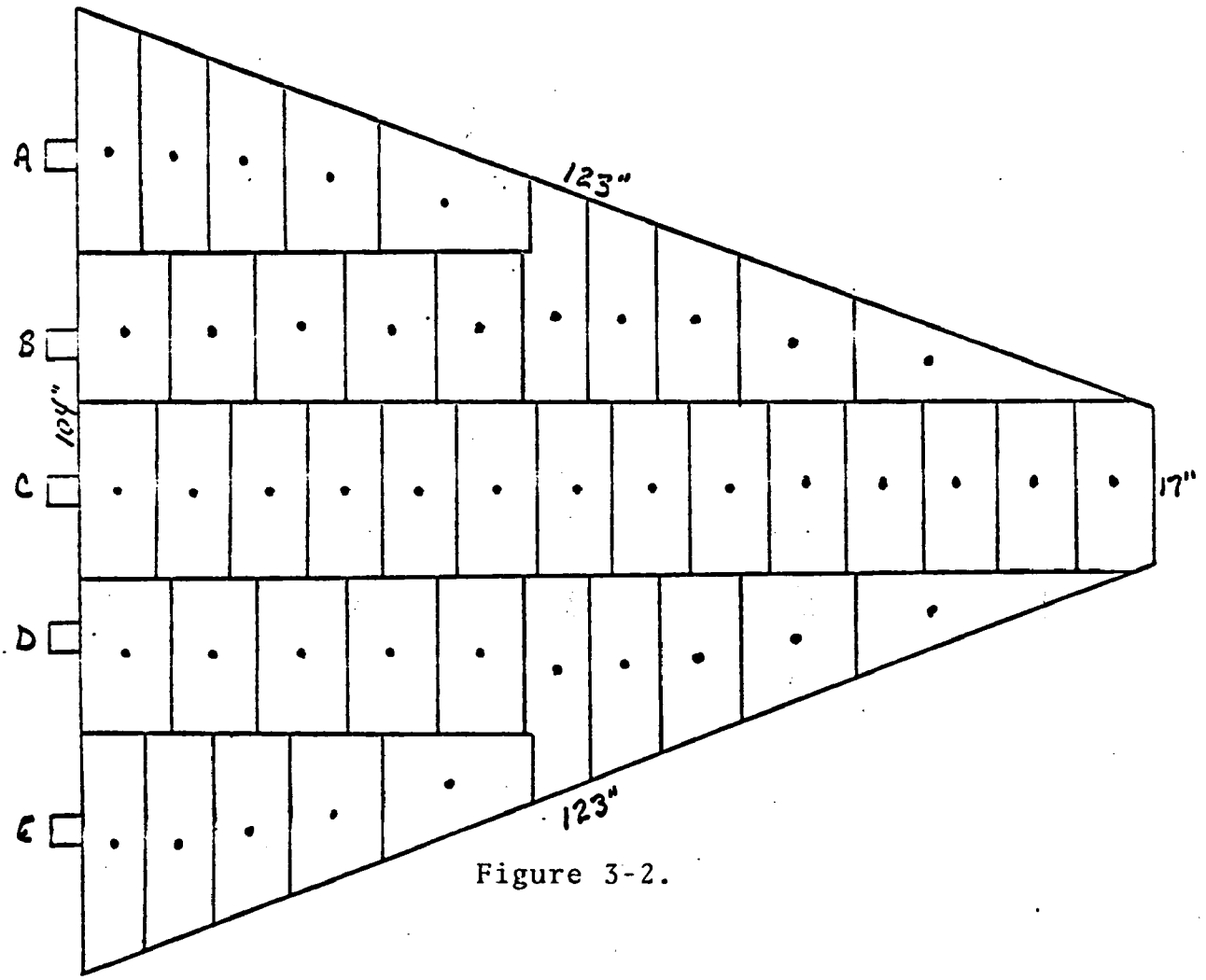


Figure 3-2.

Examples of Sampling point distributions in Eccentric Ducts

GUIDELINES FOR SAMPLING IN TAPERED STACKS

T. J. Logan and R. T. Shigehara

Tapering of the inside diameter of stacks is occasionally done when designing natural draft stacks, when there are special flow or structural considerations, and for pressure recovery. These tapers seldom exceed a few degrees. Although guidelines for the selection of a sampling site to aid in the extraction of a representative sample are given in Method 1 of the August 18, 1977 Federal Register, no mention is made about tapered stacks. The purpose of this paper is to provide the necessary background on how to deal with tapered stacks.

In order to obtain a representative sample, the particles must be extracted at an isokinetic flow rate. The condition of isokineticity demands that the particles and gases flow directly into the sampling nozzle and that the velocity be accurately measured. Therefore, two factors must be considered: (1) the effect of the taper on flow conditions within the stack and (2) the effect of the taper on velocity determination and particulate matter collection.

Effect of Taper on Stack Flow Conditions

About the only information related to this area was the work done with venturi meters. The ASME Research on Fluid Meters[1] cites that beyond a convergent included angle of 21^{o} and a divergent included angle of 15^{o} gas separation from the walls is expected to occur. This is undesirable as eddies would be formed causing particles and gases to flow in undeterminable directions.

From a physical standpoint, convergent angles of 15^{o} or 21^{o} would not likely occur in stacks due to the tremendous increase in velocity. If the larger stack diameter D is used, a tapered stack meeting the minimum 2.5 D requirement of Method I would cause an increase in velocity of about 8.6 times at the outlet for a 15^{o} included angle and 186 times for the 21^{o} included angle. Such an increase would require considerable additional power and would be impractical and uneconomical.

One builder of chimneys related that convergent stacks generally do not exceed 0.5 in. per foot.[2] This corresponds to an included angle of about 4.8^{o} for convergent stacks. Divergent stacks are normally designed at about $5 - 15^{o}$.

Based on the above, the 15^{o} included angle can be considered the maximum limit for both convergent and divergent stacks, with the understanding that the 15^{o} angle will be very unlikely in convergent stacks. The purpose for making this statement is to form the limit and basis for evaluating the effect of the taper on the velocity determination and the particulate matter collection.

Effect of Taper on Velocity and Particulate Concentration

Convergent or divergent stacks would cause an angle of attack by the gases and particulate on the pitot tube and particulate sampling probe nozzle. Data presented by Grove and Smith[3] show that such an angle will result in velocity measurements with a type-S pitot tube being biased, usually high. This higher apparent velocity also causes particulate sampling to be in error because isokinetic sampling requires that the sample gas velocity be made equal to the stack gas velocity, which is in error since

it is measured by the misaligned pitot tube. In addition to the sampling rate being over-isokinetic, the misalignment of the probe nozzle with the stack gas stream results in a reduction in the effective nozzle area.

The magnitude of the effect on the particulate concentration by being over-isokinetic and having a reduced nozzle area is a function of particle size. For particles of less than 1 micron, the concentration will not be affected. However, with the larger particles of greater than 50 - 75 microns, the sampled concentration will be low. In a practical case, where there is a distribution of particle sizes, the error will be somewhat less, and for well-controlled sources where the majority of the particles are characteristically small (<2 microns) the error will be small.

The effects of these errors on pollutant mass rate determination are not easily ascertained. The error of the higher measured volumetric flow rate and the error of the lower measured particulate concentration will act in opposite directions. The magnitudes of each of these errors is difficult to determine, and varies with the situation; therefore, no consistent rule for determining the direction or the magnitude of the consequent error in the pollutant mass rate can be established.

RECOMMENDATIONS

Based on the above discussion, the following guidelines are recommended:

1. Consider all stacks with the total included angle of

$\leq 15^{o}$ as straight stacks.

2. Use the maximum diameter (diameter at upstream disturbance if stack is convergent; diameter at downstream disturbance if stack is divergent) for determining the distances from the sampling site to upstream and downstream disturbances and the minimum number of sampling points. Use the diameter at the sampling site for determining the sampling point locations.

3. If the taper exceeds an included angle of 15^{o}, consider it a flow disturbance and:

a) modify the stack by adding a straght section at least 2.5 times its own diameter in length, or
b) treat the gas flow as non-parallel (see section on non-parallel flow).

REFERENCES

1. Fluid Meters, Their Theory and Application, Report of ASME Research Committee on Fluid Meters, 5 Ed, ASME, N.Y., 1959.

2. Personal Communication with Richard Lohr, Vice president, International Chimney Corporation.

3. Grove, J.D. and W.S. Smith, Pitot Tube Errors Due to Misalignment and Nonstreamlined Flow, Stack Sampling News, Volume 1, No. 5, pages 7 - 11, November, 1973.

SAMPLING IN DUCTS LESS THAN TWELVE INCHES IN DIAMETER

by

Robert F. Vollaro

With the August 18, 1977 revisions to Reference Methods 1-8, use of Methods 1,2,5, or 8 is not permitted in ducts less than 0.30 m (12 inches) in diameter or 0.071 m^2 (113 $in.^2$) in cross sectional area. This is due to the fact that, in ducts smaller than these limits, a standard probe assembly will block more than 10% of the cross-sectional area of the duct when fully inserted (Figure 3-4) As the velocity of the flowing gases in inversely proportional to the effective cross-sectional area of the duct, velocity readings taken by an s-type pitot tube attached to the probe will be biased high. At maximum probe insertion, this bias will be more than 10%.

If a duct smaller than twelve inches in diameter is encountered, there are three options which may be followed in order to obtain a valid test. These are: sampling at a constant rate, adding a stack extension, and taking remote velocity measurements. The latter method was devised by Robert F. Vollaro of the EPA, and his description of the method is appended to this section.

SAMPLING AT A CONSTANT RATE

For small ducts where the flow is expected to be uniform, velocity measurements and sampling may be done at the same site. Measure the velocity prior to testing, and base the sampling rate on that measurement. The velocity should be checked again following the test. If the before and after measurements differ by

more than ten percent the test results should be discarded. Monitoring of the probe's pitot lines — even though they are providing erroneous velocity readings— is useful to indicate any unexpected fluctuations in velocity during the test.

ADDING AN EXTENSION

For stacks with high flow rates, an extension 24 inches diameter will enable sampling with a standard pitobe assembly. Since this expanded extension introduces a flow disturbance, it should have a length equal to at least 2½, and preferably 10, times its diameter. Stack gas velocity, which is inversely proportional to the diameter squared, must be at least 600 feet per minute in the extension to enable use of s-type pitot tubes.

REMOTE VELOCITY MEASUREMENTS

To conduct representative sample traverses in ducts having diameters between 4 and 12 inches, it is recommended that the arrangement shown in Fig. 3-5 be used, in which velocity head (Δp) readings are taken downstream of the actual sampling site. The straight run of duct between the sampling and velocity measurement sites is necessary in order to allow the flow profile, temporarily disturbed by the sample probe, to redevelop and stabilize. The pitot tube and sampling nozzle shown in Figures 3-6 and 3-8 from those of a conventional pitobe assembly[1]; construction details of these components are discussed below:

A. Pitot tube

A standard (Type-P) pitot tube shall be used, instead of a Type-S, to monitor stack gas velocity. When D_s is less than 12 inches, a Type-S pitot tube can block

a significant part of the duct cross-section, and yield pseudo-high values of velocity head (Δp). Cross section blockage is not a serious problem with a standard pitot tube, however, for two reasons: 1) the impact and static pressure sensing holes of a standard pitot tube, unlike those of a Type-S, follow a 90° bend, and are located well upstream of the tube; 2) when properly aligned, the sensing head of a standard pitot tube is parallel, not perpendicular, to the flow streamlines in the duct.

The preferred design for the standard pitot tube is the Prandtl hemispherical-nosed design (Figure 3-6). Pitot tubes constructed according to the criteria illustrated in Figure 3 will have coefficients of 0.99 ± 0.01. [2,3] Note, however, that for most convenient tubing diameters (dimension "D", Figure 3-6) , the static and impact sensing holes of the Prandtl-type pitot tube will be very small, thus making the tube susceptible to plugging in particulate or liquid droplet-laden gas streams. Therefore, whenever these conditions are encountered, either of the following can be done: 1) a "back purge" system of some kind can be used to clean out the static and impact holes periodically during sampling; 2) a modified Prandtl pitot tube (Figure 3-7) which features enlarged impact and static pressure holes, can be used instead of the Prandtl-type. It has recently been demonstrated that the coefficients of the Prandtl and modified Prandtl pitot tubes are essentially the same.[4]

B. Sampling nozzle

The sampling nozzle can either be of the button-hook or elbow design. The nozzle shall meet the general design criteria specified in section 2.1.1 of the revised version of EPA Method 5, except that the entry plane of the nozzle must be at least 2 nozzle diameters (i.d.) upstream of the probe sheath blockage plane (see Figure 3-8).

The following procedures shall be used to perform sample traverses using the arrangement illustrated in Figure 3-5:

A. Location of sampling site.

Select a sampling site which is at least 8 duct diameters downstream and 10 diameters upstream from the nearest flow disturbances; this allows the velocity measurements site to be located 8 diameters downstream of the sampling location and 2 diameters upstream of the nearest flow disturbance. For rectangular stacks, use an equivalent diameter, calculated from the following equation, to determine the upstream and downstream distances:

$$D_e = \frac{2LW}{L + W}$$

Where:

D_e = Equivalent diameter

L = Length of cross-section

W = Width of cross-section

If sampling site located 8 diameters downstream and 10 diameters upstream from the nearest dis-

turbances is not available, select a site which meets these criteria as nearly as possible. Under no circumstances, however, shall a sampling site be chosen which is less than 2 diameters downstream and 2.5 diameters upstream from the nearest disturbances; this guarantees a minimum of 2 diameters of straight run between the sampling and velocity measurement sites, and 0.5 diameters between the velocity measurement site and the nearest flow disturbance.

B. Number of traverse points

The correct number of traverse points shall be determined from Figure 3-9. To use Figure 3-9, proceed as follows: first, determine the three distances, "A", "B", and "C", and express each distance in terms of duct diameters; second, read from Figure 3-9, the number of traverse points corresponding to each of these three distances; third, select the highest of the 3 numbers of traverse points, or a greater number, so that for circular ducts the number is a multiple of 4; for rectangular ducts, the number should be chosen so that the criteria of section "D" below can be met.

C. Location of traverse points, circular cross-sections

For circular stacks, locate the traverse points according to section 2.3.1 or Method 1. Any

traverse point located less than 1/2" from the stack wall will not be acceptable for use as a sampling point; all such traverse points shall be "adjusted" by relocating them to a distance of exactly 1/2 inch from the wall. In some cases, this relocation process may involve combining 2 adjusted traverse points to form a single "adjusted" point; thus, in some instances, the number of points actually used for sampling may be less than the number of traverse points obtained from Figure 3-9.

D. Location of traverse points, rectangular cross-sections

For rectangular stacks, divide the cross-section into as many equal rectangular elemental areas as traverse points. Follow Table 1-1 in Method 1 (August 18, 1977) to determine the arrangement of the equal areas. Locate a traverse point at the centroid of each elemental area.

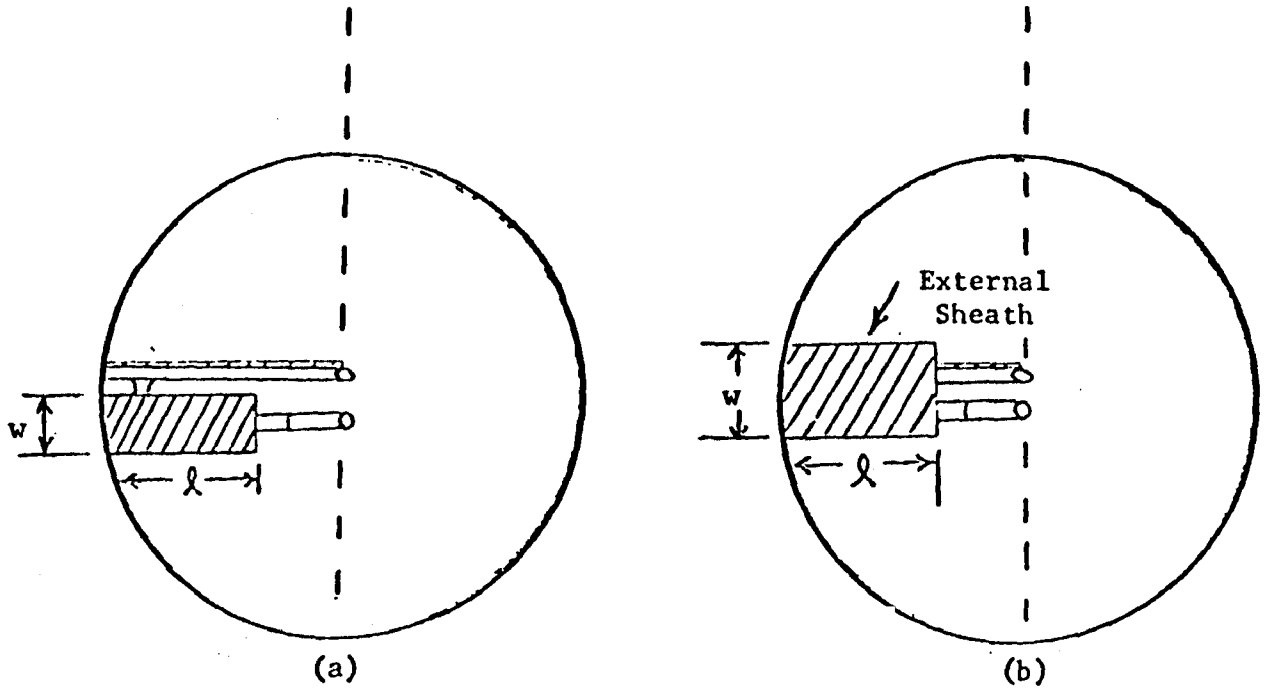
E. Sampling

Sample at each non-adjusted traverse point for the time interval specified in the method being used (e.g. Method 5). Sample at each "adjusted" point for the appropriate integral multiple of the sampling time at a non-adjusted point. For example, if the adjusted point represents the combination of two traverse points, sample twice as long at the adjusted point as at the non-adjusted points. During

each sample run, velocity head (ΔP) readings shall be taken at points downstream of, but directly in line with, the sampling points. The sampling rate through the nozzle shall be set based upon the ΔP readings; if a nomograph is used, be sure when setting it to use the correct value ($\sim$0.99) of the pitot tube coefficient.[5]

REFERENCES

1. Martin, Robert M. Construction Details of Isokinetic Source-Sampling Equipment. Environmental Protection Agency, Publication No. APTD-0851. Research Triangle Park, N.C. April, 1971.
2. Perry, Robert H., Cecil H. Chilton, and Sidney D. Kirkpatrick (editors). Chemical Engineers' Handbook, Fourth Edition. McGraw-Hill Book Company. New York, 1963.
3. Fluid Meters, Their Theory and Application. Published by the American Society of Mechanical Engineers. 5th Edition. New York, 1959.
4. Vollaro, R. F. Evaluation of Modified Prandtl-Type Pitot Tube, interoffice memorandum. U. S. Environmental Protection Agency. Emission Measurement Branch. Research Triangle Park, North Carolina. November 28, 1975.
5. Shigehara, R. T. Adjustments in the EPA Nomograph for Different Pitot Tube Coefficients and Dry Molecular Weights. U.S. Environmental Protection Agency. Emission Measurement Branch. Research Triangle Park, N. C. August, 1974.



$$\text{Estimated Sheath Blockage (\%)} = \frac{\ell \times w}{\text{Duct Area}} \times 100$$

Figure 3-3. Projected-area models for typical pitobe assemblies; shaded area represents approximate average sheath blockage for a sample traverse.

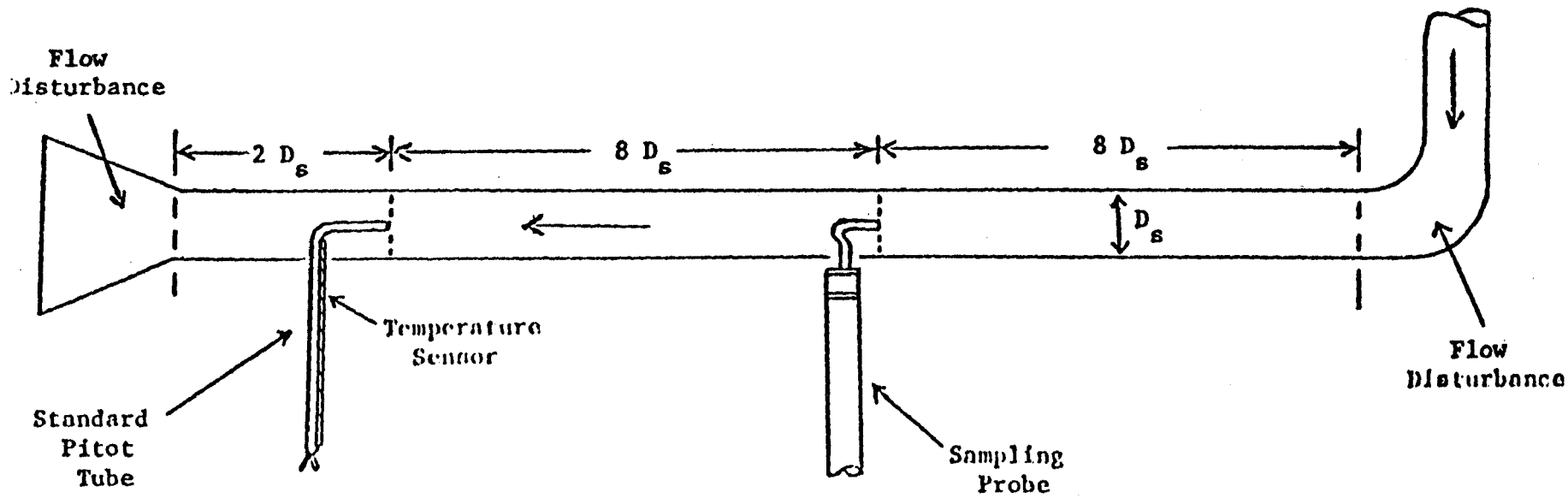


Figure 3-4. Recommended sampling arrangement, when $4" \leq D_s < 12"$.

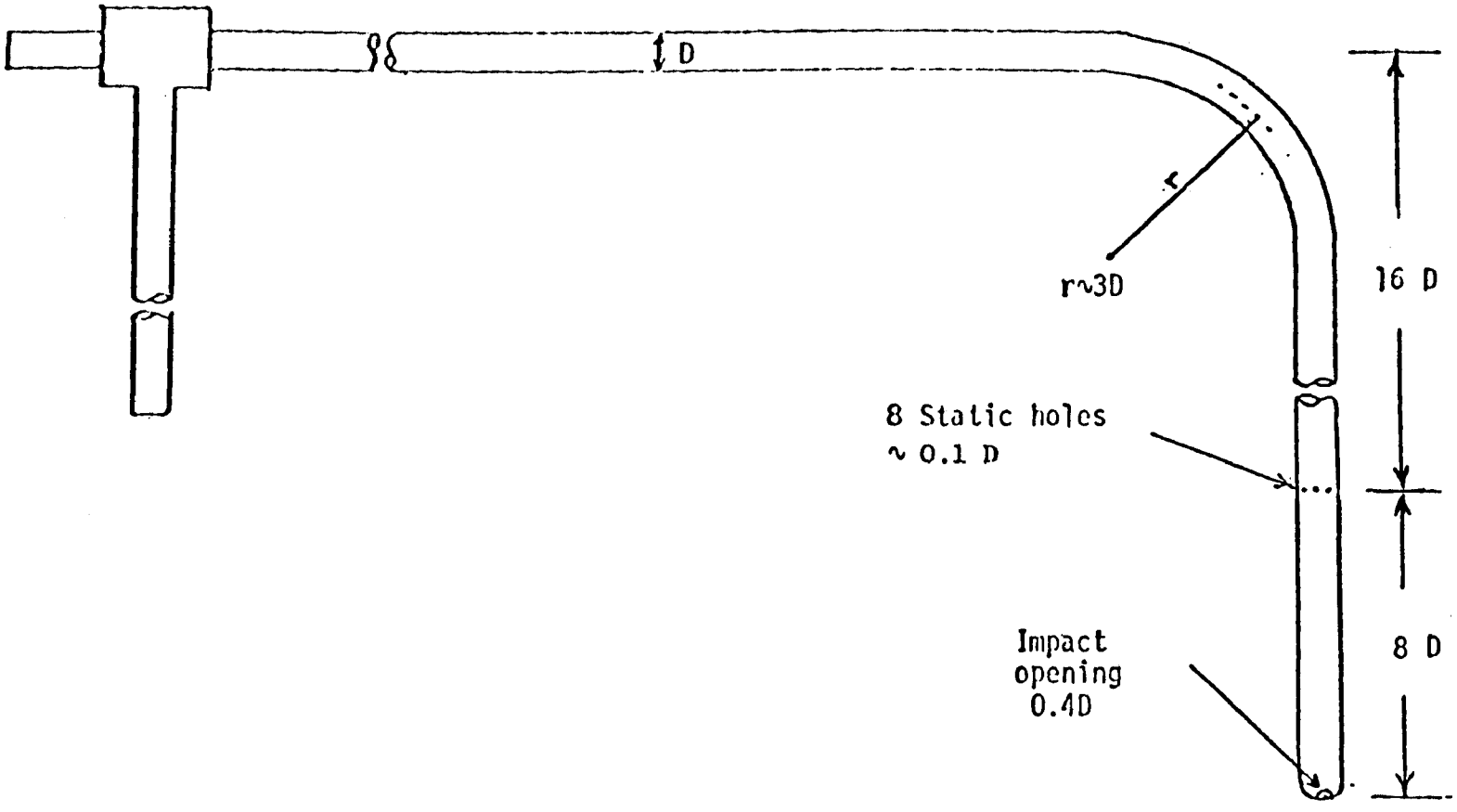


Figure 3-5. Prandtl hemispherical-nosed standard pitot tube.

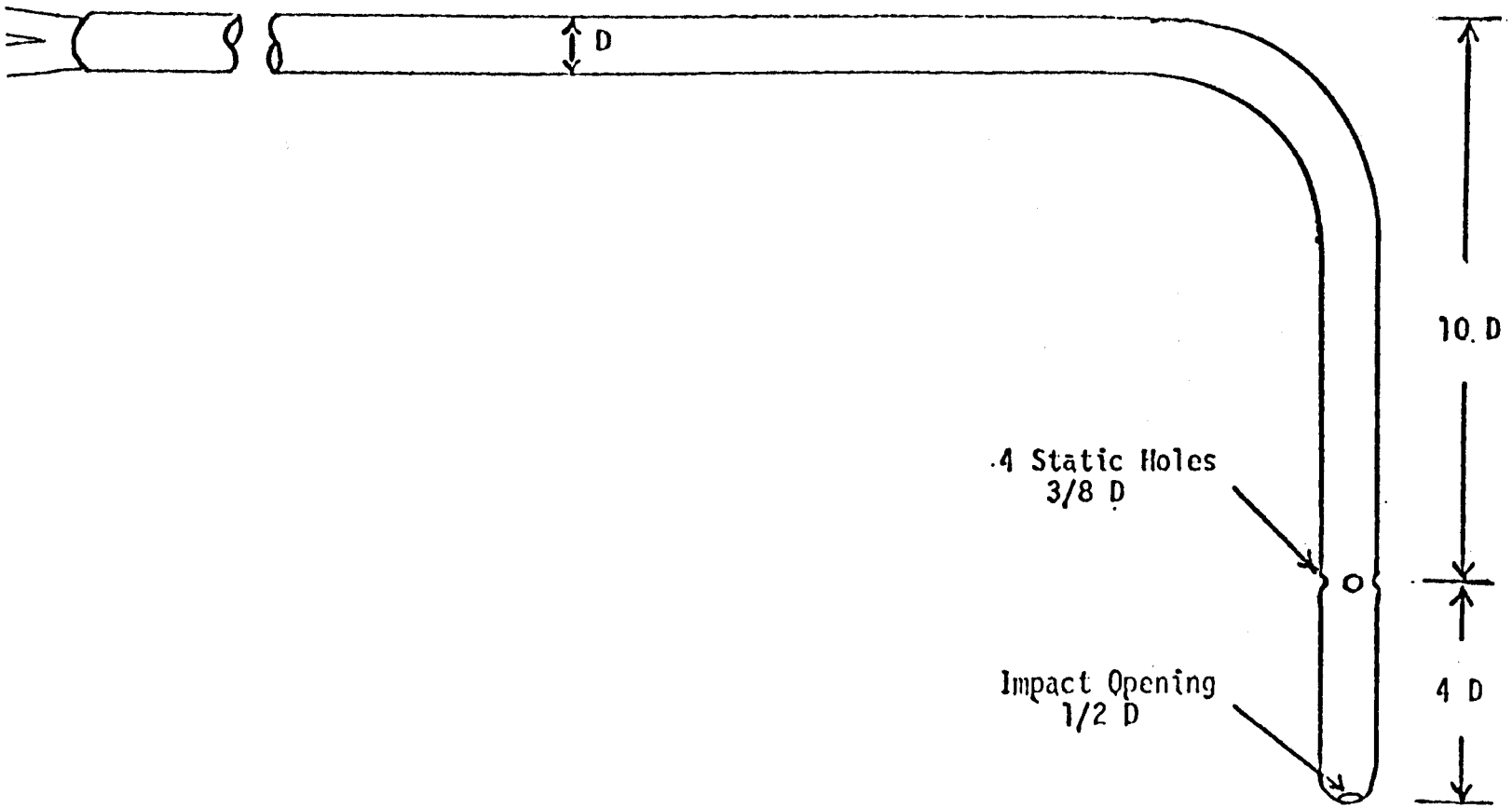


Figure 3-6. Modified Prandtl hemispherical-nosed standard pitot tube.

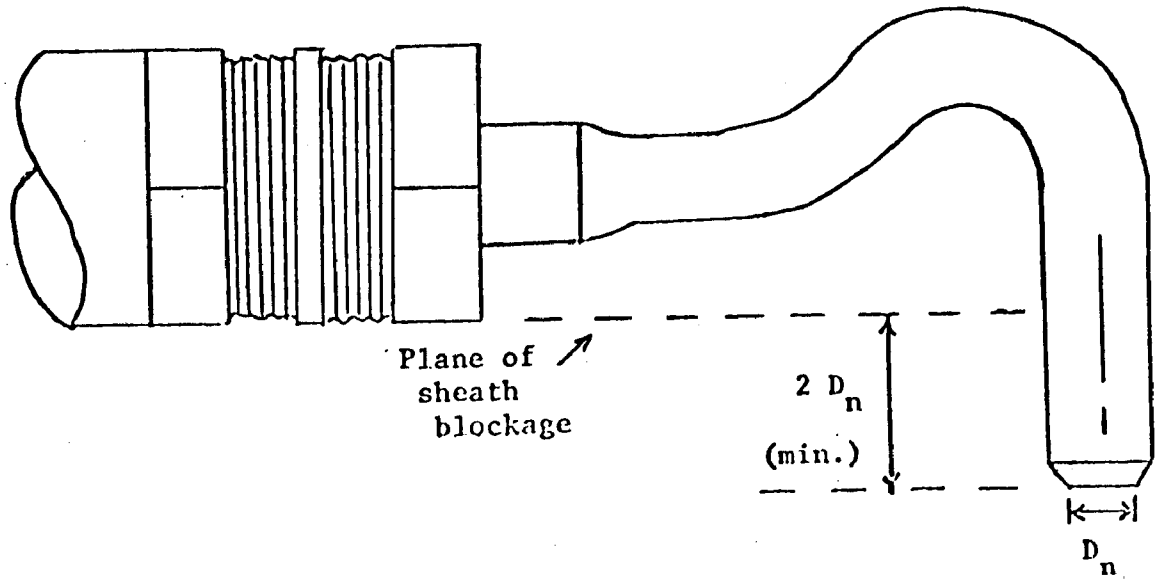


Figure 3-7. Recommended sampling nozzle design for use when $4" \leq D_s < 12"$.

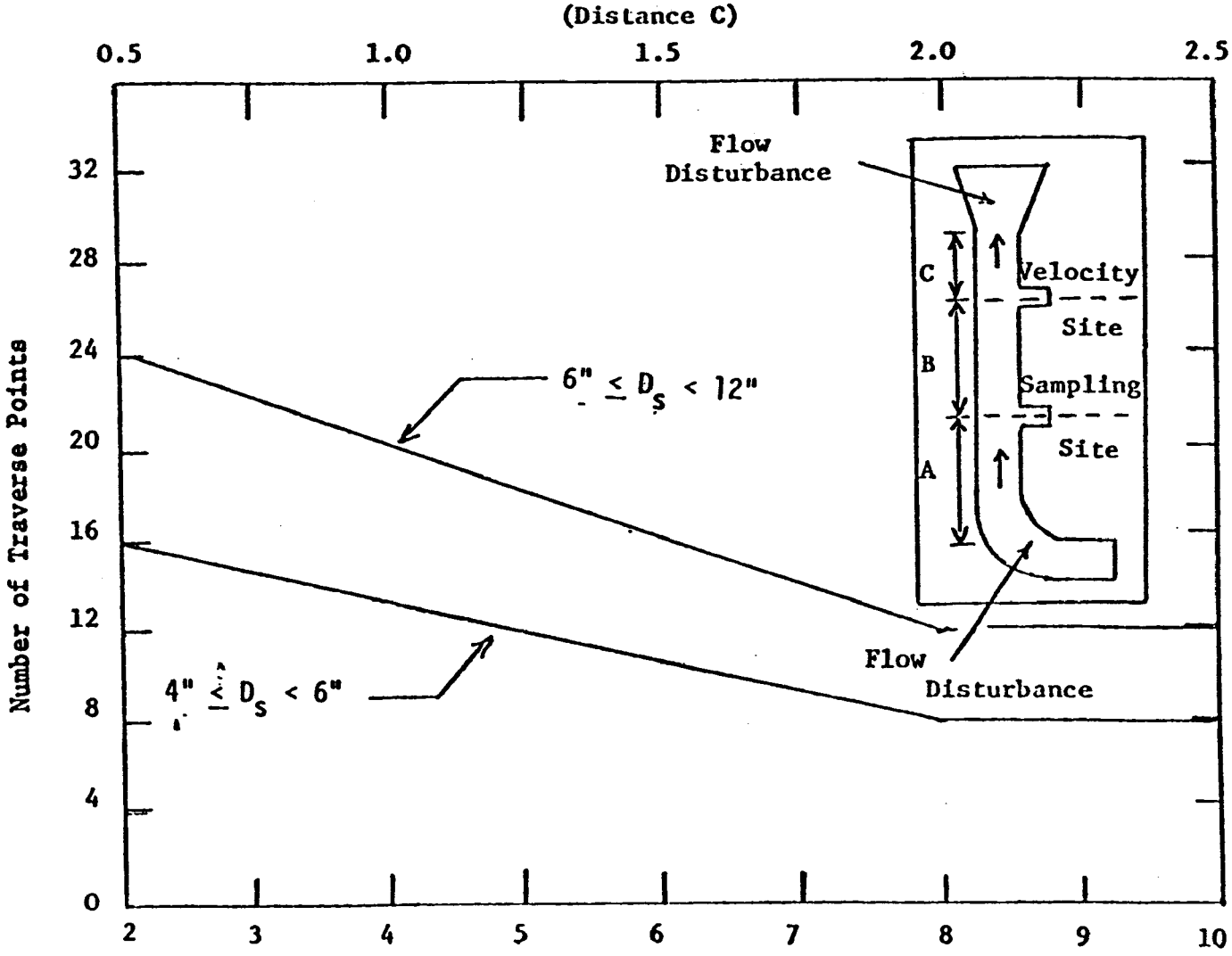


Figure 3-8. Minimum number of traverse points, $4" \leq D_s < 12"$.

SLIDE 309-0

NOTES

SAMPLING POINT LOCATION

SLIDE 309-1

METHOD 1 - CRITERIA FOR NUMBER OF SAMPLING POINTS

VELOCITY

minimum = 12
maximum = 24

PARTICULATES

minimum = 12
maximum = 48

SLIDE 309-2

RATIONALE FOR INCREASING THE NUMBER OF SAMPLING POINTS FOR NON-IDEAL SAMPLING LOCATIONS

In general, the more variation in any parameter being measured, the greater the number of readings required to obtain desired precision

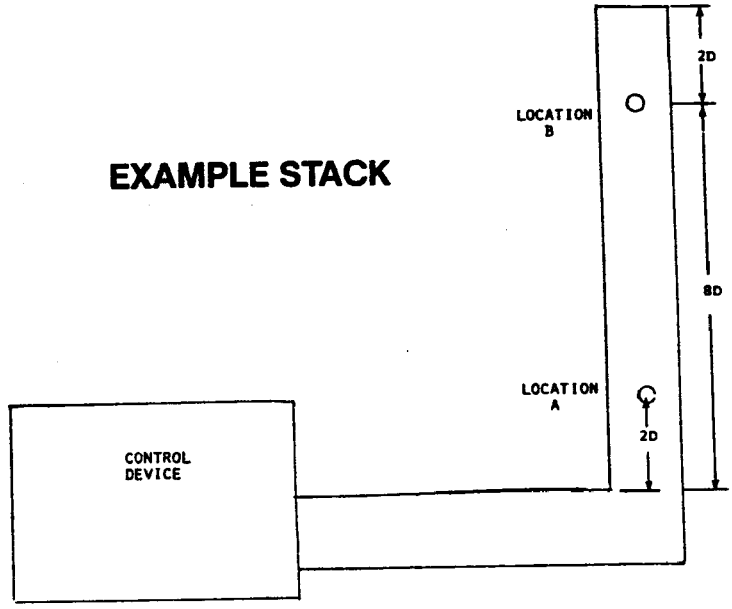
SLIDE 309-3

NOTES

FACTS ABOUT SAMPLING IN NONPARALLEL FLOWS

- measured particulate concentration will be biased low (less than true value)
- measured volumetric flow rate will be biased high (greater than true value)
- measured mass emission rate will have an undetermined bias
- measured gases pollutant concentration will not be biased

SLIDE 309-4



SLIDE 309-5

EXAMPLE STACK SOLUTIONS

SAMPLING POINTS REQUIREMENTS

location A — 48 sampling points
location B — 12 sampling points

RESULTS

location A — measured concentration likely lower
— measured flow rate likely higher

SLIDE 309-6

NOTES

RESULTS FROM INCREASING NUMBER OF SAMPLING POINTS

- will likely give a more precise measurement
- does not remove measurement bias
- makes the source test and agency observer more fatigued

Note: Never do less points than is legally required by the method

SLIDE 309-7

OPTIONS FOR TESTING AT SAMPLING LOCATIONS THAT DO NOT MEET METHOD 1 CRITERIA

option 1 — move to a new location

option 2 — sample in normal manner and results will be biased as previously noted

option 3 — use a compensation approach

SLIDE 309-8

COMPENSATION APPROACH

Agency should use all the same rationale and procedures as described in the cyclonic flow lecture

SLIDE 309-9

NOTES

NOTES OF INTEREST

EPA plans to reduce maximum number of sampling points required for particulate testing. Number will likely become the same as is now required for volumetric flow rate determination

SLIDE 309-10

RANKING OF OPTIONS

1. Change to an acceptable sampling location when feasible
2. Test in normal manner when agency must prove violation
3. Test using compensation approach when source must prove compliance

SLIDE 309-11

CONCLUSION

Suitability of sample location is more important than increasing above 24 the number of sampling points.

NOTE: this lecture assumes that there is no secondary particulate formation in the stack after sample location

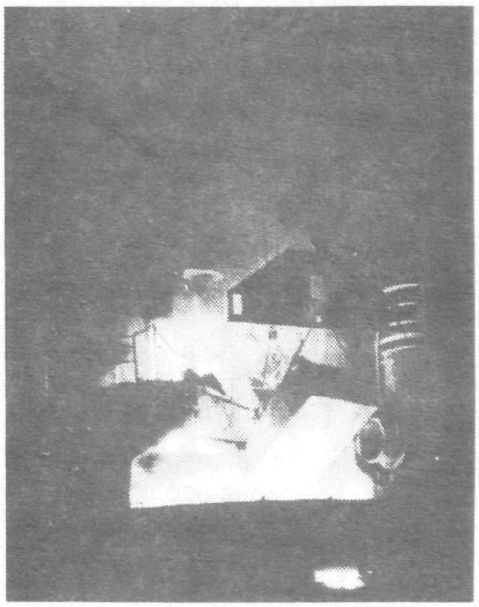
SECTION J. INTERMITTENT PROCESS OPERATION

SLIDE 310-0

NOTES

INTERMITTENT PROCESS OPERATION

SLIDE 310-1



SLIDE 310-2

ESTABLISH INTERMITTENT PROCESS OPERATION TESTING PROTOCOL

1. determine requirements and definitions of applicable emission regulation(s)
2. determine requirements and definitions of applicable test method(s)
3. determine source's normal or future normal mode of operation
4. establish testing protocol

SLIDE 310-3

NOTES

GENERALLY ACCEPTED "NO-NO'S" WHEN TESTING INTERMITTENT PROCESSES

DO NOT:

- start, stop, and restart sample run to select only certain portions of process cycle
- sample less than minimum sample volume or time requirement (usually one hour minimum)
- require source to modify normal operations to increase emissions

Note: The start, stop and restart technique may be used, but only in conjunction with mathematical correction of the final results for non-sampling time.

SLIDE 310-4

BEST SOLUTIONS FOR TESTING INTERMITTENT PROCESS OPERATION

- publish general procedures for sampling intermittent process operation
- publish specific procedures for every type of intermittent source category

SLIDE 310-5

TESTING COMPLETE PROCESS CYCLES

- set up sample time and points to complete run for minimum process cycle
- after all sample points have been tested, continue to sample at as many additional points as required to complete actual process cycle or normal process cycle

SLIDE 310-6

NOTES

CONCLUSIONS

- sampling protocols for intermittent sources are more of a legal decision than a technical one
- ensure support of agency attorney in testing protocol prior to actual test