

CHAPTER 6

MEASUREMENT OF INSPECTION PARAMETERS

In previous chapters, the use of various parameters to evaluate the performance of control devices has been suggested. In this chapter, the methods available for making these measurements will be discussed and recommendations on the most appropriate techniques and procedures will be made. Where appropriate, additional techniques for estimating some parameters will be given.

Measurement Ports

When a control system is first inspected, it is unlikely that measurement ports will be available. If some ports are available, they are not likely to be in the locations needed or of an appropriate size. The most likely port to be found is a 3 or 4 inch diameter sampling port located on or near the stack. Although a port in this location may be useful for some inspection measurements, ports of this size should, in general, be avoided. They present difficulties in sealing under both positive and negative conditions, and they may be quite difficult to open because of the large thread area.

The most useful port size for inspections is 1½-2 inches in diameter, and this size is needed only if measurements of velocity pressure are anticipated. For the more routine measurements of temperature and static pressure, ports of ¼-½ inch diameter will accommodate most measurement probes. The larger inspection ports will require the installation of a pipe stub with a threaded plug for closing. The smaller ports should simply be drilled and then covered with duct tape when not in use. Because of the potential for fire or explosion from sparks and because of possible damage to downstream equipment, the inspector should not request that ports be installed while the equipment is running. Rather, the locations and sizes needed should be marked for plant personnel, so that they may install them the next time the system is shut down.

Ports of a proper size may already be installed in some locations and used by the plant for continuous monitoring of certain parameters. In general, these ports should be avoided by the inspector. If they must be used, they should be opened only by plant personnel. Never open a port that was not placed there for your exclusive use. Plant monitoring ports may be connected to controllers that initiate equipment shut-down if the signal from them is lost.

Measurement ports are subject to the accumulation of material that may cause them to become plugged, even if they are on the clean side of the control device. Before using any

port, it should be cleaned out with a non-sparking rod to assure unobstructed access to the gas stream. Also, while making measurements the port should be sealed to prevent flow in or out around the probe. Flow into or out of the port may cause an interference with the measurements being made. For inspection ports, the best sealing technique is to insert the probe through a rubber stopper and then place that stopper into or against the port. For the larger stack-sampling ports, a rubber sanding disc may be used to cover the opening. The probe, equipped with a rubber stopper, would then be inserted through the center of the sanding disc, using the stopper to complete the seal.

Finally, the inspector should not make heroic efforts to reach existing ports and should not have ports installed in locations that cannot be reached and used in safety. This should include consideration of hazards to walking and climbing, as well as the potential for exposure to inhalation, vision, hearing, and fire and burn hazards.

Static Pressure Measurement

Static pressure measurements must be made with a square-ended probe placed at a right-angle to the flow direction. If measurements of velocity pressure are also being made, the static pressure ports on a standard commercial pitot tube that is oriented into the oncoming flow may also be used, as could one leg of the S-type pitot, if it is turned at a right-angle to its normal position. The purpose of the probe orientation is to be sure that no component of velocity pressure is impacting the probe during static pressure measurements.

The area between the probe and the port opening should be sealed to avoid errors associated with flow into or out of the duct. Errors resulting from improper sealing can be as large as 10-30 percent. Flow into the duct can result in an aspiration effect at the end of the probe that can increase (make more negative) the negative pressures being measured, while flow out of the duct can add a component of velocity pressure to the measurement of positive pressures. To further mitigate this problem, the probe should be extended well into the duct while making measurements.

There are two widely used techniques for sensing the pressures measured by the probe: (1) a U-tube manometer or (2) a Magnehelic[®] pressure gauge. The U-tube manometer is a reference instrument that is available in a flexible or slack-tube configuration, shown in Figure 6-1, to enhance its portability. The manometer is equipped with magnets at the top and bottom to facilitate temporary mounting and is equipped with threaded connectors that are used to seal the manometer during transport.

The manometer indicates the static pressure by displacing the fluid in the tube. In making static pressure measurements, one leg of the manometer is connected to the probe and the other is left open to the atmosphere. The height difference between the levels in the two columns is the pressure in height of fluid, usually expressed in inches of water. One of the principal difficulties with the U-tube manometer relates to the fluid. If the pressure in the duct exceeds the capacity of the manometer, fluid will either be drawn into the duct or blown

out onto the inspector. Also, the inspector must remember to close the seals when transporting the manometer to prevent loss of fluid and to open them before making a measurement.



Figure 6-1. Slack-tube manometer

The Magnehelic[®] pressure gauge, shown in Figure 6-2, is a product of Dwyer Instruments, Inc. It senses pressure difference by deflecting a silicone rubber diaphragm and then translating that deflection to a needle indication through a magnetic linkage. Although not as accurate as the U-tube manometer, it is much more forgiving, making it easier to use in field situations. The Magnehelic[®] is accurate to within 2 percent of full scale and has a high resistance to shock and vibration. It is available in over 70 ranges, from 0-0.25 in. H₂O to 0-20 psig. The most useful ranges for ventilation system inspection are 0-5, 0-20 and 0-50 in. H₂O. For inspection of high pressure drop wet scrubber systems, a 0-100 in. H₂O range may be needed.

Except for the 0-0.25 and 0-0.50 in. H₂O ranges, the Magnehelic[®] may be used in any orientation and can accept pressures up to 15 psig without being harmed. This property allows gauges with different ranges to be combined in one instrument package, with the gauge giving the most readable indication used for recording the measurement.

Because of the silicone rubber diaphragm, the ambient temperature range is limited to 20° to 140°F. This lower limitation can be accommodated when conducting inspections in cold environments by keeping the gauge in a location that is within the range and then taking it out briefly for making the measurement. For extended use under cold conditions, gauges with a lower temperature limit of -65°F are available on special order.

The Magnehelic[®] is not a reference instrument, so its calibration should be checked periodically. The simplest way of doing this is to check its indications against a U-tube manometer, using the set-up shown in Figure 6-3. Using a laboratory squeeze-bulb equipped with check valves, pressures from -40 to +40 in. H₂O can be easily generated. The Magnehelic[®] indications should be plotted against those of the manometer to check for accuracy and linearity. Gauges that give inaccurate or non-linear indications should be

discarded. Also, while using the gauge its zero should be checked frequently and adjusted as needed using the set-screw on the front plate. Adjusting the zero will not affect the calibration of the gauge.

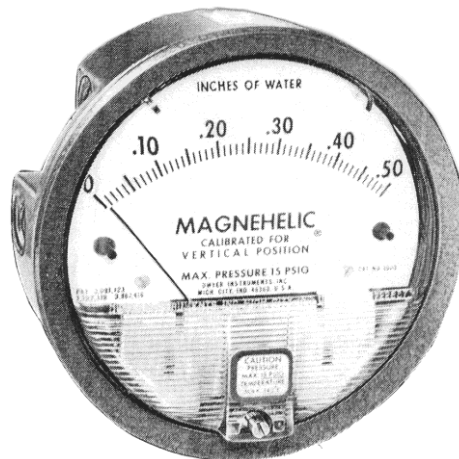


Figure 6-2. Magnehelic® pressure gauge

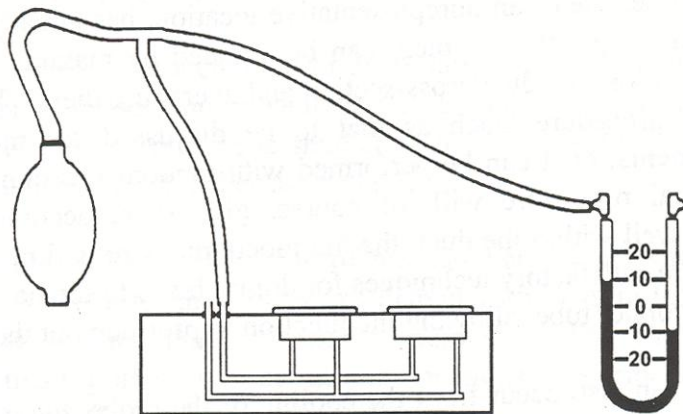


Figure 6-3. Magnehelic® calibration apparatus

Temperature Measurement

There are several techniques available for measuring temperature, including: (1) mercury thermometers, (2) dial thermometers, (3) thermistors and (4) thermocouples. Unfortunately, each of these techniques has some limitation when applied to the inspection of air pollution control systems. The mercury thermometer is constructed of glass and is subject to breakage,

with resulting exposure to a toxic material. Also, both the mercury and dial thermometers have a limited probe extension, making the measurement of temperatures across large ducts impossible. Since locations near the wall of a hot duct will be cooler than near the center, measurements made there may not be representative of actual temperatures. The thermistor, which measures temperature through the change in resistance of a fine wire sensor, is easy to use but its response becomes non-linear over some part of its temperature range, making data interpretation difficult. Finally, the potentiometer used to measure the output of a thermocouple is not available in an intrinsically-safe construction and cannot be used in areas where explosive or ignitable materials may be present.

Despite its limitations, the thermocouple is recommended as the primary method for measuring temperatures in the inspection of air pollution control systems. In situations where explosive or ignitable materials may be present, use of the dial thermometer is suggested, but the inspector should be aware of the potential problems in obtaining representative measurements on large hot ducts. The thermocouple sensor is formed by joining two wires made of different metals or alloys. If the junctions at the ends of these two wires are then held at different temperatures, an electric current flows in the wire loop. This current is produced by an electromotive force whose value depends on the difference in temperature between the junctions.

The electromotive force generated by a thermocouple is measured with a potentiometer. A variety of metals and alloys are used in the construction of thermocouples, providing for measurements over different temperature ranges. The most common thermocouple, and the one recommended for use in inspections, is Type K. The Type K thermocouple has a temperature range of -400°F to $+2,300^{\circ}\text{F}$ and is constructed with a positive wire of chromel and a negative wire of alumel. Most hand-held potentiometers are calibrated for certain thermocouple types and internally convert the measured electromotive force to a temperature indication.

The thermocouple/potentiometer is not a reference instrument and must be calibrated against a National Institute of Standards and Technology (NIST) traceable thermocouple to assure highest accuracy. Since the equipment required to do this is expensive and not likely to be available to the inspector, it may be necessary to send the unit to a specialized laboratory for calibration. For most inspection situations, however, high accuracy is not required. In these cases, an acceptable evaluation of instrument accuracy may be conducted by checking its response in an ice bath and a boiling water bath. Under frequent use, this check should be done on a weekly basis. For less frequent use, it should be done prior to taking the instrument into the field.

There are several potential sources of error in making temperature measurements. One of these, use of an unrepresentative location, has already been mentioned. With the thermocouple this problem can be avoided by making measurements at several locations across the duct cross-section and averaging them. This can be done through a formal procedure, such as that used for making velocity pressure measurements, or it can be performed with random locations and mental averaging. The formal procedure will, of

course, give more accurate averages. To reach locations well within the duct, the thermocouple wire will need to be supported. One of the more satisfactory techniques for doing this is to thread the wire through a small diameter copper tube, allowing the junction to protrude out the end.

Problems can also occur from the cooling of the probe due to air infiltration through the port or through leaks into the duct upstream of the measurement point. The former problem can be avoided by sealing the port in the manner described in the section on static pressure measurements. In addition, if a copper tube is used to support the thermocouple, it could be bent slightly so that it extends into the oncoming gas stream. To avoid problems from upstream leaks, the area near the measurement location should be inspected for holes in the duct or leaks in inspection hatches or expansion joints. If these are found to exist, the measurement location should be changed to an area where these leaks will have mixed into the flow. If this is not possible, the number of measurement points used to obtain an average should be increased.

Measurements downstream of evaporative coolers or wet scrubbers can be complicated due to the presence of water droplets. As these droplets impact on the sensor, the temperature will vary between the dry-bulb and wet-bulb values. However, since the degree of wetting will not be known and cannot be controlled, the exact condition of the measurement cannot be ascertained. Under these conditions, the most reasonable option is to shield the sensor from the water droplets. It should be realized, however, that doing this will likely slow the response of the sensor, requiring longer times to make the measurements.

Oxygen Measurement

Techniques for the measurement of the oxygen concentration in a gas stream include: (1) an Orsat analyzer, (2) a Fyrite[®] analyzer and (3) an electroconductivity analyzer. The electroconductivity analyzer determines the concentration of oxygen and other gases by bubbling the sampled gas stream through a liquid-filled cell and measuring the change in conductivity of the fluid as a result of gas absorption. In general, each gas requires a specific conductivity cell for its measurement. This instrument is moderately expensive and not likely available to compliance personnel, so it will not be discussed further.

In addition to oxygen, the Orsat analyzer can also measure carbon monoxide and carbon dioxide. The technique involves measuring the change in the volume of a gas sample as it is sequentially contacted with different absorbent fluids. The analyzer is cumbersome and somewhat fragile. The measurement method is time consuming, and the results of the analysis are influenced by the operator's skill. For these reason, the Orsat analyzer is not recommended for field inspections.

The Fyrite[®] analyzer is a product of Bacharach Instrument Company. Like the Orsat analyzer, the Fyrite[®] analyzer measures gas concentrations using an absorption technique. The absorbing fluids are similar to those used in the Orsat, but they are enclosed in separate,

self-contained units. There are units for oxygen and carbon dioxide, but not for carbon monoxide. Each unit is about 7½ inches tall and 3½ inches in diameter. The fluid used in the oxygen unit is a mixture of cuprous chloride, zinc chloride and hydrochloric acid and usually lasts for 50 to 100 measurements. The fluid in the carbon dioxide unit is potassium hydroxide and usually lasts for 200 to 400 measurements. Since both solutions contain corrosive constituents, care must be exercised when changing them.

A cutaway sketch of a Fyrite[®] analyzer unit is shown in Figure 6-4. The plunger valve is depressed from the top with a fitting on the sampling line, and the gas stream to be tested is pumped into the top reservoir using a battery- or hand-powered pump. Once a representative sample is obtained, the plunger valve is released and the unit is inverted several times to mix the solution with the gas. Absorption of the component being measured causes a pressure decrease in the unit, drawing the fluid up into the center column. A scale along the side of the center column indicates the concentration in percent.

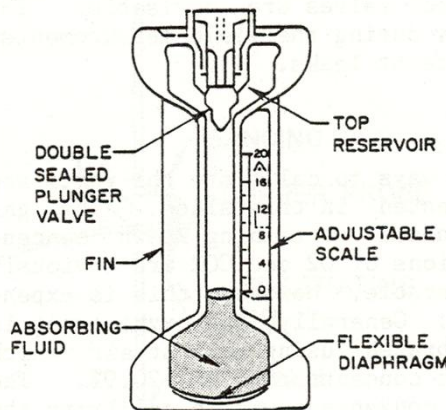


Figure 6-4. Cutaway of Fyrite[®] analyzer unit

The absorption of gases is a temperature dependent process. It is important that the solution be at approximately the same temperature as the sample being tested. If the solution is colder, the observed reading will be higher than actual. Conversely, if the solution is warmer, the observed reading will be lower than actual.

The analyzer can be calibrated using gas cylinders containing known concentrations of oxygen and carbon dioxide. While this assures an accurate calibration, it is expensive. For inspection purposes, the oxygen unit is typically calibrated using ambient air, which has a concentration of 20.9 percent. The carbon dioxide unit is calibrated using exhaled breath, which has a concentration of 4-5 percent. In each case, the position of the indicating scale is adjusted to the calibration value.

One quick check on the accuracy of measurements is to sum the oxygen and carbon dioxide concentrations. As shown in Table 6-1, the value of the sum should fall within a certain range, depending on the type of fuel being fired. The sum of oxygen and carbon dioxide

concentrations in exhaled breath should fall into the same range as for wood fired boilers. If the sum of the measurements does not fall into the indicated range, a measurement error has probably occurred, and the measurements should be repeated. If the sum still does not fall within the appropriate range, one or both of the solutions may be exhausted.

Table 6-1. Checking O₂ and CO₂ Measurements

Fuel	Sum of O₂ and CO₂ (%)
Natural Gas	13-19
#2 Oil	15-20
#6 Oil	17-20
Bituminous Coal	18-21
Lignite	18-21
Anthracite Coal	19-21
Refuse	18-22
Wood	18-22

pH Measurement

Two common ways to measure pH include the battery- or line-powered meter and indicator paper. Meters are usually accurate to within ± 0.1 pH, while the indicator paper is only accurate to about ± 1.0 pH. Intrinsically safe meters are available for use in situations where explosive or ignitable materials may be present; however, they are not necessary. The meter can be kept in a safe location and the sample taken to the meter for analysis.

Usually, the accuracy available with a meter is not necessary for inspections, making indicator paper an acceptable alternative. Indicator paper is adequate whenever the liquid does not contain strong oxidizing agents, is not highly colored, and there is not a high concentration of colloidal matter.

Prior to each set of measurements, the pH meter should be calibrated using buffer solutions with pHs of approximately 4, 7 and 10. Indicator paper should also be checked using these three buffer solutions. If the paper has aged, it will no longer work properly.

Use of Grounding Cables

When working with portable instruments in areas where potentially explosive or ignitable materials are present, all metal probes should be grounded to the duct to avoid a static discharge. The most satisfactory technique is to use a stranded cable with a pipe clamp attached to one end and a spring-loaded jaw clamp on the other, as shown in Figure 6-5. The pipe clamp is firmly attached to the probe and the jaw clamp is attached to the duct, usually at a flange or support. Care should be taken to assure a good connection at the duct and that all

paint and rust has been penetrated. One way to check the connection would be to measure the resistance between the probe and the duct using an explosion-proof ohmmeter. If the resistance is less than 3 ohms, the connection is good. Guidance on when to use grounding cables is provided by the following list:

- When the moisture content of the gas stream is low.
- When the gas stream velocity across the probe is high.
- When the gas stream contains a relatively high mass concentration of small-sized particles.
- When there is the possibility of dust deposits in the bottom of the duct.
- When there is any question about the need for a grounding cable.



Figure 6-5. Typical grounding cable

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