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APPLICATION NOTE

Sample Conditioning for Portable Gas Analysers

Summary

Various commercial sample conditioning systems exist for use with the portable flue gas analysers. This document describes the general considerations to be made when selecting a method for flue gas sample conditioning.

Introduction

All extractive analysers draw a small sample of the stack gas; this extracted gas can contain a large amount of water vapour and particulate matter. The moisture content in the sample is a by-product of the combustion process, the humidity of the air in the process and the water content of the fuel. In order to maximise measurement accuracy and optimise equipment reliability it is essential that the particulate and water in the gas sample are removed.

In addition to this it may also be necessary to protect some gas sensors from some of the components of the stack gas sample in order to prevent sensor damage or cause large errors due to cross sensitivity.

- ***Particulate Removal***

When the sample is extracted from the stack it may contain particulate in the form of grit or fine dust particles. Portable gas analysers are typically used on many different types of industrial process; the quantity and type of particulate is very dependent on this process therefore the analyser must be designed cope with a wide variety of situations. The particulate must not be allowed to travel into the analyser sampling system as it may cause a blockage or even damage to some of the internal components. To minimise the maintenance requirement it is therefore essential that particulate is removed from the gas sample prior to entering any narrow bore tubing, solenoids, pumps, sensors etc.

- ***Water Removal***

In most combustion processes the gases extracted from the flues contain a significant amount of water vapour. As the flue gas is drawn into the sampling probe and line of the analyser it starts to cool, and at some point condensation occurs. This moisture then flows down the sample line into the analyser catchpot or cooler. During this time sample gas may be in contact with the moisture for several seconds.

NO_2 and SO_2 are soluble in water; therefore if accurate measurements are to be made it is important that the gas sample is dried before the water starts to condense in the system, to ensure that none of these soluble components are lost in the condensate.

$$2SO_2 + O_2 \longrightarrow 2SO_3 \qquad SO_3 + H_2O \longrightarrow H_2SO_4$$

$$H_2O + NO_2 \longrightarrow H_2NO_3$$

The solubility of the gases is temperature dependent; Table 1 shows the relative solubility of both NO_2 and SO_2 with water at different temperatures

Gas	Solubility in 100 parts cold water (0° C/32 °F)	Solubility in 100 parts hot water (100 °C/212 °F)
NO_2	7.34	0.0
SO_2	22.8	0.0

Table1: Solubility of NO_2 and SO_2 with water

To overcome these losses and maintain the accuracy of sampling ideally the temperature of the gas sample should never be allowed to fall below the dewpoint which is normally above 100 °C/212 °F. Unfortunately it is not practical to operate most sensors at such temperatures therefore a system must be introduced to remove the water from the sample that does not affect the constituent gas concentrations.

- ***Other Sample Conditioning***

To maximise analyser accuracy and sensor life it is also essential to protect the individual gas sensors from constituent parts of the gas sample to which they may also be sensitive, or which may permanently damage or reduce the life of the sensor.

Practical Considerations

- ***Particulate Removal***

It is good practice to include a sintered filter on the sample probe tip to remove coarse particulate, and a further in-line filter to remove fine particulate.

The sintered filter must be simply removed from the sample probe for cleaning or replacement. It is essential that the condition of the fine particulate filter can be easily monitored and when necessary that it can be replaced easily

- ***Moisture Removal***

The key to success of the system is being able to condense the water from a wet sample with a minimal loss of the gas sample to be measured. Typically the approach is to maintain the sample above dewpoint and then to rapidly cool it to extract most of its moisture content.

Gas sample drying can be performed by the following methods:

- Expansion system
- Peltier or thermoelectric dryer system
- Permeation Dryer system
- Advanced Passively Cooled Expansion system

Expansion Systems

Expansion systems are suitable for removing modest amounts of moisture from the flue gas. These systems initially use air cooling of the sample as it passes through the sample probe and line, the gas then enters a chamber (which usually doubles as the water catchpot) where the gas rapidly expands causing further cooling. This additional cooling effect causes the moisture in the gas to condense and form droplets that can be collected in the analyser catchpot. Typical configuration is shown in Figure 1. The expansion chamber may be integrated in the analyser or fitted separately, depending on product design.

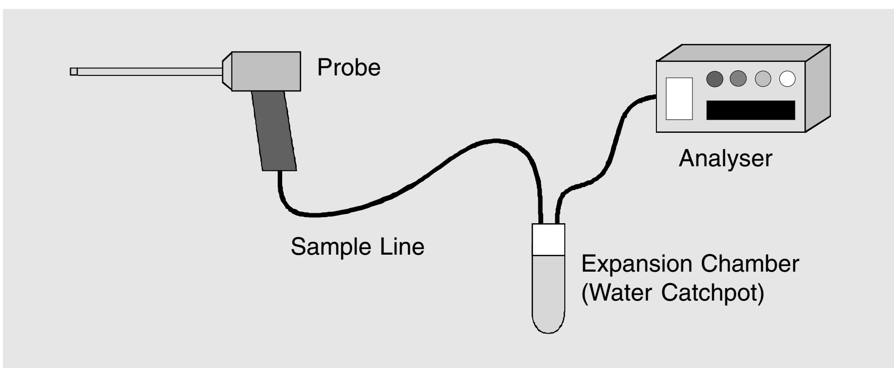

Figure 1. Expansion System

These systems are simple, inexpensive and are included with most portable gas analysers. However care must be taken to ensure that moisture does not collect in the sample hose as this will significantly degrade the performance when measuring soluble gases (e.g. SO_2, NO_2) due to absorption of the flue gas in the standing water.

Independent tests[1] have proved that this type of system can provide accurate measurements of both NO_2 and SO_2 for most industrial applications, provided the instrument is well designed.

Advantages

- Low cost
- Low maintenance
- Highly portable

Disadvantages

- Uncontrolled performance often not reported by analyser manufacturer
- Not suitable for high concentrations of water
- Relies of design of analyser to ensure optimum performance

Peltier / Thermoelectrically Cooled Systems

Traditional thinking prescribed that effective moisture removal can only be performed by rapid cooling of the hot sample. In order to achieve this, most commercially available sample dryers employ a peltier or thermoelectric cooler to lower the sample temperature to around 2 to 4 °C / 36 to 39 °F. There are two configurations offered for this kind of system

- Integrated Cooler
- Sample Probe mounted Cooler

Stand-alone/Integrated Thermoelectric Cooler

The stand-alone/integrated cooler design requires that the gas sample must be delivered to the gas dryer hot. In order to do this a heated sample line must be used (and for optimal performance a heated probe) (See Figure 2). Care must be taken at any joints between the probe, sample line, and the dryer to ensure that there are no cold spots occur. Condensation will occur in these areas which will lead to absorption of the soluble gases and render the cooling element less effective. The cooler must be designed such that it rapidly cools the sample causing water to condense and form large droplets as fast as possible. It is absolutely essential that a water mist does not occur as these small water droplets present a large surface area to the soluble gases with which they will then readily recombine. A poorly designed cooler will remove a significant amount of the soluble gases and its performance is often found to be worse than that of an expansion system. High performance coolers are usually packaged separately from the analyser, although some manufacturers have integrated systems.

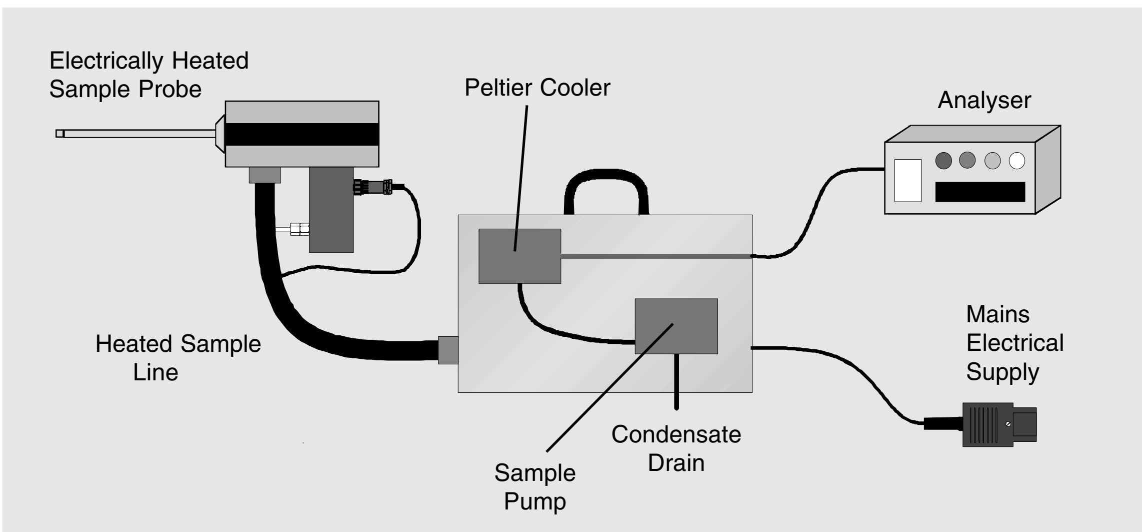

Figure 2. Peltier, Stand-alone thermoelectric cooler

Advantages
- Controlled cooling
- Usually include an automatic condensate drain
- Can give higher performance drying

Disadvantages
- Heavy / bulky - not truly portable
- Require mains electric power at the point of measurement
- Requires heated line - inconvenient and can be unreliable
- Expensive

Sample Probe Mounted Thermoelectric Cooler

Mounting the cooler in the sample probe means that a heated line is no longer required (See Figure 3). However typically these devices consist of several modules (e.g. Cooling device mounted to probe; separate catchpot and water removal system; power supply)

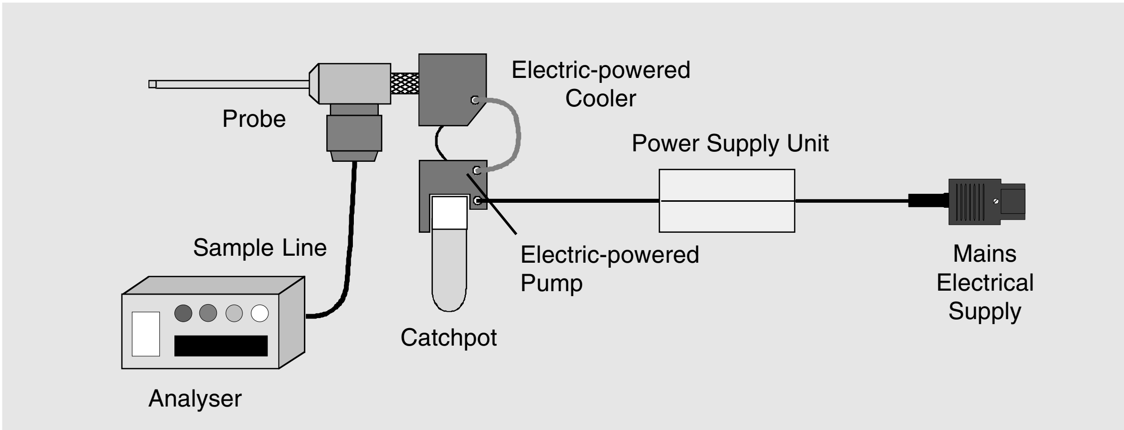

Figure 3: Sample Probe Mounted Thermoelectric Cooler

Advantages

- Controlled cooling
- Usually include an automatic condensate drain
- Can give higher performance drying

Disadvantages

- Lots of separate parts - Heavy, clumsy and inconvenient to use
- Require mains electric power at the point of measurement
- Expensive

Permeation Dryer System

The permeation dryer system is an alternative solution for sample drying. In a permeation dryer the flue gases pass through a selectively permeable membrane for moisture removal. This special material (Nafion[2]) is highly selective in the removal of water and is produced in the form of a tube through which the gas sample is passed. The water moves through the membrane wall and evaporates into the surrounding air or gas in a process called pre evaporation. The process is driven by the humidity gradient between the inside and the outside of the tubing.

Permeation dryers are usually heated, to prevent the Nafion becoming wet. A pump is often required to drive the "drying" air over the tube. The tubing material is easily sucked flat meaning that they do not work in negative pressure arrangements.

Permeation Dryers can be configured two ways:

- Stand alone Dryer
- Sample Probe mounted Dryer

- ***Stand-alone Permeation Dryer***

The stand alone dryer design requires that the gas sample must be delivered to the dryer hot. In order to do this a heated sample line must be used (and for optimal performance a heated probe). Care must be taken at the joint between the probe and the heated line, any joins in the heated line and the joint between the heated line and the dryer to ensure that there are no cool spots, as condensation will occur in these areas which will lead to absorption of the soluble gases. The drying unit is usually contained in an enclosure which requires mains electric power. The arrangement is similar to that shown for the Probe mounted dryer (Figure 4), but with the dryer in a separate case.

Advantages
- High performance
- Condensate easily removed

Disadvantages
- Requires heated line - inconvenient and can be unreliable
- Heavy
- Mains electric power required at point of measurement
- Cannot be used in negative pressure application
- Performance reduces with time making it less effective
- Not very effective in high ambient humidity environments
- Expensive

- ***Sample Probe Mounted Permeation Dryer***

Mounting the dryer in the sample probe means that a heated line is no longer required (See Figure 4). However mains power may be necessary for operation at low ambient temperatures.

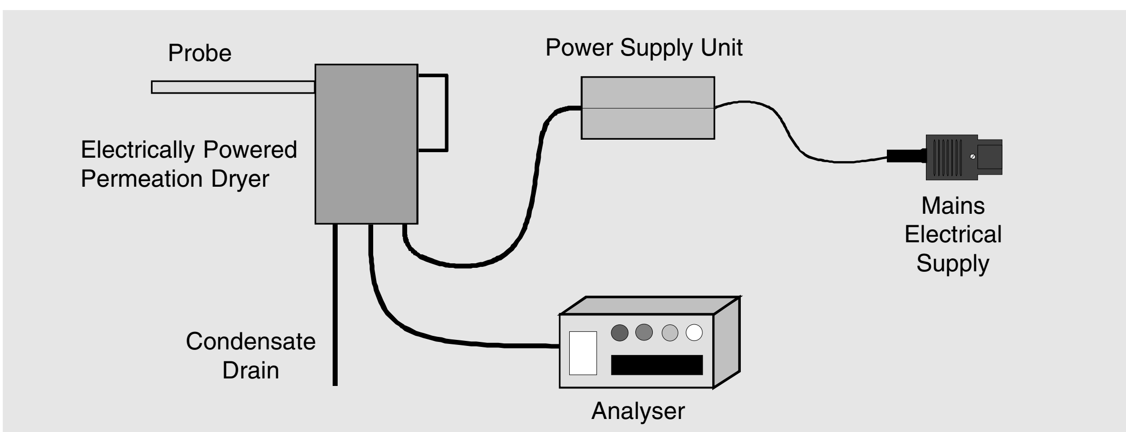

Figure 4: Probe Mounted Permeation Dryer

Advantages
- High performance
- Condensate easily removed

Disadvantages
- Requires mains electric power in most applications
- Heavy
- Complex
- Not suitable for high moisture (>25%) concentrations
- Cannot be used in negative pressure applications
- Performance reduces with time making it less effective
- Not very effective in high ambient humidity environments
- Expensive

- ### *Advanced Passively Cooled Expansion Dryer System*

An advanced passively cooled expansion system is the newest solution to sample drying for portable gas analysers. The system separates the water from the gas sample in an impinger which has a highly polished cylindrical cooled surface (See Figure 5). The hot wet sample is brought to the bottom of the cylinder through an insulated tube travels through a narrow annulus which allows to sample to retain its temperature and increase its flow velocity. The sample path is designed so that the gas is subjected to a rapid change of direction as it enters an expansion chamber where it is also influenced by the cold surface. This rapid expansion, cooling and centrifugal type effect ensure that the water very rapidly condenses on the metal surface of the impinger. The condensate falls down the cold polished surface in the form of a sheet (as opposed to droplets) which exposes minimal surface area in contact with the gas sample. The condensate then passes into a narrow bore catchpot further ensuring minimal surface area for potential contact between the sample and the condensate. Passive cooling is provided using an endothermic chemical reaction. This can be implemented using self contained disposable packs readily available at low cost at most high street pharmacies (typically sold for sports injury use). As an alternative, iced water can also be used.

The system requires no moving parts or electrical power and therefore requires no routine maintenance. It is simple to use and inexpensive to purchase and operate.

Independent tests on a commercially available system[3] have proven to provide accurate measurements of both NO_2 and SO_2 even in the presence of high water vapour content.

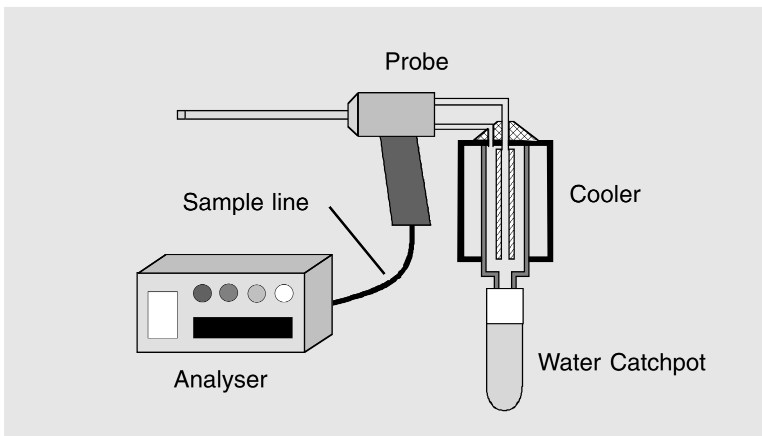

Figure 5. Advanced Passively Cooled Expansion Dryer System

Advantages
- Proven high performance
- Highly portable
- No electrical power required
- No maintenance
- Low Cost

Disadvantages
- New technique
- Consumable cooling

Other Sample Conditioning

There are two common methods for protecting sensors from gases that may either damage them or affect their accuracy (cross interference effects). These are:

- In-line chemical filter
- Sensor mounted chemical filter

Both of these methods use disposable chemical filters that have a finite usage life. It is essential to replace the filters before they become fully inactive if the gas sensors are to remain protected.

- ***In-line Chemical SO_2 Filters***

In-line chemical SO_2 filters can be used to protect several sensors simultaneously. The filter comprises a quantity of coloured beads of filter material. These beads change colour when they require replacement. With careful analyser design they can be easily installed, replaced and more importantly their condition can be easily monitored ensuring the filter is replaced before it is spent.

- ***Sensor Mounted Chemical Filters***

Electrochemical sensors generally include a chemical filter to protect them from damage or cross interference from other gases in the gas sample. In some of the newer sensors these filters are replaceable therefore lengthening the useable life of the sensor. However with both types of sensor there is no visible indication that the filter requires replacement. An indication is only received when the analyser readings become inconsistent.

Conclusion

All good portable gas analysers must include a sample conditioning system to ensure accurate gas measurement and optimum analyser performance. Methods of particulate removal and chemical protection are well defined, and simple to implement in a portable analyser, sample drying however is complex. Cooling by expansion is simple and effective but is not accepted by many Environmental Authorities when measuring soluble gases. Traditional active sample dryers comprise many parts, are bulky, require mains electric power, and are expensive, and typically renders the analyser no longer truly portable. The development of the advanced passively cooled system has solved these problems, providing a truly portable solution without the complications and costs of electrically powered systems

References

[1] UK National Physical Laboratory Test Report Number QE21/01/1035A, SO_2 tested at 50 and 500ppm, NO_2 tested at 40ppm with 10% H_2O on Land Instruments Lancom Portable Gas Analyser.

[2] Nafion® is a registered name of Dupont

[3] UK National Physical Laboratory Test Report Number QE21/02/1042, SO_2 tested at 50 and 500ppm, NO_2 tested at 30ppm, 20% H_2O on Land Instruments DrySampler™ probe.

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