Plants operating in a competitive environment are constantly looking for means to increase production and decrease costs. Cost reductions may involve such actions as the use of alternative raw materials or alternative fuels and the fine tuning of the combustion process. An increase in production is generally associated with an increase in fuel consumed and, in turn, a subsequent increase in emissions generated. In either case, monitoring emission output helps the producer to control his process for cost benefit and mitigate impact from changes in fuels and raw materials. (See Figure 1).

In addition, regulatory entities are increasingly implementing standards and setting requirements for monitoring and reporting data on plant emissions. In order to improve efficiency throughout a cement manufacturing process and at the same time meet the needs of sustainable development goals, the industry is finding an increased need for robust, reliable and accurate gas analysis methods.

To meet the needs of this demand, different technologies for gaseous emissions sampling and analysis have been developed over the years. One particular technique is to extract a gas sample and dilute that sample prior to analysis. This article explains some advantages of the dilution extractive method.

**Methods of gas analysis**
The means to generate an analysis from a process gas can be broken into three main categories. Each method then has its own particular details but in overall terms can be summarised as follows:

- **In-Situ gas analysis**
  - point
  - path

- **Full Extractive sampling gas analysis**
  - hot wet (wet basis)
  - cool dry (dry basis)

- **Dilution Extractive sampling gas analysis**
  - in stack dilution
  - out-of-stack dilution.

**In-Situ**
In-situ analysis consists of measuring and analysing the gas right at the point desired. In other words the analysis instrument is located at the process point where the measurement is needed.

An analysis performed within a very short distance of the instrument, is termed ‘in-situ point’ analysis. An example of in-situ point analysis would be an electro-optical or electro-mechanical device situated at the measurement point.

An analysis that is made over a distance, through a gas stream is termed ‘in-situ path’ analysis. An example of in-situ path analysis would be an instrument that passes some type of energetic wave (eg, light or sound) through the medium to be measured. The interaction of the energetic wave with the medium is then detected and measured. In either case, the measurement is made right at the point desired.

While in-situ analysis avoids sample transportation lines, some concerns can include the following:
- electronics and components are located remotely at the stack making maintenance and repair somewhat difficult
- instrument typically exposed to the elements and harsh stack conditions
- technologies employed may have difficulties measuring low concentrations of gas
- technologies employed may have
spectral interference from other gas components
- technologies employed may be difficult to maintain.

**Full Extractive**
The full extractive method samples a representative portion of a gas stream and transports the sample to an analyser.

While a fairly straightforward concept, gas sample transportation can be tricky and sometimes problematic. Gas from a process generally contains moisture in suspension and this moisture can create difficulty from a transportation and gas analysis standpoint.

Should the gas cool below its dew point during transportation, the suspended moisture will condense to form water droplets. This condensed water can cause plugging conditions by itself or with particulate matter in the system.

Other issues such as corrosion can also sometimes be encountered. Some gasses are partially soluble in water (SO₂, NO₂) and others fully soluble in water (NH₃, HCl, HF). Should vapour condense, acidic compounds can be created and corrosion induced on and/or within system components.

Because of these issues, sample lines on fully extractive systems are heated along their entire path to prevent the gas from cooling below the dew point. Occasionally, however, heated lines can fail or ‘cool spots’ along the heat trace can develop, allowing moisture to still condense (see Figure 2).

Measurement made on a full extractive sample can be done either with the moisture still present in the sample or, with a ‘dried’ sample. If the measurement is done with the moisture still present, this is referenced as a hot, wet or just wet basis analysis. The wet analysis methodology can have drawbacks associated with the moisture in the gas as noted above, eg such as plugging and corrosion, within the instrument. Therefore to avoid these issues, a majority of full extractive systems cool the sample under controlled conditions to condense the water out and dry the sample. Once the sample has been cooled and dried, it is then sent to an analyser. This method is referenced as the cool, dry or just dry basis analysis.

As noted above, some gasses are either partially or fully water soluble. By cooling the sample and removing the water for a cool dry analysis, some of these gasses that have dissolved in the moisture can also be removed from the gas as the water is condensed. An error can be induced on gasses such as SO₂ and NO₂. Along these same lines, it is impossible to measure highly water soluble gasses like NH₃, HCl and HF.

**Dilution Extractive**
The dilution extractive method extracts a very small representative portion of a gas stream and very accurately dilutes the sample with air before transportation to an analyser. By significantly diluting the gas sample, the dew point of the gas is lowered far beyond the lowest possible ambient temperature. This method therefore makes it impossible for any moisture in the gas sample to condense out of suspension and form water droplets.

There are two basic ways to dilute an extracted sample. One technique for diluting the gas sample takes place within the sample probe itself. In other words the dilution mechanism is part of the probe. This is termed ‘in-stack dilution’. The other technique for dilution takes place immediately after the probe right at it’s discharge. This is termed “out of stack dilution”. For all intense and purposes both techniques accomplish similar desired results. Once diluted, the sample is then transported to the analyser.

**Dilution Extractive sampling: a closer look**
Dilution extractive sampling and analysis techniques have the considerable benefit of avoiding many of the extra sample transportation and handling requirements of a full extractive sample system. The lowering of the dew point obviates the need for heated sample lines and equipment to cool and dry the sample gas prior to analysis is not required (see Figure 3).

Because of the way sample dilution is accomplished, the amount of gas collected at the probe for measurement in a dilution extractive system is considerably lower than a full extractive system. Much of the volume of gas going to the analyser is from the dilution air so the actual volume of gas from the stack or process is quite low. Flow rates into the sample probe can be two orders of magnitude lower than a full extractive system (e.g. 0.22 l/m versus 22 l/m). This means that there will be a significantly lower amount of particulate matter that needs to be filtered. This in turn means filter life is greatly extended compared to a full extractive system. Also with such a low volume of gas entering the sample probe, particulate matter traveling in the main gas stream is more likely to remain in the main stream and not enter the probe. The dilution extractive sampling method is especially appropriate for hot, dusty and moist environments.

**How Dilution Extraction works**
Dilution of the gas sample must be extremely precise and robust to function properly. Fortunately this is relatively
simple to do and is accomplished by the use of various static components. These non-moving, static components reside either within the probe itself, for in-stack dilution, or within an assembly located just downstream of the probe, for out-of-stack dilution. The main components of the probe and dilution assembly can be broken down into:

- coarse filter
- fine filter
- critical orifice
- ejector (venturi)
- sample gas inlet
- dilution air inlet
- diluted sample outlet.

The coarse filter prevents large particles from entering the sample probe and the fine filter removes small particulate matter from the gas sample. After the filters, sample dilution takes place. The sample gas passes through what is called a ‘critical orifice,’ this is one of the main components in a dilution assembly. The critical orifice allows only a very precise and fixed amount of sample gas into the assembly. The metering, and hence dilution ratio, is done by creating a vacuum. The inlet line of sample gas coming from the critical orifice is attached to the venturi tube where a vacuum is being generated by the dilution air. The vacuum created by the venturi provides the appropriate pressure drop across the critical orifice to create sonic flow conditions and pulls sample gas into the dilution assembly. The venturi itself is also a critical orifice and operates with sonic flow conditions. The combination of the ejector and critical orifice precisely controls the dilution rate (see Figure 4).

Hence, there are two precisely controlled flows through the ejector pump: the undiluted sample gas from the critical orifice, \( Q_2 \), and the dilution air going into the ejector, \( Q_1 \). The outflow of the ejector is the diluted sample gas consisting of \( Q_1 + Q_2 \) and the dilution ratio is calculated as:

\[
R = \frac{Q_1 + Q_2}{Q_2}
\]

The critical orifice, ejector, and dilution air pressure are all designed and set to deliver a pre-determined, fixed dilution ratio.

### Additional considerations of Dilution Extractive sampling

Dilution ratios of 100:1 or higher are not uncommon and care should be taken in considering the measurement range and subsequent performance requirement which results from that dilution. For example, if a 100:1 dilution ratio is selected and the gas to be sampled has a nominal value of 60ppm, then the diluted sample will have a nominal value of 0.6ppm. The analyser selected should be able to operate accurately and precisely at this low gas concentration.

The critical orifice is a function of the pressure difference between the stack and the internal assembly of the probe and pressure changes at the stack therefore have an effect on the dilution. Fortunately, these changes are linear, predictable and easily addressed. A pressure gauge becomes part of the system and is used to easily correct for changes in stack pressure.

One of the main benefits of a dilution extraction system is to lower the dew point of the gas sample so low that moisture will remain in suspension and will not form water droplets. Because there is generally no need to dry the gas, it can go directly to an analyser and gas concentrations reported by the analysers are already on a wet basis, eliminating the need for conversions.

Calibration of the system is simple...
Review of Dilution Extractive Systems in the US electric utility industry

The United States Environmental Protection Agency (US EPA) requires that utility fossil-fired generating units meet the requirements of legislation entitled 40 CFR Part 75 commonly known as the Acid Rain program. Under this program utilities must provide quarterly reports known as “Electronic Data Reports” (EDRs) that identify the source, units, emissions being monitored, sample acquisition method and analyser manufacturer.

This data is publicly available and can be obtained from the US EPA. The information provided in these EDRs can be helpful to understand, at least in the United States, trends in the use of a particular emissions monitoring method within that industry.

Since this type of reporting is not required of the cement industry and information on what methods are actually being employed is not readily available, data from the electric utility industry can be looked at as a reference to gain an understanding what that industry uses for its monitoring methods.

Below is compiled data from the year 2002 on the methods used for the gasses SO₂, NOₓ, and CO₂. (See Figure 5).

Figure 5: Dilution Extractive method used in the Electric Utility industry

and is accomplished by sending span or zero gas directly to the center of the probe inlet. The calibration gas then goes through the same dilution as the sample gas, leading to a true calibration of the full system under actual operational conditions.

Advantages of Dilution Extractive systems

There are genuine advantages to a dilution extractive system over a full extractive system which offer the user significant economic benefits both in operation and in maintenance that can be summarised as:

• no heated sample lines required
• chiller equipment for condensing moisture not required
• reduced maintenance
• less calibration gas needed
  - because such low volumes of sample gas are required, calibration gasses last much longer. An extractive dilution system typically only requires 0.2-0.4 litres/min of cal gas as opposed to the 20-50 litres required for a full extractive system. Even with daily calibrations a cylinder can last between 1 and 2 years when using the dilution extraction method.
• direct wet basis measurement
• gasses soluble in water not lost.

Summary

Cement producers today are finding an increasing need to accurately monitor and control plant emissions and in turn are seeking robust and reliable means to do so. Of the three main methods used for gas sampling and analysis, the dilution extractive method seems to offer a very attractive means to meet this need for the hot, dusty environments found at a cement plant.

References