A PROCESS SAMPLE PROBE WITH IN-SITU ISOLATION AND FILTRATION

Phil Harris
HariTec

Michael Jenkins
Universal Analyzers

KEYWORDS

Sample Probe, Sample Systems, Sample Handling, Hydrocarbons, Natural Gas

ABSTRACT

It has often been said that 80 percent of the problems with online analyzers are because of the sample system. An oft-neglected portion of the sample system is the sample probe itself. A new sample probe design has been developed and field tested. This probe provides several unique features. These include:
- In situ filtration remove particulate and liquids,
- An in-situ fast loop with a sweep the filter to prevent plugging and liquid build up on the filter surface and,
- The ability to provide positive in-situ isolation to prevent egress of toxic or combustible gases during maintenance and provide enhanced safety.

Capabilities and applications of this novel sampling accessory are discussed.

.INTRODUCTION

Sample conditioning transports a sample of potentially toxic, corrosive or combustible fluids that may be at elevated temperatures and pressures, and may contain solid or liquid contaminants or chemical reactive species, and converts that sample into a well behaved, homogenous mixture suitable for analysis by the process analyzer of choice. No simple task – and one that can be fraught with errors. "A well designed conditioning system happily accepts the sample fluid at whatever extreme conditions exist in the process and modifies those conditions to comply with the specified analyzer operating criteria" [1]. To be useful, the sample delivered to the analyzer must be representative of the process fluid.

Several definitions of a representative sample exist, such as:

- *From the Gas Processors Association publication GPA 2166-05* [2], *"The objective of the listed sampling procedures is to obtain a representative sample of the gas phase portion*

of the flowing stream under investigation. Any subsequent analysis of the sample regardless of the test is inaccurate unless a representative sample is obtained."

- *And from ISO-10715 a representative sample[3] is, "A sample having the same composition as the material sampled, when the latter is considered as a homogeneous whole."*

- *Finally, API 14.1 offers a similar statement in the latest revision [4], "a representative sample is compositionally identical or as near to identical as possible, to the sample source stream."*

These standards are the most common and current ones referenced on gas sampling procedures.

In other cases, it is made clear that representative does not mean identical to what is in the process, but rather, a sample that is suitable for analysis and is of appropriate chemical composition to allow accurate estimation of what is in the process. For example, the sample may have undergone treatment to remove particulate or other unwanted phases, lower the dewpoint of the gas by controlled condensation, scrub chemicals which lead to corrosion or plugging problems, or other modifications. As long as these operations can be done in such a way as to produce a sample for analysis which is strongly correlated to the process sample, the analytical sample may be said to be representative of the process sample.

Most sample conditioning systems begin with a sample probe, a physical means of extracting a "representative" sample from the process pipe or vessel. The sample probe is typically designed to extend into the central 1/3 of the pipe, although this depth of insertion is not always required. The sample probe serves several functions [1] including:

- To filter the sample
- To achieve a faster response
- To sample from an appropriate place in the pipe or vessel

The probe filters the sample partially due to its placement away from the walls of the pipe or vessel. Solids and entrained liquids (in a gas phase stream) tend to collect near the walls where there is little flow. The use of a probe tends to reject these elements in favor of the gas phase sample. "The rejection or removal of unwanted contaminants from a sample at the sample probe is a good example of intentional sample modification while still retaining representative sampling from an analysis application perspective" [5].

The use of even a simple sample probe will improve sample response speed, especially as compared to sampling from a sample flange on a pipe nozzle. In the absence of a probe, the nozzle volume becomes a significant part of the sample system, and acts as a mixing volume which must be purged at least three times before a representative sample is delivered. The probe provides a much smaller cross-sectional area through which the sample must be drawn, which results in substantial reduction in the volume of fluid needed to purge it and much higher velocities thru the probe.

The gas or liquid near the walls of a pipe or vessel may not be representative of the bulk fluid. This can occur due to reaction or chemical deposition near the walls, or due to the fact that there

UNIVERSAL ANALYZERS INC.

5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UniversalAnalyzers.com

is a viscous and nearly stationary boundary layer near the walls. The use of a sample probe allows us to sample from a region of the pipe where a more representative sample may exist.

In addition to the above reasons to use a sample probe, other features may be desirable. Such features might include additional elements in the probe to improve filtration and response time, or to provide enhanced safety for end-users of the equipment. In some cases, corporate specifications and requirements may demand that means to isolate the sample be provided, preferably through a block and bleed system. Additional features for probe maintenance and improved reliability are also an asset.

A multitude of probe designs and configurations are available, with many specific configurations used in varying applications. Some obvious examples include probes designed for stack gas analysis, dilution probes, iso-kinetic samples etc. Upon review of a number of applications, it appeared that there was an opportunity for a sample probe which provided enhanced features to the hydrocarbon processing industry, especially for the extraction of gaseous samples from combustible or toxic streams in which there may be entrained liquids or solids.

CURRENT STATE OF THE ART IN PROBE DESIGN

There exists a wide variety of different types of sample probes that have seen application for process and emissions analyzers. Sherman [6] dedicates an entire chapter and almost 50 pages to covering a number of the different types and configurations. Of particular interest is sampling gas phase streams which may contain liquid (aerosol) or solid contaminants, and in which the desire is to reject these contaminants and provide a reliable sample of the gaseous material. A common belief credits probes with omitting 85% of the particulates in a process stream [1]. Omitting the use of a probe in any application where the sample gas may contain solid or liquid contaminants will inevitably lead to additional maintenance of other sample system components as well as the analyzer itself.

The most common type of probe is undoubtedly a simple quill probe – a pipe or a tube placed into the process to remove a sample of gas. Quill probes are often fabricated from ½" Schedule 40 pipe welded to a flange, from a piece of pipe welded into an NPT fitting, or from tubing fed thru compression fittings in a flange. In all such cases, these simple probes are used and provide some filtration and rejection of entrained particles and liquids. The filtration occurs due to momentum, in that the fast moving process flow sweeps the entrained phase past the probe entrance and gaseous molecules preferentially make the bend and into the sample probe.

In other cases, the probe may include an in-situ filter. Such a filter may be as simple as a piece of sintered metal tubing welded onto the quill probe. More complex designs have been developed which use an in-situ membrane filter to selectively pass gas phase material and reject entrained liquids. In-situ membrane filtration has proven to be a very effective technique. To quote Don Mayeux "If liquid is present in the source gas, then it should be removed from the sample gas at the prevailing pressure and temperature of the flowing source gas before a pressure reduction or temperature increase takes place. The best method is to separate the liquid from the gas sample "inside" of the pipeline allowing only the gas phase to enter the sample conditioning system."[7]

UNIVERSAL ANALYZERS INC.

5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UniversalAnalyzers.com

One of the potential issues with in-situ membrane probes is that the membrane is often isolated from the main process flow and has no bypass flow. Bypass flow or fast loop flow provides an additional means to pre-filter the gas via momentum filtering. Entrained droplets and particulate tend to follow the fast loop flow. A traditional fast loop filter is shown in Figure X. If one assumes that the bypass flow is substantially larger than the flow through the filter element, three useful results are realized. Firstly, the bypass flow sweeps particulate and droplets past the filter element and pre-filters the gas passing thru the filter. Second, the rapid flow of bypass gas acts as a fast loop, bringing in fresh gas and ensuring that gases and liquids on the surface of the filter are at equilibrium. Finally, in the event that the filter element gets partially saturated with liquid during an excursion, the fast loop can help dry the filter after such events.
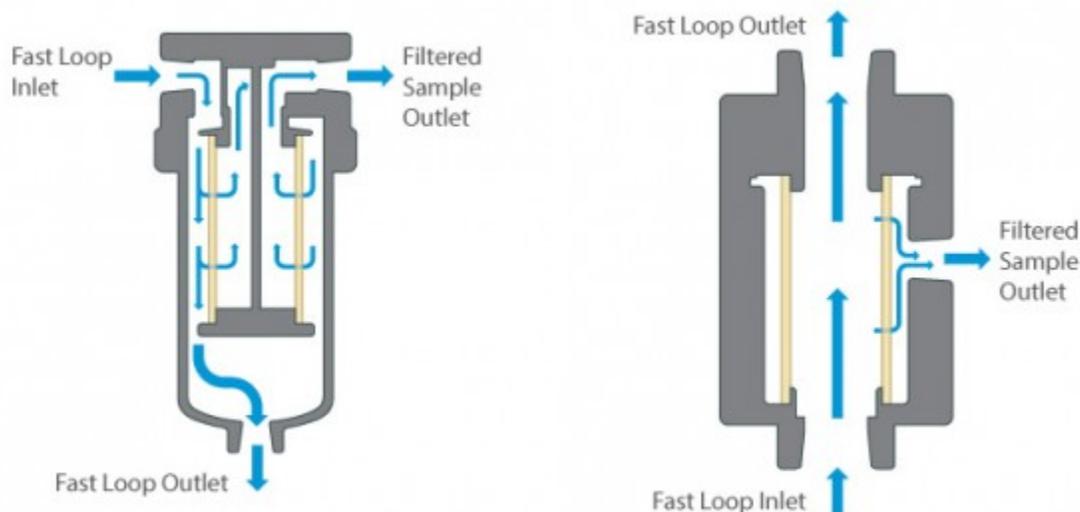

FIGURE 1. FAST LOOP MEMBRANE FILTER CONFIGURATIONS [8]

Of course, to promote gas flow, a pressure differential is required. In many cases, this is provided by either venting high pressure gas to a lower pressure header or to atmosphere. However, in the case of a flowing pipeline or process pipe, the energy associated with the gas or liquid flow may be used to create the differential pressure and force flow. This has been done to create sample extraction probes powered by the process flow. One such probe manufactured by Hobre Instruments is shown in Figure 2.

The process flow impacts on the angled probe in which the bevel is introduced to drive flow into the probe body. A secondary jacket is beveled in the opposite direction and creates a lower pressure zone, thus developing the differential pressure to drive flow through the system.

Another desirable feature which is becoming increasingly important to facilities is the ability to isolate the process sample from the flow system, preferably through means of a block and bleed

UNIVERSAL ANALYZERS INC.
5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UniversalAnalyzers.com

valve. The block and bleed configuration is preferred as it provides increased safety in applications where the sample gas is combustible, toxic and or at high pressures.
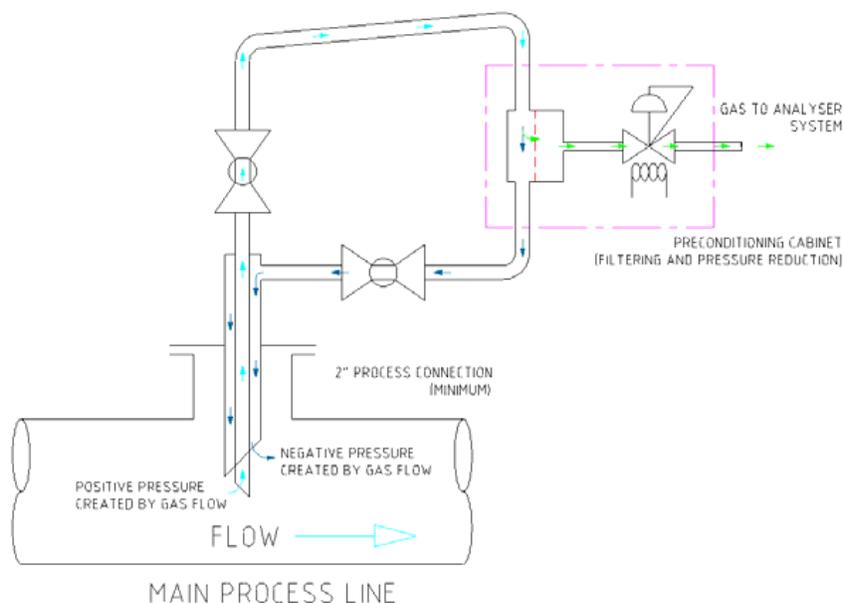

FIGURE 2. HOBRE FLOW IMPACT PROBE

Consideration of the aforementioned benefits and features was instrumental in defining a set of criteria and goals for a newly designed probe. The criteria are shown in Table I.

TABLE I PROBE DESIGN CRITERIA

Provide maintainable in-situ filtration	The probe was to be designed to allow for an in-situ filtration system that could be removed while the process was under pressure.
Provide a fast loop bypass for the filter	The in-situ filtration should include a fast loop to: 1) Provide additional momentum filtering 2) Improve speed of response 3) Clean and equilibrated the filter
Provide a reliable means to isolate the filter from the sample	This was a requirement in order to ensure the filter is maintainable
Provide a reliable means to determine if the filter isolation is secure	A safety consideration such that the operator can test that the isolation has been successful
Provide an integrated block and bleed capability at the sample point	In many applications, block and bleed isolation is preferred or required. This feature was to be integrated into the probe.

UNIVERSAL ANALYZERS INC.

5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UniversalAnalyzers.com

IMPLEMENTATION

The probe design began with the concept of an in-process fast loop and means to implement that. It was desirable to ensure that the fast loop would remain operational without any external power and thus the most obvious means of doing so was to employ the concept of an impact probe to power the fast loop. It is simplest to consider the impact probe in the form of a pitot tube, with one port facing the flow and the other facing away from the flow, as shown in Figure 3.
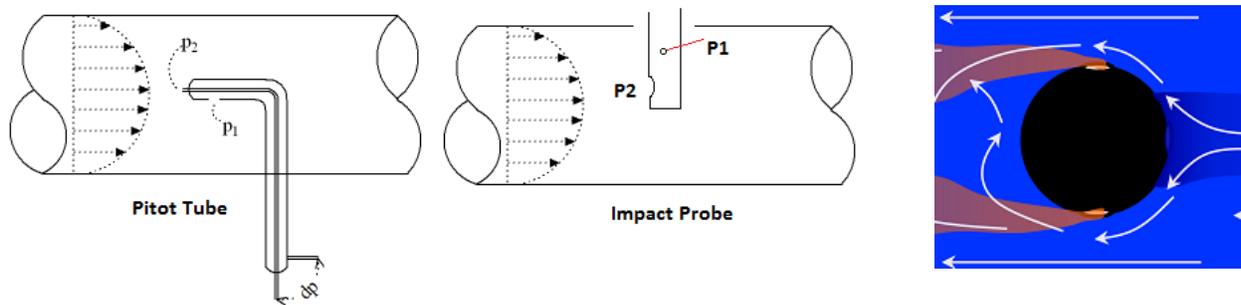
FIGURE 3. PITOT TUBE CONFIGURATION AND COMPARABLE IMPACT PROBE

In the impact probe, the low pressure ports are placed on the sides of the probe where the stream velocity is the highest. The gas impacts the lower port which is positioned to be in the central 1/3 of the pipe if possible.

We can apply Bernoulli's principle to determine the dependence of pressures P1 and P2 on the flow velocity as shown in Equation 1.

$$P_1 + \frac{1}{2}\cdot\rho\cdot v^2 + \rho\cdot g\cdot y_1 = P_2 + \frac{1}{2}\cdot\rho\cdot v^2 + \rho\cdot g\cdot y_2 \qquad (1)$$

Where P_1 and P_2 are the pressure, y_1 and y_2 are the elevations of the ports, v is the velocity of the gas in the pipe, ρ is the density of the gas and g is the acceleration due to gravity. Consider that for most practical applications of a sample probe, the height is effectively the same ($y_1=y_2$). Also, at point 2, the stack gas stagnates (stops) and velocity there is effectively zero. This results in a higher pressure at P_2 since Bernoulli's principle states a decrease in a fluid's speed creates a pressure increase. Given this, we can simplify Bernoulli's equation to give:

$$P_2 = P_1 + \frac{1}{2}\cdot\rho\cdot v^2 \quad \text{or} \quad \Delta P = \frac{1}{2}\cdot\rho\cdot v^2 \qquad (2)$$

Thus the pressure difference between the inlet port and the side ports will be uniquely determined from the process gas flow velocity and density. It is this pressure difference which will drive flow through the probe body.

UNIVERSAL ANALYZERS INC.
5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UnversalAnalyzers.com

Assuming we know the effective diameter of any flow restrictions between the inlet port, and the outlet ports, we can estimate the flow thru the probe body from Darcy's law as shown in Equation 3.

$$\Delta P = \frac{8 \cdot \rho \cdot f \cdot L \cdot Q^2}{\pi^2 \cdot D_{eff}^{5}} \tag{3}$$

Where f is the moody friction factor, L is the length of the flow path, D_{eff} is the effective diameter of the flow path and Q is the volumetric flow rate through the system at the given pressure drop ΔP.

The probe housing body is designed to be inserted through a standard ¾" NPT fitting into the process pipe, and the length of the nozzle portion may be extended to suit the pipe diameter.

The housing utilizes the Bernoulli principle to achieve one of the design goals which is a means to force fast loop flow thru the probe body and keeping all that flow internal to the process. The purpose for this fast loop flow was to create a bypass loop around an in-situ filter element. It was also desirable that there be a means to isolate the filter element from the process such that it could be replaced while process pressure still existed in the pipe.

This combination of goals requires two additional components, as shown in Figure 4. The first is a filter housing insert that can act as a valve to isolate the filter when necessary. The second is the filter body itself, which supports the in-situ filter and provides a flow path for gas to leave the process and be transported to the ports on either side of the probe body.

FIGURE 4. PROBE BODY, VALVE/FILTER HOUSING AND FILTER ASSEMBLY

UNIVERSAL ANALYZERS INC.
5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UnversalAnalyzers.com

The internal valve assembly operates on a principle similar to that of a spool valve as would be used in hydraulic equipment or automatic transmissions. This valve design has been well proven for high pressure applications and for repeated use. The valve housing screws into the probe body via an ACME transversal motion thread, such as might be used on vises, lathes or jack screws. These coarse trapezoidal threads are well suited to power screw applications and provide a large transvers range of motion for each rotation. Rotating the valve body (which also serves as the filter housing) moves the valve seat O-rings up or down in the probe assembly, allowing for a valve open / valve closed position select. Figure 5 shows the probe assembly with the valve in the open (flowing) and in the closed (isolated) position.
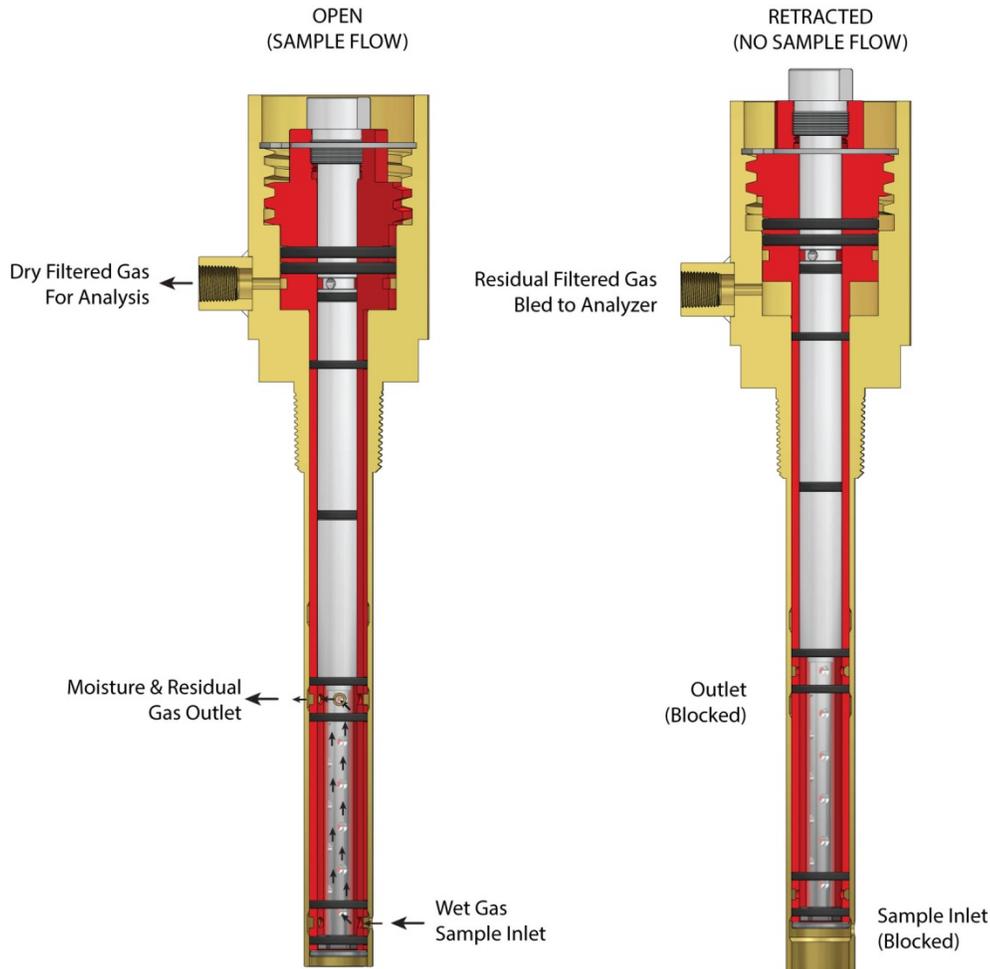
FIGURE 5. PROBE ASSEMBLY IN "OPEN" AND "CLOSED" POSITION

In the left hand example shown in the above figure, the filter housing has been fully inserted via the ACME thread. In this position, O-ring seals are above and below the both the entrance port at the lower extremity of the probe and the exit ports halfway up and on the sides of the probe. This forces the gas that is driven thru the probe to enter through the ports in the filter housing and pass up over the membrane filter in a bypass loop. Similarly, O-Rings in the head port vent the exit port of the filter housing to the two side ports, which may be used for sample line

UNIVERSAL ANALYZERS INC.
5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UniversalAnalyzers.com

attachment, venting the probe or for pressure measurements. In this configuration, flow in the process pipe forces gas thru the fast loop, while the vent to the analyzer in the probe head draws sample gas through the filter. Thus we achieve the proper flow paradigm for a membrane filter with bypass.

The bypass flow occurs in an annular region between the filter element and filter housing body. We can calculate the equivalent pipe diameter for an annular region via [9]:

$$D_{eff} = \left[(ID + OD)^2 \cdot (ID - OD)^3 \right]^{\frac{1}{5}}$$

(4)

Where ID is the diameter of the inner cylinder and OD is the diameter of the outer cylinder. This allows us to solve for Q, the flow rate through the bypass, as a function of the stream velocity, v, by equating Equations 2 and 3 and solving for Q. This gives:

$$Q = \sqrt{\frac{v^2 \cdot \pi^2 \cdot D_{eff}^5}{16 \cdot f \cdot L}}$$

(5)

In practice, the bypass loop as shown by the flow path in Figure 5 previously will experience about 7 liters per minute of gas flow for every meter per second of velocity in the pipe.

In the right hand example, filter housing has been rotated in the acme threads, causing transvers movement of the filter housing in the probe body. This movement pulls the O-ring seals above their associated ports. Isolation occurs in three areas:

- At the lower extremity the opening in the filter housing is isolated from the process flow impacting the entrance port in the probe body,
- At the exit points of the bypass loop, the O-Rings are again above the exit ports, isolating the filter from the process gas and pressure at that point, and
- In the head of the Probe Body, the O-Rings have been raised above the sample line / pressure tap connections, providing isolation of the sample system from process fluids and pressure.

An important consideration is what occurs if any of the seals should leak. If the lowermost seal leaks, gas can enter the filter assembly through the filter. However, the gas can only fill the filter assembly but is blocked from the sample line connection by the O-Rings in the upper assembly. A similar effect occurs if the intermediate O-ring pair should leak – the analyzer is still isolated from process gas and pressure by the upper seal. Finally, should the upper seal leak, the system is still isolated provided the lower seals area in place. The only way to get a leak to the process connection is if two sets of seals fail.

A pressure gauge can be attached on one of the exit ports, or to the head of the filter assembly. The use of a vent valve and the pressure gauge would allow a technician to bleed the process pressure off with the probe isolation closed, and then close the bleed valve to observe if there is

any pressure build up. If the pressure increases over time, the technician will know that one of the seals has failed and appropriate action should be taken prior to removing the filter assembly. Once certain that there is no pressure buildup and the system is isolated from process gas, the technician may remove the filter assembly to perform any required maintenance. The extra side port or port in the filter assembly may also be used to purge the sample system, or attached to a gas detection system to check for the release of toxics.

APPLICATIONS AND SUCCESSES

The probe is suitable for use in any application where a quill or thermocouple probe is currently used. It is especially applicable to sample points where there is risk of entrained liquids or particulates and there is some desire to reject these at the probe. Of particular interest is the sampling of wet natural gas streams as may be seen in shale gas applications. Others may be any type of contactor overhead application in which there is risk of entrained mists or aerosols.

In addition, the probe provides important safety features for use in applications where the process gas is at high pressures and contains toxic or combustible gases. The probe allows for isolation of the process gas inside the pipe, thereby mitigating the risk to personnel and the facility. If deemed necessary, the probe outlet can be attached to an additional block and bleed valve for extra protection.

The merits of the fast loop bypass as part of the filtration loop cannot be overstated. In one particular application, the client was using a conventional in-situ membrane filter probe. The probe was part of a heated sample system transporting produced natural gas to a gas chromatograph for BTU analysis. For a period in excess of a year, the client was finding that some material would make it past the membrane filter and gum up the GC injection valves, requiring a valve rebuild on a monthly or bimonthly basis. The client had performed appropriate maintenance on the membrane filter. We postulated that with no bypass, all the probe flow must go through the filter element and this drove the condensable fluids through the filter when the stream was especially wet.

The new probe was installed in August of 2013, and the customer has not had to rebuild the GC injection valve since then. Nor has there been any need to perform filter maintenance since the filter surface is kept clean by the bypass flow and additional benefit of momentum filtering.

CONCLUSIONS

There exists a multitude of probe designs for process sampling applications. A new design has been developed and commercialized which combines many of the best features into a single, cost-effective package. The new probe geometry ensures substantial fast loop flow past an in-situ filter and has been demonstrated to provide improve filtration, better protection of upstream analyzers, and reduce maintenance costs and time. The probe also provides safety features not available in other products, most notable a means of double isolation of the sample point.

UNIVERSAL ANALYZERS INC.
5200 Convair Drive
Carson City, NV 89706 USA

Telephone: +1 (775) 883-2500
Fax: +1 (775) 883-6388
Email: Sales.UAI-BAT@Ametek.com
www.UniversalAnalyzers.com

References

1. Waters, Tony, <u>Industrial Sampling Systems: Reliable Design and Maintenance for Process Analyzers</u>, Swagelok Company, 2013.

2. GPA (Gas Processors Association) Standard 2166-05, <u>Obtaining Natural Gas Samples for Analysis by Gas Chromatography</u>. 2005.

3. ISO 10715, <u>Natural Gas – Sampling Standards</u>, Ed 1, 1997.

4. Manual of Petroleum Measurement Standards, <u>Chapter 14-Natural Gas Fluids Measurement: Section 1-Collecting and Handling of Natural Gas Samples for Custody Transfer, 6th Edition,</u> 2006.

5. Houser, E.A, <u>Principles of Sample Handling and Sampling Systems Design For Process Analysis</u> UMI Books on Demand, reprinted 1997.

6. Sherman, Robert E., <u>Process Analyzer Sample-Conditioning System Technology</u>, John Wiley and Sons, New York 2002.

7. Mayeux, Donald P., Advances in Natural Gas Sampling Technology, American School of Gas Measurement Technology, 2002.

8. http://www.classicfilters.com/product/fast-loop-filters/

9. <u>Petroleum Engineering Handbook</u>, edited by Howard B. Bradely, Third Printing, published by The Society of Petroleum Engineers, 1987.