WHAT'S THE SCOOP?
ADVANCES IN PROCESS SAMPLING

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ABSTRACT

Many sampling systems, whether for grab sampling, composite sampling, or online analytical systems suffer from response time issues and not having representative samples present at sampling points. Often these issues can be resolved if a fast loop were present, but these may not be considered if a low pressure return point is not available or if the maintenance of a pump is to be avoided. These issues may be overcome with a properly installed probe that utilizes the internal energy of the process flow to drive the fast loop.

A uniquely designed sample probe, capable of driving a full pressure fast loop with process return has been developed. The use of such probes allows fast loop operations with a single point of entry, and can be used to return high pressure gases to process, and, for example, mitigate environmental emissions in natural gas pipeline applications. The probe is uniquely suited for applications such as:

- Continuous feed to a grab sampling panel
- Continuous feed to a composite sampler
- Response time improvement in at-line vaporization systems for gas chromatographs
- Continuous flow through high pressure analyzers like dewpoint analyzers
- Continuous flow through at line liquids analyzers such as pH, conductivity etc.

This paper focuses on the application of these probes to critical refining, gas process and petrochemical applications.

SAMPLE PROBES AND FAST LOOPS

Extracting a representative sample is essential for accurate and reliable online measurements in the process industry. A representative sample is one that adequately reflects the composition and characteristics of the process stream being measured such that the purpose of the intended measurement can be achieved. If the sample is not representative, the measurements obtained from the analyzer may not reflect the process conditions, leading to incorrect reporting, errors in custody transfer calculations or ineffective process control

The importance of a representative sample can be illustrated by considering the many variables that can affect the quality and composition of the process stream. These may include changes in temperature, pressure, flow rate, viscosity, and chemical composition, as well as the presence of contaminants, solids, or gases. Any of these variables can affect the properties of the sample and therefore the value, reliability and usefulness of the online measurements.

To ensure that the sample is representative, it is important to consider the location and response time of sampling, the size and type of sampling equipment, and the procedures used for sample handling and transport. The sample point should be selected to ensure that the sample is taken from a representative portion of the process stream, and that the sample response is appropriate for the process being measured.

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 desirable. 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" [2].

In the process analytical industry, sample probes are used to extract a representative sample of the process stream, which is then transported to the grab sample station, composite sampler or online analyzer for analysis. The quality and timeliness of the sample is critical in ensuring that the analyzer provides useful and reliable measurements. Any errors or inaccuracies in the sampling process can result in incorrect readings, which can have serious consequences in terms of process control, product quality, and safety. The extraction system should be designed to minimize any potential losses or changes to the sample during transfer, such as fractionation, condensation, or chemical reactions.

A continuously flowing fast loop is an important component of an online analyzer or grab sample system in the hydrocarbon processing industry. The fast loop is a bypass loop that allows a small, continuous flow of process stream to pass through the analyzer or composite sampler, providing real-time data on process conditions.

There are several reasons why a continuously flowing fast loop, such as that shown in Figure 1, improve analytical performance, including:

- Timeliness: A fast loop allows for continuous monitoring of the process stream, providing faster response and near real-time data on process conditions. This enables operators to detect changes in the process quickly and take corrective action to maintain product quality and safety.

- Representative Sampling: A fast loop ensures that the analyzer or composite sampler is always receiving a fresh, representative sample of the process stream, minimizing the risk of contamination or bias in the data.

- Maintenance: A fast loop allows for routine maintenance and calibration of the analyzer or composite sampler without interrupting the process stream. This reduces downtime and ensures that the equipment is always in good working condition.

- Efficiency: A fast loop can improve the efficiency of the overall process by enabling operators to optimize process conditions based on real-time data, minimizing waste and energy consumption.

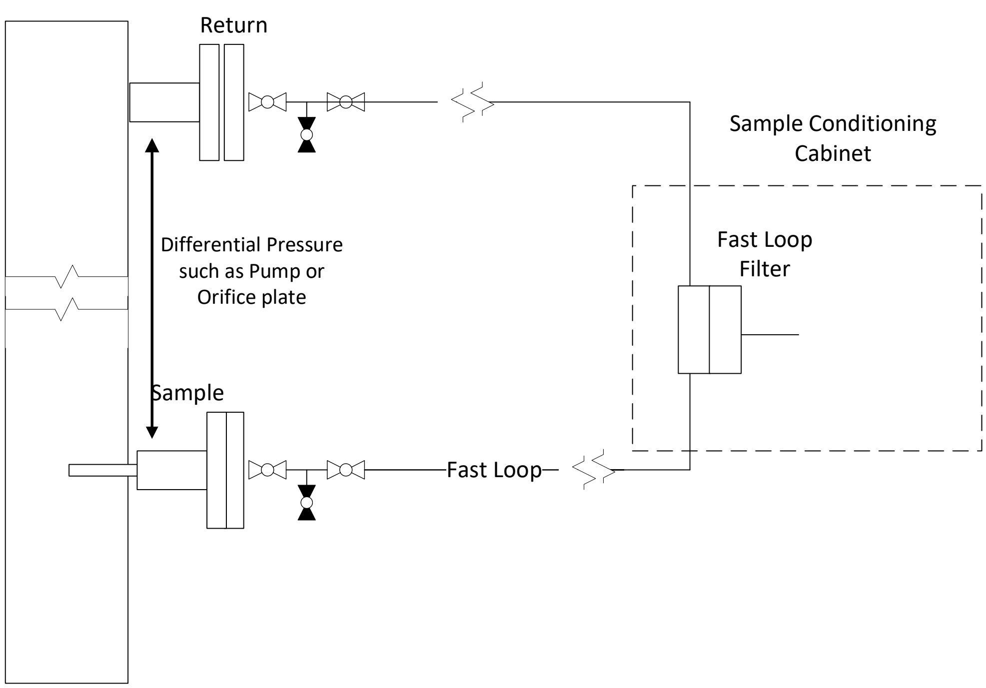


FIGURE 1. A TYPICAL SAMPLE EXTRACTION AND FAST LOOP SYSTEM

A common issue in many installations however is that there is not a convenient low pressure return point or there is no suitable source of differential pressure to drive flow through the system. These issues are commonly present when sampling for process piping but can be mitigated with a custom designed and optimized sample probe.

FLOW DYNAMICS AND BERNOULLI'S PRINCIPLE

Whenever we introduce an object or disruption into a flowing process line, we cause the flow path to deviate and this can create regions of higher and lower pressure, as well as turbulence and vortices. This phenomenon can be used to engineer sample probes that use the energy of the flowing process fluid to create a continuously flowing fast loop with no external sources of differential pressure.

Bernoulli's Principle is a fundamental concept in fluid mechanics that describes the relationship between the speed of a fluid and its pressure. According to this principle, as the speed of a fluid increases, the pressure of the fluid decreases, and vice versa. When it comes to the flow of fluids around cylindrical objects, Bernoulli's Principle predicts there is a region of high pressure on the front side of the cylinder and a region of low pressure on the back side of the cylinder. In addition, the highest flow rates are on the sides of the cylinder and as such the lowest pressure is on the sides of cylinder as well. The magnitude of this differential is related to the speed of the fluid and the size and shape of the cylinder. The faster the process fluid flows in the main pipe, the greater the pressure differential created between the fronts and sides of the cylinder. A graphical depiction of the higher pressure (low velocity) region at the front and low pressure regions at the sides is shown in Figure 2.

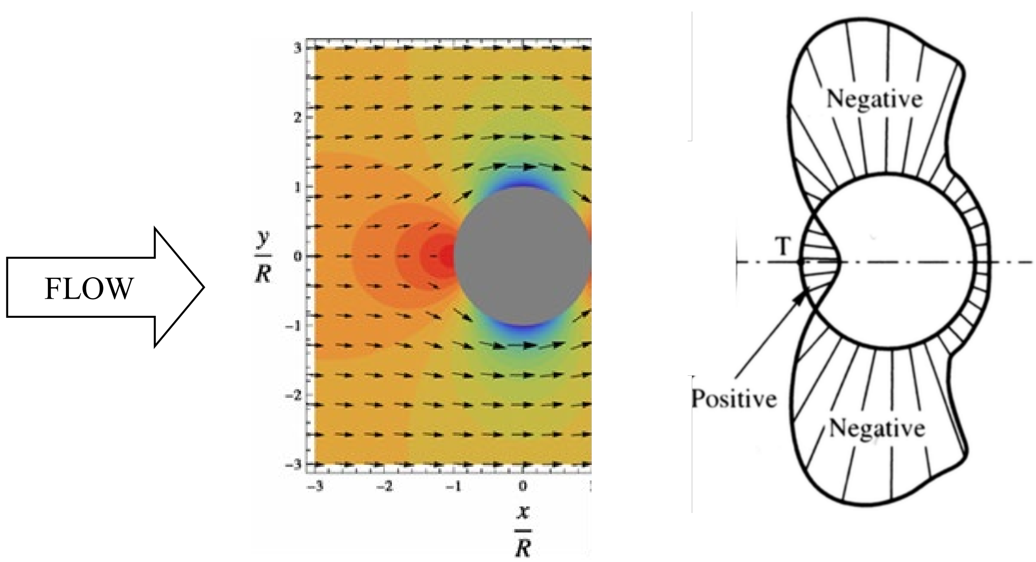


FIGURE 2. HIGH AND LOW PRESSURE REGIONS CREATED BY PROCESS FLOW

Since a differential pressure is created as the fluid flows around the probe or other objects, this differential pressure may be used as a mechanism to drive flow through the system. The concept of using the differential pressure generated by the flowing process fluid is not new, and some early examples are seen in the works of major oil companies such as Exxon or Shell.

Flow impact probes have been used which employ two entry points in the process for some time. In such configurations, it is common to use two sample probes, one with a port facing the direction of flow, and a second probe with the entrance port facing downstream. In this configuration, they operate much like a pitot tube and create differential pressure in the same manner. Rather than measuring the differential, in these applications the probe orientation is used to create flow over a measurement device such as a sensor (FIG 3.).

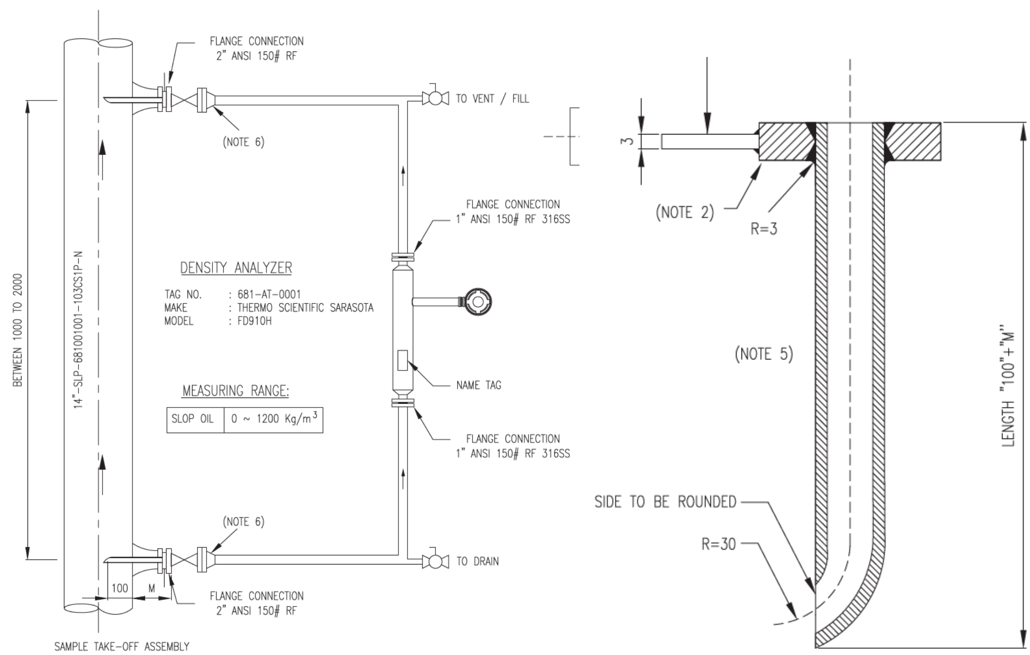
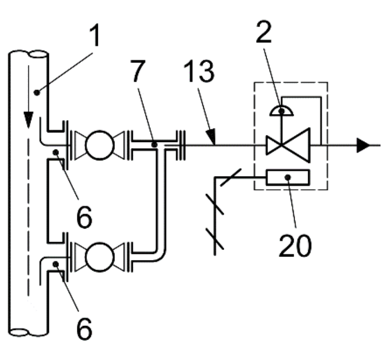
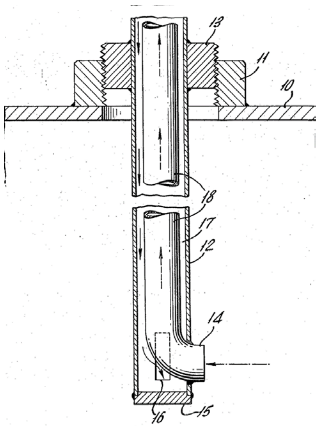


FIGURE 3 USING TWO PROBES TO GENERATE DIFFERENTIAL PRESSURE



Shell Global Solutions International did some design and testing of a flow impact tube-based probe system in 2000 that did testing of flow loops with flow induced by two separate probes with the upstream probe tip bent to face the oncoming flow and the downstream bent probe tip facing away from the flow. The fast loop created allowed continuous flow of LNG past the entrance to the vaporizer and reliable sample of refrigerated products. This formed much of the foundation for ISO 8943, and the use of two probes as in FIG 4 (excerpted from [4]).

FIG 4 PROBE ISO 8943



Exxon patented a self-powered sample probe in 1971 [3] that was made by bending the end of one tube and welding it on the inside of a larger tube with the bent end sticking through the side and facing the process flow. It had sample flow return/exit ports located on either side of the outer tube (approximately ±90° from the front facing inlet port) and one of the patent claims is that this location for the sample ports creates a higher pressure differential than a rear facing return/exit port. The probe was designed for use in process analytical applications to potentially provide continuous flow to an analyzer or sampler.

FIG 5 EXXON MOBIL SELF_POWERED PROBE

The concept of using a single probe which created a fast loop was also proposed by Harris and Jenkins [5] as a means to provide an in process sweep to an inline filtration assembly in natural gas sampling. This is currently marketed as TrueProbe® by Mustang Sampling.

Another well-known implementation of the concept was developed by Hobre. 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 fluid from the flow system, preferably through means of a double block and bleed valve. The double 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.

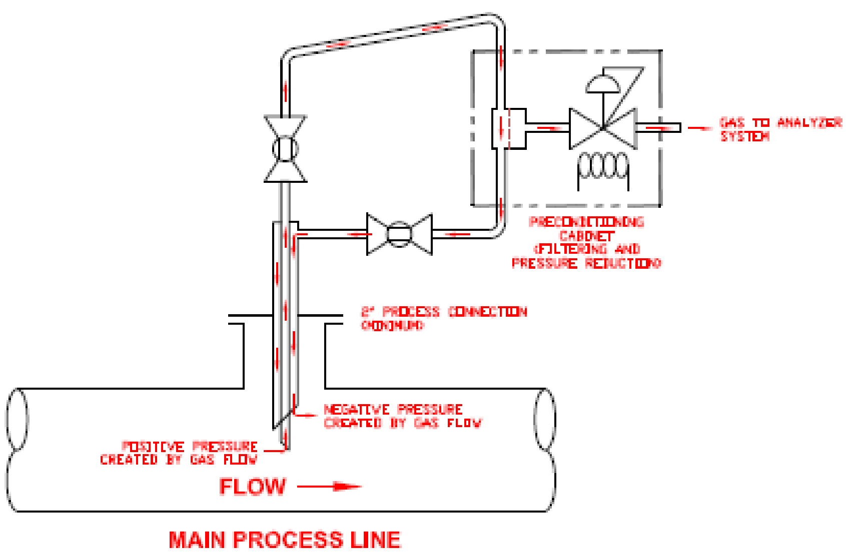


FIGURE 6. HOBRE FLOW IMPACT PROBE

OPTIMIZATION AND IMPROVEMENTS

Probe assemblies which are using the process flow dynamics can only generate limited amounts of differential pressure. In the best of cases, the maximum amount of differential pressure which can be generated to drive flow is ρv^2 where ρ is the density of the process fluid and v is velocity of the flow in the pipe. There are several shortcomings to many of the existing designs which prohibit them from providing the maximum around of differential pressure and flow rate.

First is the position of the return port. In many designs the return port is oriented to face downstream of the direction of flow in the belief or assumption that this is where the lowest pressure return point will be. As noted by Exxon, and as computational fluid dynamics shows, the lowest pressure occurs on the sides of the cylindrical probe tube.

A second limiting factor is the construction of the entry port where flow enters the probe. In the conventional systems this is a 90º bend which causes the flow to impact on the wall and some of the differential pressure is lost through the abrupt change in flow direction. Computational fluid dynamics has shown that the shape can be optimized to minimize pressure loss during the acceleration associated with the change of direction of flow, and this optimization improves the overall flow and utilization of differential pressure.

Optimization of the probe involved a number of considerations, such as making the probe tip out of a solid piece of material by either 3D printing, casting or machining allows more flexibility in geometry than fabricating the probe tip by bending and welding tubing. This additional design flexibility allows the design to be optimized to generate higher pressure differentials, higher induced flow rates, and less sensitivity to orientation that previous designs. Specific improvements include:

- Changing size and shape of elliptical inlet opening to both increase induced pressure differential and reduce orientation sensitivity as compared to probe tips made from bent tubing where the opening size and shape is dictated by tubing size and bend radius. This ability to change the opening geometry also makes it possible to create probes for small process pipes where an elliptical opening with transverse rather than vertical major axis can be used to reduce required probe insertion length.
- Optimizing contours of internal passages on both the inlet and return sides of the probe to include features such as bends with non-parallel and non-constant radii of curvature, gradual tapers/transitions, chamfers and radii provides higher flow rates because of reduced pressure drops. This is especially important for viscous liquids. The ability to have non-parallel and non-constant radii of curvature can also provide higher pressure differentials by keeping the first section of the inlet passage more horizontal than what is possible with bent tubing style and especially 45° cut style designs.
- Connecting the inside tubing to the probe tip by forcing the inside of the tubing over a taper on the probe tip, eliminates the extra welding of previous designs, which simplifies assembly, lowers cost, and allows replacement of the inside tube if required.
- The two return ports on the sides of the probe tip (at approximately 90°) to the inlet port were included in the 1971 Exxon Patent, but this new design incorporates internal baffles in the

probe tip to eliminate cross flow between the two ports that can be created by small pressure differentials between the two sides of the probe. These internal baffles reduce performance sensitivity to probe orientation by allowing the two side ports to function independently.

- Manufacturing the probe tip as a single component by 3D printing, casting, or machining reduces manufacturing tolerances compared to welded bent tubing designs and so improves repeatability in performance.
- Manufacturing the probe tip as a single component by 3D printing, casting or machining makes it possible to change the external contours of the probe tip to incorporate variable diameters and streamlined shapes to reduce the pressure drop and flow disturbance that the probe creates in the process pipe. This also makes it easier to make probes for smaller process connections such as ½" NPT.
- Version with internal shaft installed in probe body allows the probe tip to be rotated for alignment with process flow before locking in place with locknut or other locking means. This design also make it possible to align probe when process is pressured up which is not possible with previous tubing style probes installed with a compression fitting. Grooves on the OD of the shaft allow the process fluid flow through the probe to be routed through optional isolation valves.

Note we commonly refer to this as a "Scoop" probe do to the shovel like head shown in Figure 6.

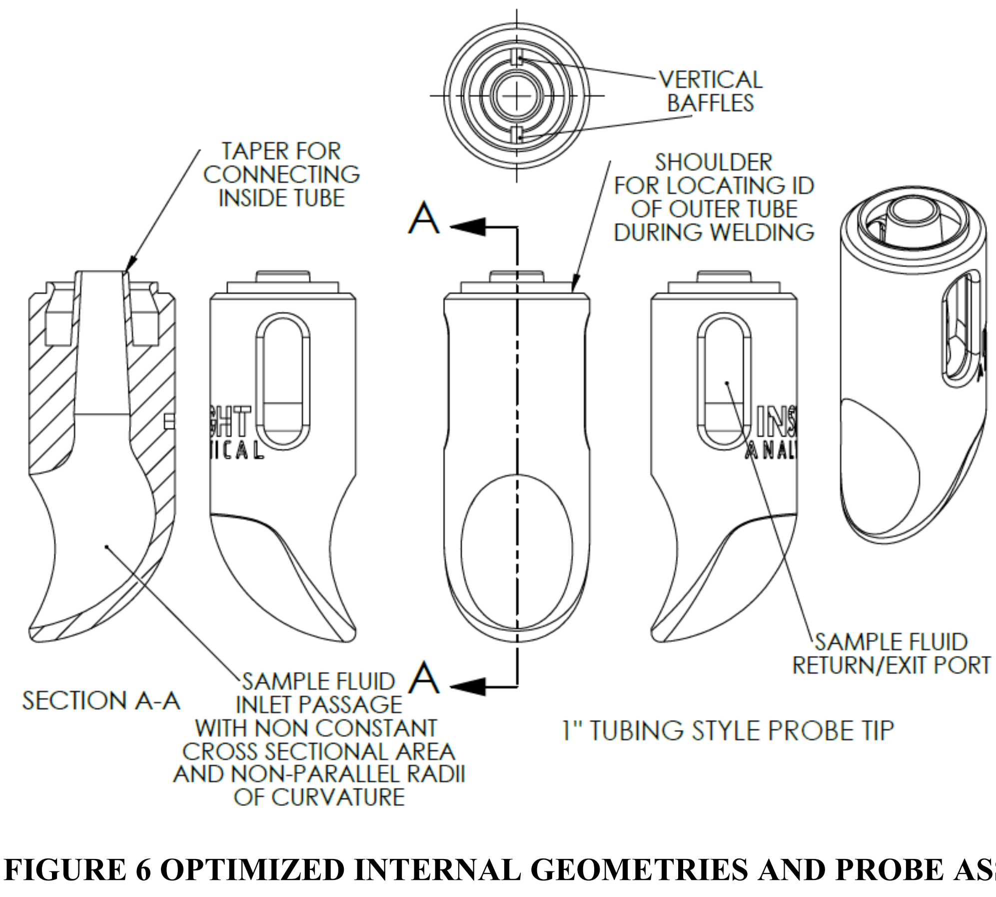


FIGURE 6 OPTIMIZED INTERNAL GEOMETRIES AND PROBE ASSEMBLY

APPLICATIONS AND IMPLEMENTATION

Scoop probes have unique advantages in a variety of applications. In the gas phase, they can be used to provide a continuous flow of sample which is returned to the process. This minimizes environmental releases and the amount of gas returned to flare headers. Scoop probes may also be used to ensure that we have fresh samples at a grab sample station while again mitigated environmental releases.

In liquid phase, probes such as this can help overcome the difficulty of finding a suitable vent or return point when sampling. While gases may often be returned to the flare header, liquid samples often require a low pressure process return point, long and expensive fast loops, expensive pumps and/or elaborate sample recovery systems. In many applications, the implementation of a scoop or fast loop probe can reduce sample system complexity and reduce response times.

GAS PHASE APPLICATIONS

Scoop probes or fast loop probes work extremely well in gas phase applications. The fact that gases are of low density, low viscosity and are compressible all contribute to ensuring that a scoop probe will work well to provide continuous fast loop flow. One of the primary advantages of this is the mitigation of environmental releases from fast loop vents. The scoop probe can be employed in applications where the process gas is at very high pressure and still returns the fast loop to process.

In Figure 7 two relevant configurations and applications are shown. In the first, the probe is used to provide a fast loop directly to a measurement device, which could be:

- An inline sensor such as O2 or Density,
- A grab sample or composite sample point, or
- An inline measurement head such as a Near Infrared Cell or a Raman probe.

In the second, the probe ensures a representative sample is flowing through the bypass filter before conditioning.

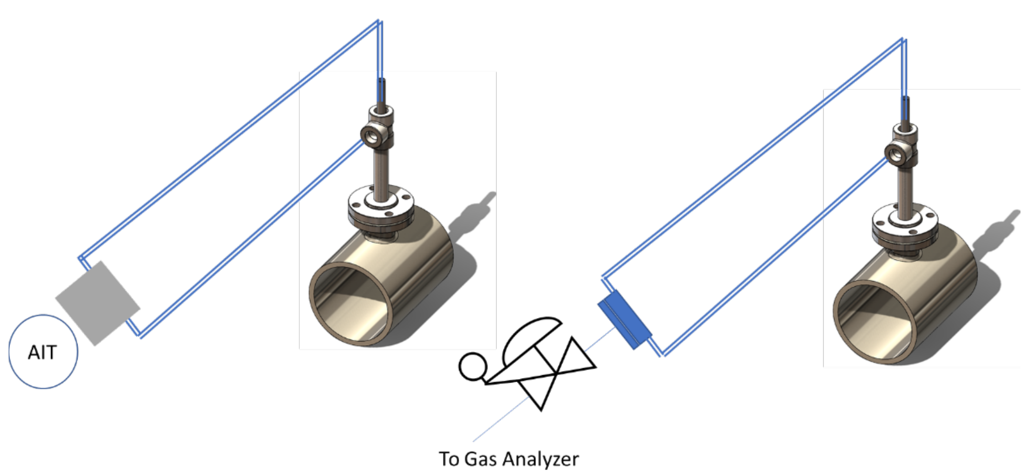


FIGURE 7 A) FAST LOOP TO SENSOR B) FAST LOOP TO CONDITIONING

In each case above, the scoop or fast loop probe ensures that free process gas is flowing past the fast loop filter or the sensor and is returned to process, mitigating environmental emissions while providing rapid response.

LIQUID PHASE APPLICATIONS

The scoop probe is equally applicable to liquid phase sampling applications, the some additional concerns during project engineering must be addressed. Liquids have much higher density than gases and as such the effect of height changes and hydrostatic head become much more important. From Bernoulli's Equation (Equation 1) we see that the velocity changes are associated with the pressure changes, however, there is a term involving the hydrostatic head.

$$P_1 + \frac{1}{2} \cdot \rho \cdot {v_1}^2 + \rho \cdot g \cdot h_1 = P_2 + \frac{1}{2} \cdot \rho \cdot {v_2}^2 + \rho \cdot g \cdot h_2 \qquad (1)$$

The amount of differential pressure which can be developed in a flowing stream is small and may be insufficient to overcome a large amount of hydrostatic head which will occur if we try to make the system flow uphill.

Ideally, the probe will be installed off the side of the flowing liquid pipeline, as shown in Figure 8. As well, it is best if the probe is installed on a pipe run which is above the height of the analyzer or measurement point. While at first glance this may seem problematic, it actually provides a solution to a major problem at many GC applications. It is not uncommon to see a vaporizing regulator installed on a process line high up in the pipe racking with no reliable and safe access to the sample point. Furthermore, vaporizers mounted at the sample tap often don't have any fast loop or bypass flow and as a result have a substantial time delay on the inlet side to the vaporizer [1].

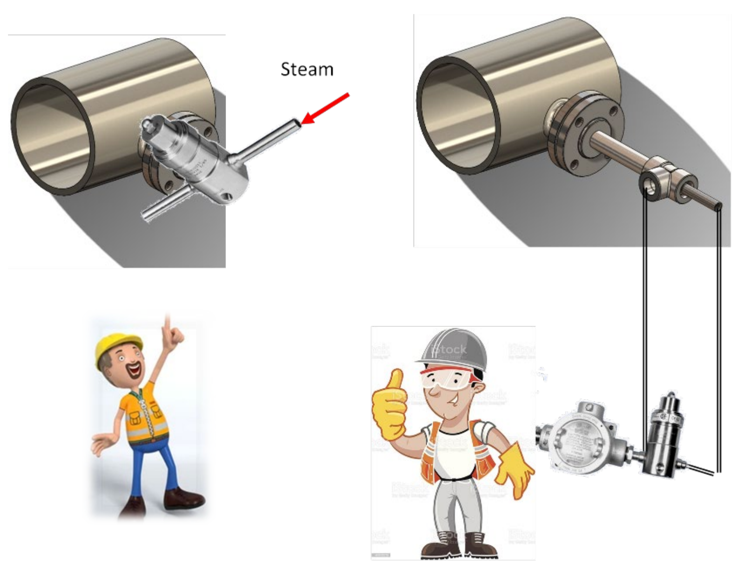


FIGURE 8. STEAM VAPORIZER IN PIPE RACK VERSUS FAST LOOP TO GRADE AND MAINTAINABLE

Similarly, the use of a scoop probe to create a fast loop that requires no pump or additional sample transport mechanism provides an economical and reliable method to optimize systems for composite samplers, for inline analyzers such as FT-IR, NIR and Raman analyzers as well as to optimize flow paths for grab sampling stations.

CONCLUSIONS

Process flow can be used as the driving force to generate differential pressure and flow in grab sampling, composite sampling and analyzer sample systems. With careful engineering design the amount of differential pressure can be optimized and flow rates may be maximized for improved response times. The use of such systems mitigates environmental releases and allows process fluids to be returned directly back to the process they were sampled from.

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