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Engineer's Guide to Gas Metering & Analysis

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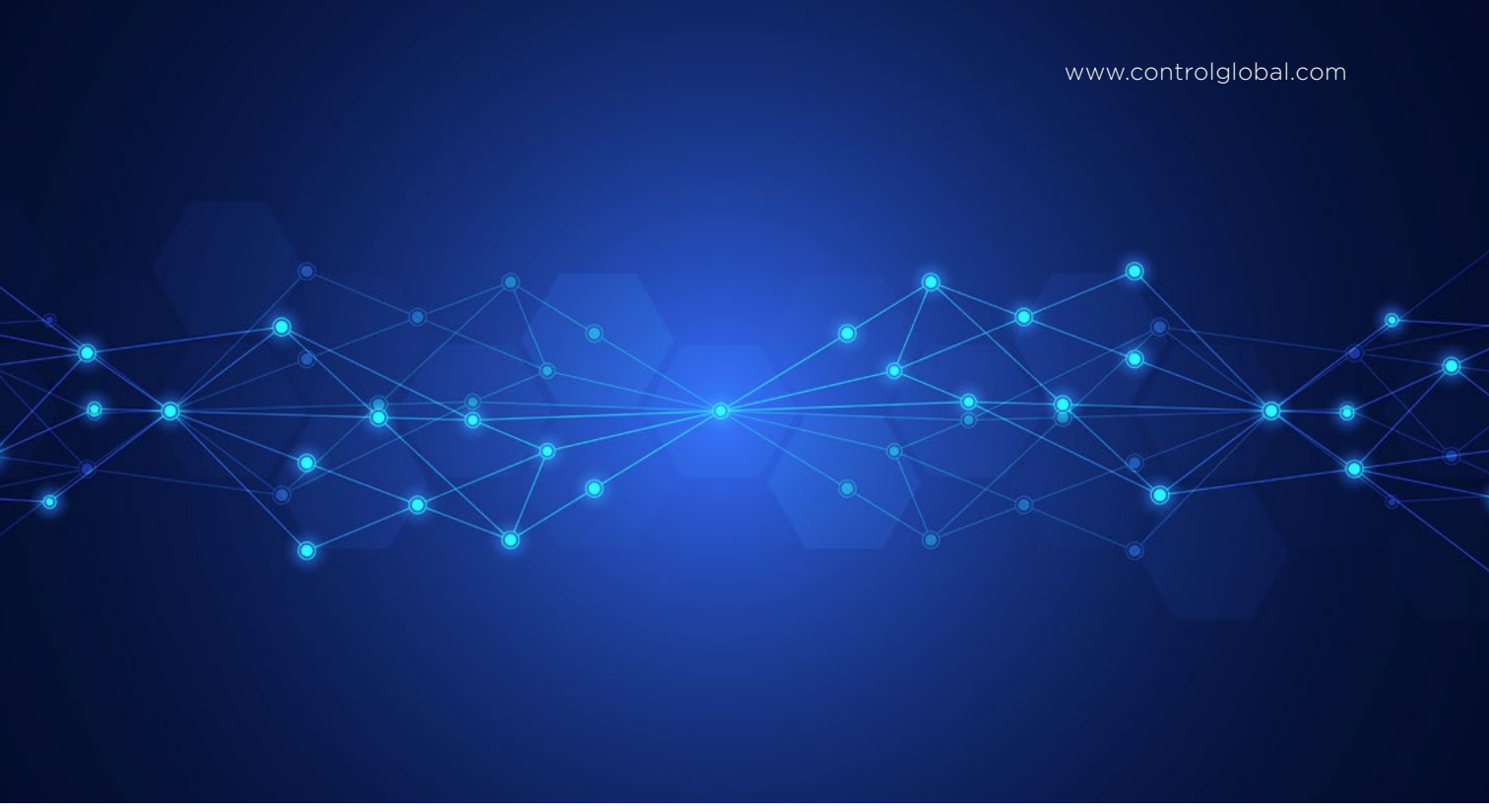

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FLOWSIC600-XT: THE BEST MEASURING PERFORMANCE FOR LOST AND UNACCOUNTED FOR GAS

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Sensor Intelligence.

In order to meet the growing demand for natural gas while also battling cost pressures and environmental sensitivities, there is a need for an intelligent measurement solution that enables accurate and reliable measurement of natural gas flow. With SICK's ultrasonic gas flow meter, FLOWSIC600-XT, you can get the best possible measuring performance for lost and unaccounted for gas. With the built-in i-diagnostics™ solution, you'll get intelligent application diagnostics and measurement data. Ultrasonic gas meters from SICK deliver maximum measurement accuracy, long-term stability, and unrivaled operational safety. We think that's intelligent. www.sick.com

Why and how to use ultrasonic flowmeters for flare flow metering

Accurate flare flow metering is important to account for production and energy loss

By Fawaz AlSahan

Accurate flare flow metering is important to account for production and energy loss, closing the gaps in the plant mass balance, and in reducing emissions and protecting the environment.

USING CLAMP-ON ULTRASONIC FLOWMETERS FOR FLARE

Clamp-on ultrasonic flowmeters can't measure low-pressure flared gas in a metallic pipe because the flared gas has lower acoustic impedence than metallic pipes. This causes the acoustic signal to travel in the pipe and not to the second transducer across the pipe.

To address this limitation, there are two solutions. One option is to increase the flared gas pressure, which is difficult to accomplish. The other is to install a clamp-on flowmeter on a nonmetallic pipe. This will lower the acoustic impedence of the pipe and increase the possibility of acoustic signals traveling across the pipe and measuring the flow. Using a nonmetallic pipe in the flare header is also a challenging option and will require a very comprehensive assessment before implementation.

Existing industry regulations and standards provide helpful guidelines by defining the acceptable accuracy limits for flare flowmeters. The challenge has always been how to reveal the flowmeter inaccuracy and minimize errors in flare flow measurement. We've found practical tools to properly select, configure, install, test and maintain flowmeters in flare ap-

	Actual volume	Standard volume	Mass
Case 1—Propane increased			
Differential pressure meter	34%	34%	25%
Thermal flowmeter	2-15%	2-15%	35-45%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	0%
Case 2—Hydrogen added			
Differential pressure meter	31%	31%	45%
Thermal flowmeter	100-300%	100-300%	300-700%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	112%
Case 3—CO_2 increased			
Differential pressure meter	9%	9%	8%
Thermal flowmeter	2-5%	2-5%	15-20%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	15%

TABLE I: ERRORS RELATED TO USING A FIXED COMPOSITION*
***The approximate measurement error under constant flow conditions when using a fixed composition of 1% CO2, 0.9% H2S, 97% methane, 1% ethane and 0.1% propane and the flare composition changes to:**
Case 1: 0.53% CO2, 0.47% H2S, 51.08% methane, 0.53% ethane, 47.39% propane
Case 2: 0.4% CO2, 0.36% H2S, 38.8% methane, 0.4% ethane 0.04% propane, 60% hydrogen
Case 3: 12% CO2, 0.8% H2S, 86.22% methane, 0.89% ethane, 0.09% propane
Source: API MPMS 14.10

plications, and how to determine the flaring source using the built-in features provided by these flowmeter technologies.

Each of the different flowmeters used for flare applications has limitations. For example, differential pressure (DP) flowmeters such as orifice plates and pitot tubes are sensitive to fouling and composition changes, and will require frequent calibration. Conventional thermal flowmeters are also sensitive to fouling, liquid and composition changes, and will require frequent calibration unless they have automatic composition measurement and correction. Vortex flowmeters also have limitations in sensitivity to fouling and liquid, maximum flow capacity and maintenance difficulties.

An experiment (Table I) was carried out to demonstrate the possible errors in flare flow measurement using different types of flowmeters with different gas compositions. Because of the accuracies demonstrated in

Table I and the above considerations, this article focuses on the use of ultrasonic flowmeters for flare applications.

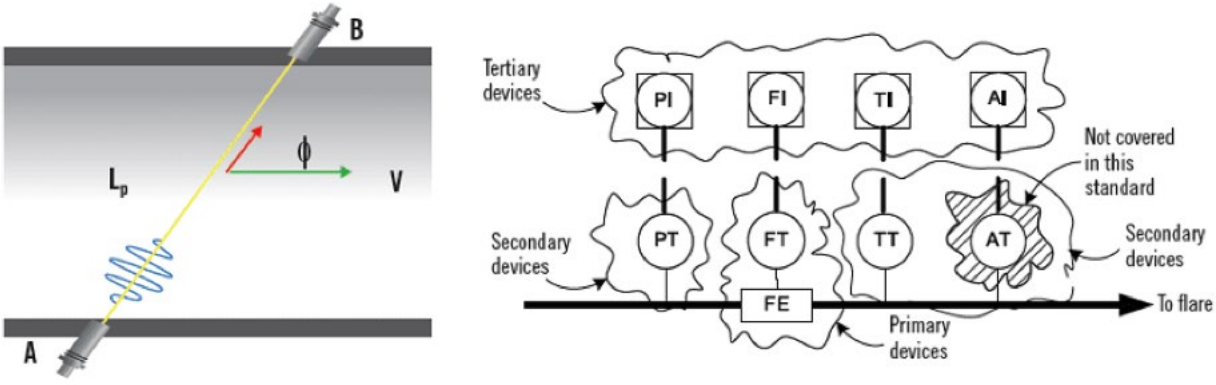
FLARE FLOWMETER CHALLENGES

Flare applications introduce many challenges on flow measurement and flowmeters, the major ones being:

- Flare can have a very low flow (0.01 m/sec) and a low pressure drop across the meter (typically 0.5 psig is required).
- The flow can be non-axial and asymmetric. Laminar-turbulent transition flow introduces inaccuracy, and stratification (by sun or wind) can happen and affect the flow profile. Pulsating flow is also possible as the gas entry to the flare header is not continuous.
- High flow may cause low signal-to-noise ratio and probably liquid carry-over. High CO2, H2S, N2 and H2 can cause attenuation to the signal.
- Flare flow has a large turndown (2,000-4,000:1) and the gas composition is variable.
- Primary flow elements have uncertainties due to electronics drift, metrological (pipe diameter, alignment) and process buildup. Secondary instruments (temperature and pressure) have uncertainty due to electronics drift, mounting location and process buildup.
- The application might require a dual-path ultrasonic flowmeter (i.e., two sets of transducers) to either improve accuracy, cover very low flow conditions, or reduce the straight piping requirement.

ULTRASONIC PRINCIPLE OF OPERATION

Ultrasonic flowmeters (UFM) can be either insertion or cross-pipe. Both types are installed as single- or dual-path. These flowmeters (Figure 1) determine the flow



ULTRASONIC ESSENTIALS

Figure 1: Ultrasonic flowmeters determine the flow velocity by measuring the difference in the travel time for a pulse moving from one transducer at one side of the pipe to another one at the other side and vice versa. Secondary instruments for pressure and temperature are required to calculate the volumetric flow at standard conditions. Source: API MPMS 14.10, SIO 17089-2

velocity and speed of sound by measuring the difference in the travel time (tab - tba) for a pulse moving from one transducer at one side of the pipe to another one at the other side (tab) and vice versa (tba). The transducers are inserted through the pipe wall, either by hot tapping or as an inline flowmeter (installed on a spool pipe). The flowmeter calculates the flared gas velocity (V), volumetric flow at operating conditions (Qact) and volumetric flow at standard conditions (Qstd).

Sound velocity (C) is also calculated by this flowmeter. The value of sound velocity is used to estimate the molecular weight (MW) of the flare gas mixture. A mathematical or graphical correlation is experimentally extracted by testing many gas mixtures and defining their sound velocity and MW relationship. MW measurement helps in calculating the density and therefore the mass flow.

Secondary instruments for pressure and temperature are required to calculate the volumetric flow at standard conditions. The setup of these secondary instruments is shown in Figure 1 or as advised by the flowmeter's manufacturer.

Referring to Figure 1, the main equations are:

- V = [L /(2cosØ)] x [1/tab-1/tba]
- C = [L/2] x [1/tab+1/tba]
- Qact = V x pipe area
- Qstd = Qact x P/Ps x Ts/T

Where:

- V: flow velocity
- C: sound velocity
- Qact: volumetric flow at actual flow conditions
- Qstd: volumetric flow at standard flow conditions
- L: distance between transducers
- tab: time for signal travel from transducer a to transducer b (and vice versa for tba)
- T, P: operating temperature, pressure
- Ts, Ps: standard temperature, pressure

SPECIFICATION AND TESTING

ISO 17089-2 and BS 7965 define the required flowmeter uncertainty in flare application to be ≤10% for the flow above a certain minimum limit. This uncertainty can increase by 5% due to flowmeter installation effects. The flare flowmeter needs to be tested at the factory or at a third-party calibration shop. The main testing requirements are:

- Air is usually the testing media. A Reynolds number is used to account for differences in densities (between air and flared gas composition).
- Expansion of the flowmeter shall be considered in high velocity.
- Testing shall cover 0.03 m/s to the maximum design velocity. The flowmeter shall be tested at velocities 0.03, 0.15, 0.30, 0.61, 1.5, 3.0, 6.1, 15, 30 and 15 m/s increments up to the maximum operating velocity.

- The flowmeter shall be tested with the same pipe size and upstream/downstream straight piping.
- Pressure transmitter accuracy shall be maximum ±0.67 kpa.
- Temperature transmitter accuracy shall be maximum ±2 °C.
- The testing facility shall be traceable to NIST or equivalent national or international standard, and shall be accredited by ISO/IEC 17025.
- The factory and testing facility shall provide all the testing data and records of the installation, configuration and diagnostics data at the test bench.
- The manufacturer shall provide the flowmeter uncertainty and the installation effects.
- Testing shall be done at a low pressure and at ramping up and down.

INSTALLATION AND COMMISSIONING

Requirements stated in API MPMS 14.10 and 22.3, ISO 17089-2 and BS 7965 will help users reach an accurate flare flow measurement. The major points to follow are:

- Manufacturer or manufacturer-certified entity shall be responsible to install and commission the flare flowmeter and all secondary instruments. This will eliminate critical problems, like transducer misalignment.
- The end user shall decide early on the installation approach (i.e., hot tapping, cold tapping or a complete spool piece). Definitely, the last option is the best option as it will eliminate all installation errors.
- Transducers shall be retractable to allow online removal for testing and replacement.
- Recommended piping straight run is generally 20 diameters (20D) upstream and 10D downstream. This requirement can be relaxed based on the specific flowmeter installation and manufacturer recommendations, which must be verified.
- The end user shall consider accessibility for flowmeter maintenance and gas manual or automatic sampling.
- Pressure and temperature sensor mounting locations shall follow the flowmeter manufacturer's recommendations.
- Vibration shall be avoided by selecting the right location for the flowmeter and its associated panel.
- Any control valve with noise attenuation or fittings up or downstream shall be checked, as this can produce interference with the transducer pulses.
- The installation shall avoid liquid accumulation.
- Rapid pressurization or depressurization when removing or installing transducers shall be avoided.
- Manufacturer shall provide the accuracy impact when replacing any part or software of the flowmeter system.
- The hardware serial numbers, firmware and testing shall be submitted by the vendor.

- All data and software configuration in electronics are saved as a backup. After commissioning, management of change (MOC) is required.

FIELD VERIFICATION

To verify the reading of an installed ultrasonic flare flowmeter, there are many techniques. The steps and tools below can be used:

- The flowmeter manufacturer shall be requested to provide a written procedure for functionality testing and verification, inspection intervals and dimensional verification. Also, uncertainties and speed of sound calculations shall be provided.
- Wall thickness, inclination angle of transducers, length of acoustic path, the pipe internal diameter and pipe cleanness shall be verified.
- Installed meter specifications and current operating conditions shall be checked to match the flowmeter's specification sheets and drawings.
- The installed flowmeter configuration and serial number shall be verified with the manufacturer requirements.
- Straight piping and installation of the meter, pressure and temperature transmitters shall be verified.
- Wiring shall be inspected for signs of moisture or physical damage.
- Performance of the flowmeter using the same transducers model and the same installation setup at a calibration shop can be checked. This is to verify the accuracy of the installed flowmeter, considering the same straight piping and mounting of the current field installation.
- The ultrasonic flowmeter reading can be verified using a secondary device such as:

1. A second insertion flowmeter (such as a pitot tube).
2. Optical method (laser doppler anemometer tracer), which requires a steady velocity.
3. Tracer dilution technique: injecting a gas (like SF6 or helium) and measuring the flow rate increase using a secondary flowmeter.
4. Radioactive tracer: introducing a gaseous radioactive tracer and inserting two detectors to detect the passage (based on transit time). BS-5857-2 can be referenced for details.

- The transducers and the electronics can be verified using a zero flow box. This will provide zero calibration of transducers, and will also check speed of sound measurement for air compared to the estimated value (performed by the manufacturer software). Also, zero testing can be done for the electronics and cabling using dummy transducers and checking the signals.
- Absolute speed of sound (C) comparison, like injecting N2 and determining C.
- Verification of the ultrasonic flowmeter can be also done by taking a sample of the flared gas and measuring SOS, and then comparing the measured value to the flowmeter estimated SOS. Difference shall be less than 0.25%.

- Another verification tool is comparing C and the velocity reading of one path, and comparing it to the second path. This is only applicable for dual path measurement (i.e., when two sets of transducers are installed).
- Flaring volume could be estimated by conducting mass balance or using process simulation, and the result can be compared to the flowmeter reading.
- Computational fluid dynamics (CFD). This is a modeling and verification technique, which is a cost-effective solution and helps to reveal installation errors. Also, it provides a correction for the flow profile and the missing straight piping run. The flow is modelled in 3-D coordinates considering turbulence and wall roughness. Manufacturers of flare flowmeters or some flow calibration labs can provide this service.

ONLINE PERFORMANCE MONITORING

Ultrasonic flowmeters have the advantage of providing online diagnostics. Diagnostics can be used to check the health, performance and the accuracy of the flowmeter without the need to remove and physically check, calibrate or replace any part. Once the flowmeter is proven to be correctly selected, installed and commissioned, diagnostic parameters can be collected and used as a baseline for future online performance monitoring.

The flare flowmeter manufacturer shall be requested to provide detailed diagnostics parameters along with their acceptable limits. Having these diagnostics parameters in the local display and also reflected in the remote workstation (i.e. distributed control system) is crucial for online performance

DETERMINING FLARING SOURCE

Observing flared gas and not being able to determine which operating flare branch it's coming from is very frustrating for operating facilities. In many circumstances, the source of the flared gas is a leaking valve. However, identifying which valve and from which operating unit is difficult and time consuming.

An ultrasonic flowmeter offers a solution to this problem because the most valuable advantage of the technology is the sound velocity measurement. There's a determined sound velocity value for every type of gas and for every mixture of gases. Knowing the sound velocity will determine the molecular weight and composition of the flared gas. Knowing the composition will help the operating facility identify the potential sources of flaring. This is a unique feature of ultrasonic flowmeters.

monitoring. The main diagnostics parameters to be displayed and monitored are:

- System diagnostics: Transducers and electronics functionality check, flow profile. This diagnostic parameter helps with the recalibration decision.
- Speed of sound (C): The measured C and the actual C can be compared to check the health of the flowmeter. Actual C is calculated using a gas sample and the flowmeter manufacturer software. Also, compare the initial flowmeter C reading and the current C.
- Signal strength/quality indicator: Signal-to-noise ratio (SNR) indicates the quality of ultrasonic signals. Distribution of SNR among transducers might indicate a source of a problem such as noise.
- Automatic gain control (AGC) level: As meter performance deteriorates, AGC level increases and a fault happens.
- Flow profile: A change in flow profile indicates viscosity changes and/or changes to pipe wall roughness.
- Axial velocity through the flowmeter.
- Meter performance: The ratio of transducers good pulses received to rejected pulses received. As the flow rate increases, meter performance decreases. Performance also decreases with a decrease in pressure.
- Temperature: Can indicate stratification in the gas flow.

Following the above steps will assist end users in evaluating their installed flare flowmeters and could also result in modifying or even replacing existing flowmeters to fix the system performance and installation errors.

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- Saudi Aramco best practice (SABP-J-202)—flowmeter for flare application

Basis hydrogen

Versatile gas analysis in the production of ammonia

HOW SICK CAN HELP YOU GAIN THE HIGHEST LEVEL OF GAS ANALYSIS IN AMMONIA PRODUCTION

Ammonia is a material that influences food production more than others may expect. As the main component in the production of nitrogen fertilizers, ammonia is used in a wide range of industrial processes due to its physical and chemical properties. The basis for the production of ammonia on an industrial scale is hydrogen. Since hydrogen typically does not occur as a natural resource, it is generated on a large scale by various chemical processes.

The most important processes for hydrogen generation are steam reforming of light hydrocarbons, partial oxidation of hydrocarbons, or carbon and water electrolysis. Steam reforming of natural gas is the dominating technology with about 90% of worldwide production of hydrogen. SICK offers customized gas analysis for process and emission monitoring for industrial processes related to ammonia production.

CONTROLLED WORLD GROWTH

As a starting material for a wide range of products such as fertilizer and nitric acid, ammonia is one of the most produced chemicals in the world. In 2018 alone, more than 150 million tons were produced. The Haber-Bosch process for ammonia synthesis is considered one of the most important chemical processes of the 20th century and has a huge effect on the world population due to its widespread use in fertilizer production. The hydrogen needed

for ammonia synthesis is produced and purified in several steps as described above in the steam reforming process.

The hydrogen then reacts with atmospheric nitrogen at high pressure and temperature and becomes ammonia. The high reaction speed and material throughput require efficient process control in every step. Continuously measuring extractive gas analyzers can monitor H_2, CH_4, CO, CO_2, and NH_3 and offer significant advantages compared to gas chromatographs thanks to their robustness and ease of use.

In the ammonia synthesis, CO and CO_2 would function as catalyst poison and cause salt formation. That is why they must be removed before the synthesis step. To minimize disruptions by CO and CO_2, even very small amounts in the ppm range must be detected.

FERTILIZER FROM NITROGEN

Nitrogen is one of the bases for the growth of plants. Plants cannot absorb the nitrogen contained in the air we breathe. Through ammonia synthesis and the fertilizer created in this way, nitrogen becomes a nutrient for plants. The "bread from air" comparison was created during the discovery of the Haber-Bosch process about 100 years ago. Interestingly, the property of "air," or more accurately the composition of the gases, still plays a decisive role today in the successful process of ammonia production. Gas analysis systems with a modular design are extremely useful for monitoring and guaranteeing this condition.

For example, SICK's product range includes a special solution for monitoring the efficiency of the steam reformer and control of the downstream shift converter by measuring methane (CH_4) and carbon monoxide (CO). This solution can be implemented by SICK with the S700 or GMS800 extractive gas analyzers from SICK. However, there are different licenses available for the industrial production of ammonia with various technologies. Which license is selected also depends on the raw materials used as well as the surrounding conditions.

In principle, the solution described above can be transferred to other licenses for ammonia synthesis based on steam reforming. Customer and system-specific adaptations required for this measurement can be implemented by SICK.

THE HIGHEST LEVEL OF GAS ANALYSIS

SICK offers analysis solutions for the entire ammonia synthesis process and some subsequent processes. Experts from SICK support in the selection of the right products for the respective application. The S700 and GMS800 therefore build the foundation for customized gas analysis for process and emission monitoring for hydrogen and ammonia production. All relevant gas compo-

nents for this process can be measured with both the S700 and GMS800 – with up to three or even six different analysis modules.

Different housing types are available depending on the measuring task, location of use and ambient conditions. This also includes a wall housing with ATEX certification for explosion-hazardous areas, which is suited for industrial environments. Equipped with modern software, the GMS800 also features all the interfaces required for remote monitoring via networks through to the connection to a distributed control system.

For more information on SICK's gas analyzers, please contact a SICK representative today.

Basics of Analyzer Sample Systems

Here's How to Know Your Process Conditions by Calculating Dead Spaces, System Lag Time and System Pressure Drop, Simplifying a Planned System and Picking the Right Equipment for It

By Ian Verhappen

If you had to design and install a process analyzer sample system today, how would you do it? First, remember that an analyzer system includes the sample tap, sample system, analyzer, sample return, signal transmission and control system. If any of these components fail, your company won't gain the economic benefits the system was supposed to produce. And don't forget, it's generally accepted that sample systems are victims of the Pareto principle, which is that 20% of a system consumes 80% of the resources because they're responsible for 80% of analyzer system problems.

While the engineer's golden rule of "keep it simple, stupid" (KISS) also applies to sample systems, this time it also stands for: Know your process conditions; Involve the right people; Simplify the system; and Select the right equipment.

GET THE RIGHT PEOPLE

In addition to process engineers, a project team will involve several other people as well. A likely group will include the following:

A chemist — A representative from the laboratory who will not only provide the stream composition but also know the present method of analysis used on the stream.
Maintenance/Analyzer Technician — A person, or group of people who must be involved from the beginning, not only to gain get a sense of ownership of the process, but also to

understand the technology and equipment before it arrives on-site to get commissioned.

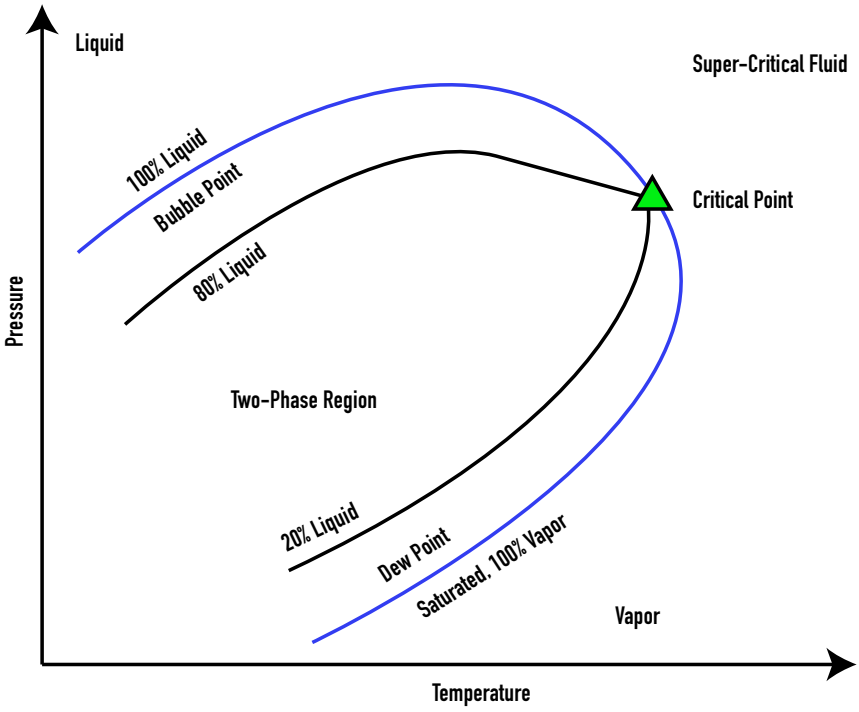
Project Manager — A person who coordinates the entire project, gets the funding, arranges for necessary approvals and other important duties as they come up.

KNOW THE PROCESS CONDITIONS

It's important to understand the process conditions, not only at the sample inlet, but also at the analyzer and all along the sample loop.

To do this, three basic calculations must be made: 1) dead spaces; 2) system lag time; and 3) system pressure drop.

Using this information, a phase diagram (Figure 1) should be generated for all sample streams. This diagram represents how the fraction of liquids, solids and vapors change as a function of pressure and temperature. It is invaluable when trying to determine if there are condensable products in the stream that can later be vaporized as the pressure decreases. This is similar to checking for cavitation in control valve sizing, only in reverse, since rather than looking for vapor in a liquid, one is looking for a momentary liquid phase in a vapor stream. A process or chemical engineer can generate this diagram, along with a range of pressures and temperatures over which the system may be operating, from the stream composition.

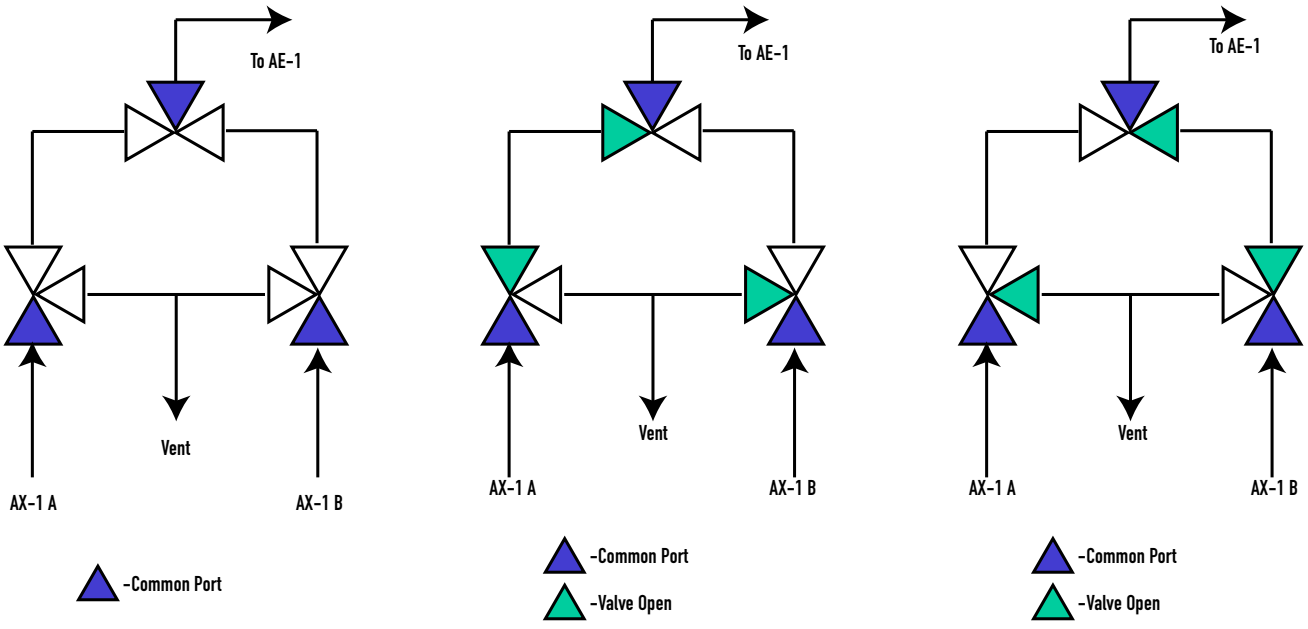


GAS, LIQUID AND SOLID

Figure 1: An example of a phase diagram shows how the fraction of liquids, solids, and vapors change as a function of pressure and temperature.

DEAD SPACES OFTEN OVERLOOKED

One of the biggest and often overlooked items when designing a sample system is dead spaces or volumes. Dead spaces are parts of the sample system where pockets of fluid can become trapped and can't move along with the remainder of the sample. Perfect places for dead volumes are tee fittings, separators or any other sharp-edged flow change. To minimize its effect, use the following rules:



LESS DEAD TIME AND DEAD VOLUME

Figure 2: A sample system configuration that is designed to minimize dead volume (left), as well as a configuration designed to minimize dead volume—AX-1A on analysis (middle), and configuration designed to minimize dead volume—AX-1B on analysis.

- Minimize tee fittings in the system;
- Purge the sample system three times for each analyzer cycle;
- Use the smallest size fittings able to do the job within other constraints;
- Use the minimum number of fittings possible, which reduces dead time and minimizes potential leak or failure points;
- Operate your continuous sample systems in the turbulent flow regime.

For example, the first column of Figure 2 shows a configuration designed to minimize dead volume. The three-way valves eliminate elbows, and when a stream isn't flowing to the analyzer for measurement, it's still flowing to a vent or sample return point, ensuring a continuously fresh sample at every point in the system. The second two columns show the configuration when streams AX-1A and AX-1B, respectively, are being analyzed.

LAG TIME DEPENDS ON VELOCITY AND VOLUME

The second item to consider and one of the first things to calculate is the system lag time. System lag time is the sum of the analyzer cycle/measurement time and the sample lag time. Meanwhile, sample lag time is the amount of time it takes for the sample to travel from the sample point to the analyzer sensor. It's simply the volume of the sample system divided by the velocity of the flow and can be calculated using Equation 1.

$$t = \frac{V \times L \times P_a \times Z}{F_s \times T_a}$$

Where:

t = time

V = sample system volume

L = distance from the sample point to the analyzer sensor

Pa = absolute pressure

Z = compressibility factor

F_s = flow rate under standard conditions

T_a = absolute temperature

COMPRESSIBILITY IS A FACTOR FOR GASES AT HIGHER SYSTEM PRESSURES

For liquids, compressibility is negligible and the compressibility factor is Z = 1.0. However, in gas systems operating at more than about 35 to 50 psia, compressibility must be considered. For gases, compressibility changes as a function of pressure and temperature according to the rules of the ideal gas law, as shown in Equation 2

$$Z = \frac{P_a V}{nRT_a}$$

Where:

Z = compressibility factor

P_a = absolute pressure

V = volume

n = moles of fluid

R = gas constant

T_a = absolute temperature

The compressibility factory Z can be determined from compressibility charts and the associated reduced temperature Tr and reduced pressure Pr.

The reduced temperature and pressure are calculated as follows:

$$T_r = T_a / T_c$$

$$P_r = P_a / P_c$$

Where:

$T_c = y_1 T_{c1} + y_2 T_{c2} + y_3 T_{c3}$ ... (y_x is the mole fraction and Tcx is the critical temperature of component x)

$P_c = y_1 P_{c1} + y_2 P_{c2} + y_3 P_{c3}$ ... (y_x is the mole fraction and Pcx is the critical pressure of component x)

In addition, don't forget that the ideal gas law uses absolute pressures (P_a) and temperatures (T_a), so calculations must be done in psia or kPa (abs) and degree Rankine (R = F + 460) or degrees Kelvin (K = C + 273.15). Also, by combining and rearranging Equation 2 at two conditions and neglecting n, which remains constant, it is also possible to estimate the effect of pressure or temperature on volume.

$$\frac{Z_2}{Z_1} = \frac{P_2 V_2 T_1}{P_1 V_1 T_2}$$

Thus,

$$\frac{V_2}{V_1} \approx \frac{P_1}{P_2} \qquad \frac{V_2}{V_1} \approx \frac{T_2}{T_1}$$

Where:
Subscript 1 refers to the inlet condition
Subscript 2 refers to the outlet condition.
Calculate Sample Flow
If you have a certain size and length of line and want to figure out an appropriate sample flow rate (F_s), at standard conditions, rearrange Equation 1 as shown in Equation 3

$$F_s = \frac{V \times L \times P \times Z}{t \times T}$$

Once you know the volumetric sample flow rate (F_s in liters/min), you can determine the velocity (v in ft/sec) of a stream using Equation 4.

$$v = \frac{F_s \times 0.1079}{D^2}$$

Where:
F_s = volumetric sample flow rate (liters/min)
0.1079 = a conversion factor to get the final result into ft/sec
D = internal pipe diameter (inches).

As a general rule of thumb, the sample system velocity should be in the range of 1 to 2 m/s (3 to 6 ft/sec) to ensure that any components in the sample are carried along with the sample proper and do not drop out of solution.

SYSTEM PRESSURE DROP ON VELOCITY

The pressure drop in the system can be calculated using the sample system velocity calculated in Equation 4. This is not as difficult as it sounds, although it is important. Often the hardest part of the exercise is getting an estimate of the stream properties. The equation for pressure drop per 100 feet of tubing is shown in Equation 5.

$$\Delta P_{100} = \frac{0.13 \times f \times \rho \times v^2}{D}$$

Where:
ΔP_{100} = pressure drop per 100 feet of tubing (psi)
f_d = Darcy Friction Factor
ρ = density (lb/ft3)
v = velocity (ft/s)
D = pipe diameter (inches)

To calculate the Darcy friction factor (f_d) we need to calculate the Reynold's number, as shown in Equation 6.

$$\mathrm{Re} = \frac{\rho D v}{\mu}$$

Where:
R_e = Reynolds number
ρ = density
v = velocity
μ = viscosity

If the Reynolds number is less than 4000, the Darcy friction factor is calculated as shown in Equation 7

However, if the Reynolds number is greater than 4000, then A.K. Jaini's non-iterative equation can be used, as shown in Equation 8.

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log\left(\frac{\varepsilon}{D} + \frac{21.25}{Re^{0.9}}\right)$$

Where:

f = Darcy friction factor

ε = absolute roughness in inches

D = diameter of the pipe in inches

R_e = Reynolds number

Meanwhile, the Moody friction factor, also known as the Fanning friction factor, is one quarter (+) the Darcy friction factor calculated in Equation 7 or Equation 8. Make sure you know which friction factor you're using and, if needed, adjust accordingly.

The last step in the pressure drop calculation is to determine the equivalent length of pipe. The equivalent length (Le) is a parameter used to represent the total length of pipe of a single diameter that would be equivalent to the actual pipe with all its fittings and line size changes. Crane Technical Paper 410-C is the standard that is used to obtain these parameters.

The Crane standard uses the concept of "equivalent length" to assign a factor to each type of fitting or change in pipe diameter to a length of straight pipe that would equate to the same pressure drop as the fitting. Each type of pipe change is assigned a "K" factor as a function of a nominal friction factor (ft). The Crane factor (ft) is a function of nominal pipe size. The equivalent length K factor in the Crane manual is empirically determined from experimental data. After the K factors have been determined for all the fittings, they're summed, and this total equivalent length is then added to the actual pipe run length to calculate a total equivalent length. For example, a pipe system with two 90° elbows and plug valve, the calculation would be as follows:

(f_t) = 0.027 (from the Crane Manual)

Plug valve: K = 18 ft (from the Crane Manual)

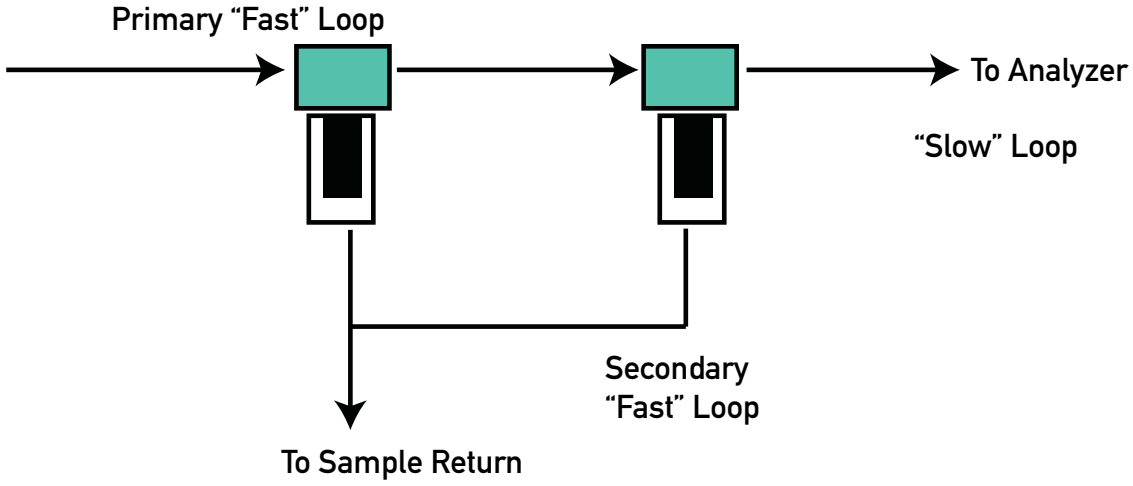
Elbow: K = 30 ft (from the Crane Manual)

Therefore, L_e = (1 x 18 x 0.027) + (2 x 30 x 0.027) = 2.1 feet.

Using this total equivalent length, the system pressure drop can be calculated. Because this exercise is performed so often, two spreadsheets were developed to calculate a simple pressure drop using Equations 6, 7 and 8. Spreadsheet A is for calculating the pressure drop in a vapor line. Spreadsheet B is for calculating the pressure drop in a liquid line. (For links to these spreadsheets, go to the online version of this article at www.controlglobal.com/samplesystems.)

Finally, the last two rues for pressure drop calculations are:

- If the calculated pressure drop is greater than one-third of the total pressure (i.e., inlet pressure divided by three), then calculation should be done in shorter segments, so the outlet pressure of the segment is greater than one third the inlet pressure of that segment.



QUICK LOOP

Figure 3: A fast loop is an external loop with minimal sample conditioning that's cycled to a close proximity to the analyzer and from which the actual sample to the analyzer is taken.

- Elevation differences between the inlet and outlet of the sample system must be taken into account for liquid streams (the affect on vapor streams will be negligible). Remember, it takes 10.84 psig to move a column of water up a 25-foot pipe rack. Conversely, and more likely, a water stream gains 10.84 psig on its way down from the same pipe rack. This could make a difference in how you set your pressure relief valves.

The equation to be used is:

$$\Delta P = \frac{\rho \times g \times \Delta h}{g_c}$$

Where:

DP = pressure drop (feet of liquid or meters of liquid)

r = density (lb/ft^3 or kg/m^3)

h = height (feet or meters)

g = local acceleration due to gravity (ft/sec or m/sec)

g_c = gravity constant (32.17 ft/sec or 9.814 m/sec)

SIMPLIFY THE SAMPLE SYSTEM

The easiest way to simplify a sample system is to make sure only the sample you need is collected. Start with the sample tap itself. Taps can be designed in one of the following three ways, and should ideally be installed on vertical pipe runs.

- Continuous, in which a representative continuous slipstream of the process fluid is withdrawn and transported to the analyzer, is the most common sample system. To be representative, the sample probe must extend into

the center third of the process pipe.
- Isokinetic and its probe are designed to remove a sample from the stream at the same level of kinetic energy, normally represented as velocity, as the process stream itself. It's used in multiphase streams to insure all components are sampled.
- Discrete. In difficult streams, which are usually extremely hazardous, corrosive or dirty, the most reliable sampling system may be discrete, in which only a small aliquot of the process fluid is transferred as a plug from the sample tap to the analyzer.

To further improve samples from the system, users should seek to minimize dead volume by designing the system so there's always a continuous flow in all lines by selective use of three-way sampling valves. If the stream isn't routed to the analyzer, then route it to either a vent or a recovery system. This also results in a lower lag time. Another way to avoid the problem of dead volume is to insure that the sample system is swept through three times per analysis cycle.

This raises and compounds another common problem with sample systems—the analyzer only requires a very low flow rate. Thus, a fast loop is often used (Figure 3). A fast loop is an external loop with minimal sample conditioning that is cycled to a close proximity to the analyzer and from which the actual sample to the analyzer is taken. A common way to separate the secondary (slow) loop from the primary or fast loop is to flow the sample through a bypass filter. The stream that passes through the filter is the slow or analyzed loop. The fast loop remains unfiltered and also removes any excess material that is trapped or coalesced on the filter.

Another important consideration is material compatibility, not only to the process fluid but also to the ambient atmosphere and plant conditions. Most designers are very aware of the process compatibility and normally specify 316SS as their tubing material, going with more exotic materials only when required. However, 316SS is not a good choice where it can be exposed to seawater. The chlorine in seawater will cause the metal to fail in a short period of time. Another choice, Tygon tubing, should not be used if it could be exposed to sunlight. After exposure to the ultraviolet light in sunshine for three to four years, the tubing becomes brittle and fails.

The only remaining problem is how to move all this material around the sample system. This is ideally done through judicious selection of the sample source and return points. If at all possible, two process points of sufficient differential pressure drop should be selected, so no prime mover is required in the sample system. If a prime mover is required, the normal choices are a centrifu-

gal pump, positive displacement pump or an eductor.

If a positive displacement pump is used, then be aware that it tends to require more maintenance than a centrifugal pump because it has more moving parts, and will likely introduce a pulsating flow to the system. A positive displacement pump also has advantages; it is a constant-volume device, and typically has a much higher differential pressure output.

If an eductor is used, then be sure to check the phase diagram to insure that the process liquid doesn't enter the eductor at less than 25 °F below the bubble point. If it does, experience has shown that there is sufficient pressure drop in the eductor throat to cause the fluid to vaporize (cavitation), and so most of the energy introduced to the eductor to induce flow in the secondary stream will be lost.

SELECT THE RIGHT ANALYZER

After doing all the calculations to ensure that your analyzer system will operate properly, it's vital that the sample system be linked to the analyzer itself. In most cases, the analyzer selected will dictate to some degree the type and size of sample system installed. However, if the analyzer is not suitable or able to detect the components of interest in the general surrounding process stream, then all is for naught.
In conclusion, the three Rs of analyzer selection are:

- Reliability—The analyzer must be highly reliable so it will maintain a service factor in excess of 95%.
- Repeatability—The output of the equipment must be repeatable for a given input. It need not be accurate (though, of course, this is desirable), but it must always give the same numeric output for a given calibration or process sample.
- Return—Every analyzer system installation must have an economic return or justification. If it is not used for some form of continuous monitoring or control, then the unit will not get the attention it receives to remain in operation at the required service factors to be considered reliable.

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Modular Gas Analyzer SICK GMS800 Overview

The SICK GMS800 is an innovative family of extractive analyzers which can measure more than 60 different gases. The GMS800 is characterized by its modular design: seven analyzer modules, one gas module, I/O module, and a local operating/display unit. Standard 19″ racks can be used for economic system integration in cabinets. Wall mounting enclosures with optional Ex approval for hazardous areas can be used in rough industrial environments. Equipped with modern software, the GMS800 comes with all the standard interfaces for remote control via networks through to connection to process control systems.

GMS800 GAS ANALYZER

RELIABLE GAS ANALYSIS FOR PROCESS AND EMISSION MONITORING

The modern DEFOR (NDUV/UVRAS) analyzer is a specialist for extremely selective NO measurement, while also providing direct monitoring of NO_2 and SO_2. The highly selective UNOR (NDIR) analyzer is especially insensitive to external vibrations due to its variably adjustable chopper frequency, and the multi-component MULTOR (NDIR) analyzer can measure of up to 3 gases plus H_2O for internal cross-sensitivity correction. Internal calibration cells are optionally available on all three analyzer modules.

Oxygen measurement is provided by the high precision OXOR-P paramagnetic analyzer, also available in solvent-resistant or corrosion-resistant, or the electrochemical OXOR-E module. Rounding out the range of gas modules is the THERMOR thermal conductivity analyzer, and the FIDOR flame ionization detector (FID) for continuous measurement of hydrocarbon emissions.

YOUR BENEFITS

The GMS800 is approved to all worldwide emission monitoring standards, and can be installed in general purpose or Ex areas (NEC 500/505 Division/Zone 2) without purging. Easy maintenance and simple upgrade of existing installations is possible due to the modular design, as well as minimal service and repair effort due to replacement of complete modules or assemblies. Reliable measuring results are guaranteed by proven measurement technology and minimal influence of ambient temperature through thermostatically controlled modules. Save on expensive test gases and the long-term cost of daily validation with optional internal calibration cells, and NOX monitoring without a catalytic converter by direct measurement of NO and NO_2.

TYPICAL APPLICATIONS

- Emission measurements at very low concentrations, e.g. in power plants, cement plants or waste incineration plants, and in the pulp and paper industry
- Measurement of very low SO_2, NO, and NO_2 concentrations, e.g. from gas turbines
- Efficient emission monitoring in denitrification plants by direct measurement of NO and NO_2 as well as summation to total NO_X in the analyzer
- Furnace gas measurement in iron and steelmaking industry
- Reliable CO monitoring for explosion protection in coal mills and coal bunkers/silos
- Efficient process gas analysis in applications of the chemical and petrochemical industry
- High H_2S content in reactive or sour gases
- Quality audits in air separation plants and purity measurement of gases, e.g. < 1 ppm CO concentration in H_2 in hydrogen production

Accurately scoping process analyzer projects

This article covers the formal details of a project approval scope document, including front-end engineering design, front-end loading, project execution modeling, and independent project analysis.

By Gary Nichols, PE, Jacobs Engineering Group

The first article in this series ("How to Launch an Analyzer System Reliability Program," Control, July 2006, pp 49-53) noted the close relationship between the lifetime cost of a process analyzer project and the attention given to reliability during the concept (scope development) and design (detailed engineering) project stages. This article covers the details of a project scope document.

One of a project engineer/manager's most challenging jobs, especially during project scope development, is the avoidance of "meatball engineering"—a poorly scoped project that leads to minimally effective results. (Gregory Hale, InTech, Oct. 2004) Key to this avoidance is "knowledge management" and "good client" development, says Hale.

The engineer must elicit from the client—the funding source—all the information required for a good project and gently, but persistently, minimize chances that he becomes his "own worst enemy," causing unwise scope-cutting or, conversely, "scope creep," or demanding procedural shortcuts, illogical cost-cutting and schedule changes. The project engineer must ensure communication with clients or accept--often unjustly--responsibility for missing project goals, and it falls to him or her to make sure this doesn't happen. (Mark Hoske, Control Engineering supplement, Dec. 2004, pp.12-14)

The information that must be addressed is often part of the front-end engineering design, the front-end loading, the project execution model, and the independent project analysis. (R. Mead, H. Sedgwick, and S. van Soest, Hydrocarbon Processing, Sept. 2004, pp. 69-74)

Now we shall address formal details of the project approval scope. Following are the working assumptions:

- The analyzer project engineer begins with a brief capital work order that includes an operative statement, such as, "Install analyzer on West Final Purification Tower to measure residual reactant." Other information includes a desired project completion date, the purpose of the project (safety, environmental, economic expansion, etc.), and sufficient technical detail for the engineer to generate a few questions for the first user-client inquiry.
- The management approval package must include a written scope, cost estimate (+/-10%), preliminary impact review (personnel and process safety, environmental and utility), red-lined (marked with additions, changes and demolitions) drawings, project schedule and analyzer, and associated instrument specifications.

We shall concentrate on the written scope, which probably has a standard format, but note that other documents frequently contain information needed to develop the project scope and, conversely, that the project scope will eventually be reflected directly or indirectly in the other documents.

Table I shows a typical project approval scope document structure. For simplicity, let us assume that the detailed estimate document generally follows the structure of the detailed scope, and that the latter does not include dollar amounts.

TABLE 1:

Typical Project Approval Scope of Work Document Structure

1. Project Title and Number
2. Project Purpose
3. Brief Project Scope
4. Brief Project Justification
5. Detailed Scope
6. Potential Construction Problems
7. Potential Cost Problems
8. List of Supporting Documents

Table 2 shows the detailed scope structure that would be included under Item 5 in Table I.

TABLE 2:

Typical Work Types Included in Detailed Scope

• Architectural and landscaping
• Civil
• Foundations
• Structural and pipe racks
• Roadways and yards
• Railroads
• Waterways and navigation

• Below-ground piping, trenches, ditches and excavation
• Mechanical
• Unfired pressure vessels
• Fired pressure vessels
• Storage tanks
• Rotating equipment
• Above-ground piping
• Instrument and Electrical
• Field instruments (other than final control elements and pressure safety devices)
• Final control elements
• Pressure safety devices
• Local signal cabling (analog and discrete)
• Home-run signal cabling
• Rack-room wiring
• PLC and hardwired relay panels
• DCS
• Software
• Computers
• Voice and digital/protocol-based communications
• Motors
• Electrical below 480 Vac (including local wiring)
• Electrical above 480 Vac but below 13.8Kvac
• Electrical above 13.8KV
• Spare Parts
• Commissioning
• Construction Indirects
• Construction management and field supervision
• Equipment rentals
• Temporary changes

Expenses

• Preliminary engineering
• Detailed engineering
• Startup
• Repair and relocation
• Dismantling, demolition, and disposal
• Decontamination and remediation

Table II includes much detail that we don't have space to discuss. Readers will be able to develop scenarios wherein any of these factors could influence—or be influenced by—a process analyzer project. It is highly unlikely that all would be included in a given project, but the wise reader should not be surprised if any one of them is included.

Look closely at the key items in Table II. An analyzer is a field instrument; therefore, the first item under Instrument and Electrical should be carefully worded to describe the proposed system. The words "analyzer system" are important to convey the idea that the project involves more than a single instrument and includes the analyzer or analytical sensor, a sample handling system (SHS) and additional equipment and devices. This document is probably not the appropriate one for these details, but it is important to plant the notion that analyzers tend to be more complex (and expensive!) than conventional field instruments.

As a field instrument, an analyzer system naturally requires local wiring, home-run signal cable, low-voltage power wiring, rack-room wiring and control room (DCS, PLC, etc.) work. These items constitute the probable minimum hardware scope for a process analyzer project.

Non-hardware capital items include commissioning, construction management and

rental equipment. Among the expense items, startup is the minimum (in addition to engineering).

But the scope of most process analyzer projects goes beyond these "minimums." An analyzer is a "field instrument," which puts it in the same category as temperature, pressure, flow and level transmitters, all of which measure extensive properties. But an analyzer measures chemical composition, which is an "intensive property" of the manufacturing process at a given point, making it inherently more complicated than its conventional counterparts, and making system project scopes longer and affecting more scope line items.

With an active client, the analyzer project engineer should not be alone in the effort to develop an acceptable detailed scope. Each project should have safety, environmental and utility reviews early in scope development and feasibility study. These reviews usually require a face-to-face meeting among at least some of the project team members and have a set format or form. These reviews often clarify, suggest or require the addition of many of the scope items. If allowed under the review procedure, these meetings are an excellent opportunity for the analyzer project engineer to ask explicitly about these scope items and listen to client concerns not previously raised.

Most line items in Table II will have direct labor and direct material costs, reflected on the estimate page of the project approval package. Table III is a list of typical red-lined drawings that would accompany the project approval scope and that would clarify and amplify the verbal content of the written scope for all members of the project team.

TABLE 3:

Typical Redlined Drawings and Sketches for Analyzer Project Scope Development

Required/Minimum

• Piping and instrument drawing (P&ID)
• Instrument loop sheet
• Instrument location drawing

As Needed/Usually Helpful

• Process flow drawing (PFD), may be called energy and material balance
• Sample handling system (SHS) drawing or sketch
• Analyzer system elevation drawing or sketch
• Photos

The analyzer system project engineer may also wish to use drawings from other disciplines such as site plans and elevations, piping isometrics and vessel drawings to clarify scope.

ABOUT THE AUTHOR

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