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SAMPLING SAVVY

Because power plant operating decisions often rely on water and steam chemistry information, a properly designed and operated water and steam sampling system must be in place to ensure accurate sampling data.

Corrosion in boilers and steam turbines is among the most expensive causes of outages in utility and industrial power plants. Deposits and scale buildup reduce efficiency and capacity in many units. To control corrosion and impurity ingress, important cycle streams must be continuously or periodically sampled and analyzed. Deposits or chemical reactions in the sampling system and a nonrepresentative sample withdraw can lead to large sampling errors. In water chemistry and corrosion control audits, sampling problems were found in approximately 70 percent of the plants.[1]

A recent steam plant audit found that an improperly designed sampling system had prevented plant personnel from identifying severe deposition. The cycle chemistry control was ineffective because it was based on analysis results that were in significant error. Sampling system deficiencies included nonisokinetic sampling, large diameter (0.5 inch) sample tubing, full-time sample filtration, poor control of sample temperature, and slow sample flow velocity in the tubing (0.1 ft/sec to 1 ft/sec). Severe deposit buildup in the sample tubing regularly resulted in plugged sample lines. The large sample filters also periodically plugged (Figure 1) and had to be replaced.

Figure 1. Blowdown sample filter plugged with iron oxide (~ 50 grams)

Because the samples contained relatively low concentrations of corrosion products when they reached the analyzers and grab sample locations, plant personnel did not identify the high concentrations of corrosion products (iron oxide). The sampling system oxides also reacted with other water and steam impurities, influencing pH, conductivity and other control parameter monitoring.

In steam plants, the chemical parameters of interest include: pH, conductivity, sodium, calcium, magnesium, chloride, sulfate, fluoride, phosphate, acetate, formate, propionate, total organic carbon (TOC), silica, copper, and dissolved and suspended iron (oxides); at concentrations from 1 part per billion (ppb) to several parts per million (ppm).[2]

SAMPLING SYSTEM DESIGN

A meticulously performed analysis is of little value if a bad sample is used. To produce a sample that is representative of the sampled stream, the proper design of a sampling system is critical.[3,4] Sample withdraw, transport, collection and handling are often major sources of errors that can lead to incorrect or unnecessary corrective actions. Table 1 illustrates the large number and variety of sampling errors.

A typical sampling system consists of an isokinetic sampling nozzle, isolation valves, sample tubing, a primary cooler (for steam and high temperature liquid samples), a secondary sample cooler, pressure reduction and total flow regulation valves, a distributor for individual analyzers and grab samples, back pressure regulator, and sample drains (Figure 2). All sampling system components should be made from stainless steel to prevent the components from corroding and contaminating the sample.

The isokinetic sampling nozzle (Figure 3) is a critical part of the sampling system. If designed incorrectly, the nozzle could provide a sample that is not representative of the conditions in the pipe. In addition, the effects of vortex shedding on vibration and the strength of the nozzle attachment to the pipe must be considered during nozzle design to prevent high stresses and potential failures.

WHY ISOKINETIC SAMPLING?

In isokinetic sampling, all phases (solid oxides and precipitates, liquid droplets and vapor) of the sampled fluid enter the sampling nozzle with the same velocity vector (velocity and direction of flow), and the flow velocity into the nozzle is the same as the mainstream velocity. Primarily, isokinetic sampling is necessary because the sampled stream is almost always a two-phase fluid (gas-liquid, gas-solid, liquid-solid) and the second phase has a very different chemistry composition than the steam or water.[6] In addition, the second phase (droplets or particles) has a different density and inertia than the primary phase (gas or liquid) and therefore would not be proportionally represented in a sample that is not withdrawn isokinetically. The benefits of isokinetic sampling were verified during an EPRI development project[6] and independently[3]. For steam sampling, the sample error when using a pipe surface tap is approximately 50 percent.

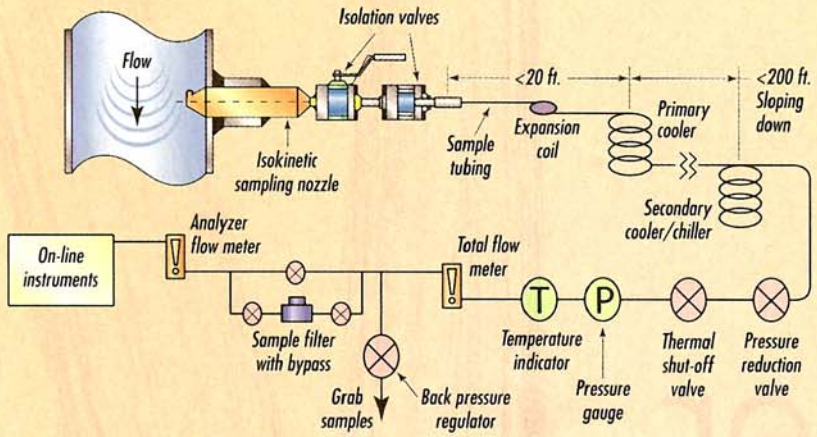
Figure 4 shows the recommended locations for isokinetic sampling nozzles and an example of parameters commonly monitored at the economizer inlet along with their normal limits.[2]

SAMPLE TUBING CHARACTERISTICS

All sample tubing should be made from stainless steel. In addition, sharp radius bends should be avoided and the number of bends should be kept to a minimum. The length of the sample tubing should be kept to a minimum to limit both the pressure drop in the system and the lag time from when the sample enters the nozzle to when it reaches the analyzers.

Sample tubing between the nozzle and the primary cooler should be as short as possible (less than 20 feet)

FIGURE 2
EXAMPLE OF A GOOD SAMPLING SYSTEM



to reduce the possibility of impurity deposition in the sample tubing as the sample begins to cool. The ID of this sample tubing should be close to the nozzle bore size to minimize changes in cross-sectional areas. The tubing should form an expansion coil after the isolation valves to allow for any movement or expansion of the pipe.

Sample tubing located after the primary sample cooler should be short (less than 200 feet to the sample panel) and downward sloping. It should be sized so that the sample flow velocity is 4 ft/sec to 6 ft/sec[1,5-8] to minimize deposition in the sample lines and to reduce the time required to achieve equilibrium between impurities in the flowing sample and the tubing. Several studies have shown that linear velocity rather than Reynolds Number (Re), a unitless dimension that describes the amount of fluid turbulence, controls the net deposition of particulates in sample lines.[9-11] Therefore, turbulent flow alone (Re > 4,000) is not sufficient when sampling high purity streams where impurity concentrations are measured in ppb (steam, condensate, feedwater).

An EPRI experiment determined that it took less than 30 days to reach equilibrium when the sample was flowing at 6 ft/sec compared to several years for a sample flowing at 1 ft/sec.[10] Low sample residence time in the tubing is also needed because it limits chemical reactions, such as oxygen scavenging and sorption on oxides. The sample velocity should be kept as constant as possible to maintain equilibrium between particle deposition and particle re-entrainment and chemical equilibrium between the sample and deposits.

Large diameter tubing can result in an unnecessary waste of sample water, require impractical sample-conditioning equipment, and place an extra and expensive burden on the make-up system. Table 2 compares sampling rate, Re, estimated pressure drop, and the annual volume of water consumed for several tubing sizes with a sample flow velocity of 5 ft/sec.

ADDITIONAL CONSIDERATIONS

Other considerations when designing a sampling system (Figure 2) include:

- ***Nozzle Installation Location.*** *The preferred nozzle location is in long vertical sections of pipe, away from all flow disturbances (bend, valves, etc.). Ideally, the nozzle should be at least 35 internal pipe diameters downstream and four pipe diameters upstream of any flow disturbances. If this is not possible, the nozzle should be positioned so that the ratio of its distance from the upstream disturbance to downstream disturbance is about 9-to-1. If a long vertical section is not available, the nozzle may be installed in a long horizontal section, provided the nozzle is installed on the top of the pipe between the 10 o'clock and 2 o'clock position to keep the nozzle dry during inactive periods.*
- ***Isolation Valves.*** *These valves should be rated for the application temperature and pressure and provide a minimum change of cross-section between the bore of the sampling nozzle and the orifice of the valve. Valves should be made of stainless steel.*
- ***Primary and Secondary Sample Coolers.*** *Counter flow*

TABLE 1
CAUSES OF SAMPLING ERRORS (IN ORDER OF PRIORITY/IMPACT)

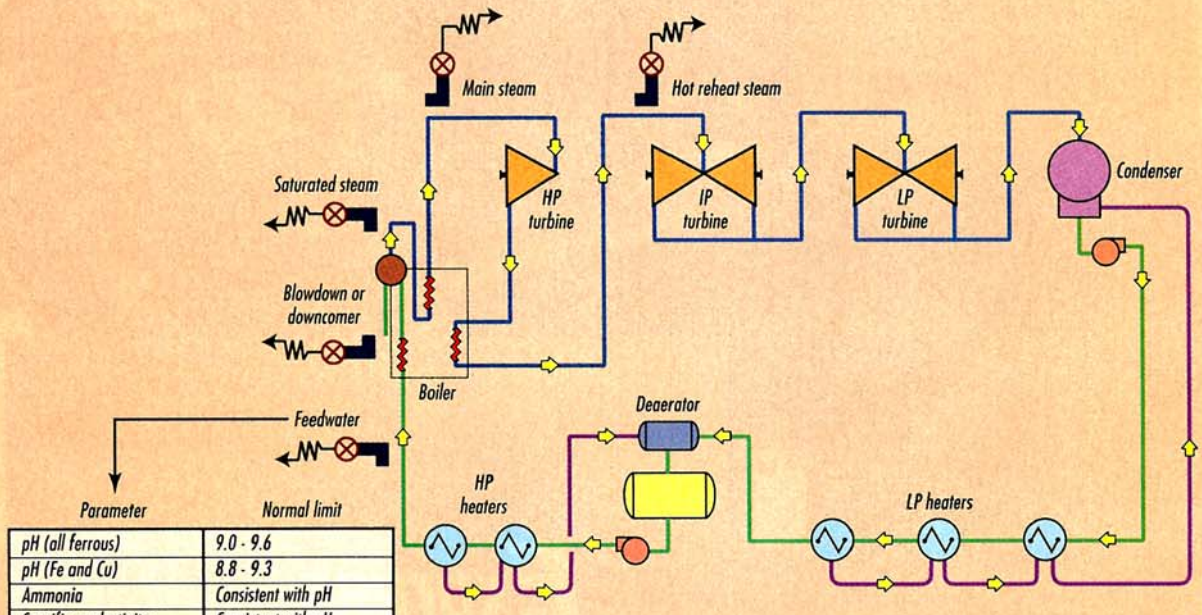
• Sample Withdrawal
* Sample does not represent the sampled stream (wall effects, stratification, nonisokinetic, mixing, etc.)
* Sample does not represent all phases (solid, liquid, gas)
• Deposition in sample line (could also result in plugging)
• Deposit release (leading to spikes)
• High pressure drop resulting in insufficient sample flow
• Changes in sample flow rate
• High sample temperature (causing pH and conductivity errors)
• Chemical reactions in sample lines or coolers (oxygen reduction, etc.)
• Deposition in the pressure-reducing device
• Dissociation of water in the pressure reducing device — forming $O_2 + H_2$ (high pressure and high temperature water)
• Cooling water leaking into the sample - leaking sample cooler
• Corroded sampling system - corrosion products are generated
• Filters in the sampling system interfere with sampling suspended solids
• Sorption on sample tubing and suspended oxides removes a portion of monitored chemical species
• Air leaks into grab sample container (increases O_2 and conductivity, reduces pH, possibly introduces bacteria)
• Metal species dissolve or precipitate and plate-out in the sample tubing and containers

designed coolers should be used and sized to ensure adequate cooling capacity, allowing for reduced heat transfer due to scaling. When sampling steam, the primary cooler acts as a condenser. The coolers should be made from stainless steel or Inconel.

- ***Pressure Reduction Valve.*** These valves are used to reduce pressure and therefore control a cooled sample's flow to protect online instruments and plant personnel. For samples equal to or greater than 500 psig, the pressure reducer should be a rod-in-tube type orifice or capillary, and for samples less than 500 psig, the pressure reducer should be a needle valve.[6]
- ***Thermal Shut-off Valve.*** This valve protects personnel and downstream components by automatically interrupting sample flow when the sample temperature reaches a preset limit in the event of an insufficient amount or loss of cooling water or a fouled sample cooler.
- ***Pressure and Temperature Gauges and Flow Indicator.*** The indicator provides the operator with verification that the system is working properly.
- ***Back Pressure Regulator.*** The regulator maintains a slight pressure (approximately 20 psia) in the sample tubing before the grab sample location. This ensures proper flow to the online instruments.
- ***In-line Sample Filters.*** During commissioning, or any other time high concentrations of corrosion products (iron, copper) are present in the sample, in-line sample filters should be installed to protect online instruments. These filters should be installed after the grab sampling line (Figure 2) or must be removed when obtaining grab samples for iron and copper analysis.
- ***Online Analyzers.*** The sample flow rate, temperature and pressure must be within the instrument manufacturers' specifications. A chiller may be required to cool the

Figure 3. Weld-in Style EPRI Single Port Isokinetic Sampling Nozzle

FIGURE 4
RECOMMENDED LOCATIONS FOR ISOKINETIC SAMPLING NOZZLES WITH AN EXAMPLE OF PARAMETERS TO BE SAMPLED AT ECONOMIZER INLET AND RECOMMENDED NORMAL LIMITS



Parameter	Normal limit
pH (all ferrous)	9.0 - 9.6
pH (Fe and Cu)	8.8 - 9.3
Ammonia	Consistent with pH
Specific conductivity	Consistent with pH
Cation conductivity	≤ 0.2 µS/cm
Iron	≤ 10 ppb
Copper	≤ 2 ppb
Oxygen	≤ 5 ppb

sample streams to the proper temperature. ASTM D5127 requires that the sample temperature be 25 C ± 1 C, when measuring pH. ASTM D5391 requires that the sample temperature be controlled to 25 C ± 0.2 C, when measuring conductivity if specialized temperature compensation is not available. Such strict temperature control may not be practical; therefore, modern pH and conductivity analyzers include temperature compensation algorithms.

- ***Booster Pumps.*** *Booster pumps may be required for long sample lines (high pressure drop) or low-pressure samples (condensate).*

Once all the sampling components are specified, the estimated pressure drop (ΔP) through the system should be calculated. The pressure drop throughout the entire sampling system (including primary and secondary coolers, tubing, valves, elbows, etc.) must be low enough to ensure that there is enough pressure to provide adequate flow velocity (approximately 6 ft/sec) through the tubing to the online instruments and grab sample tap (Table 2). A high-pressure drop through the system could result in insufficient sample flow at the sample panel, or the deposition rate in the sample lines could be high, which could result in a plugged sample line or a sample that is not representative of the conditions in the pipe. The design must also ensure that the maximum pressures recommended by the online instrument manufacturers are not exceeded.

COMMISSIONING THE SAMPLING SYSTEM

After the sampling system is installed, the following should be performed to ensure proper operation of all components:

- *Check all sampling points to ensure proper location and sampling nozzle orientation*
- *Verify that all sample tubing and cooling water tubing is properly sized for the required flowrate*
- *Ensure all valves and flowmeters operate properly*
- *Confirm proper flow rate of cooling water to the primary and secondary sample coolers*
- *Check for leaks along the entire length of sample tubing, including the sample panel*
- *Perform startup and calibration of all online instruments in accordance with the original equipment manufacturer's instruction manual*
- *Verify that online instrument readings agree with the DCS readings and that alarms are working properly*
- *Check sample flow rates*
- *Check sample temperatures after primary and secondary sample coolers*
- *Check sample pressure*
- *Ensure flow rate through online instruments meets manufacturer's*

TABLE 2
REYNOLDS NUMBER, SAMPLING RATE, ANNUAL VOLUME AND PRESSURE DROP (ΔP) FOR WATER (T = 100 F) FLOWING THROUGH VARIOUS SIZES OF TUBING AT 5 FT/SEC

OD (in.)	ID (in.)	Wall (in.)	Suggested Maximum Working Pressure Rating of Stainless Steel Tubing (psig)* T = 100 F	T = 1000 F	Reynolds Number	Sampling Rate (cc/min)	Annual Volume (gal/yr)	Estimated ΔP (psi) per 100 feet of tubing
0.250	0.120	0.065	9,590	7,290	$6.8x10^3$	670	93,000	57
0.250	0.152	0.049	7,050	5,360	$8.6x10^3$	1,070	148,000	42
0.375	0.245	0.065	6,110	4,640	$1.4x10^4$	2,780	386,000	24
0.500	0.370	0.065	4,790	3,640	$2.1x10^4$	6,340	879,000	14

*- "Tubing Data," Swagelok Company Product Literature, July 2002

requirement
- *Check for any vibration problems*

OPERATION AND MAINTENANCE

Once the sampling system is installed, accurate sampling must be ensured by following these proper operation and maintenance requirements:

- ***Sampling Time.*** *There should be a minimum of six hours of isokinetic sample flow to stabilize the sample chemistry before taking a sample for analysis. Continuous flow is preferred.*
- ***Grab Samples.*** *These samples should be obtained in accordance with ASTM D3370 and ASTM D4453. Samples to be used for iron analysis (ASTM D1068) or copper analysis (ASTM D1688) should be preserved with nitric acid (HNO_3) to a pH of 2 or less (approximately 2 ml/L) immediately at the time of collection. Samples to be used for TOC analysis (ASTM D2579) should be collected in a TFE-fluorocarbon-lined glass bottle with an aluminum-lined cap and acidified to a pH of 2 or less. If stored more than 24 hours, all samples should be kept refrigerated and analyzed within one week of sampling.*

- ***Calibration and Maintenance.*** *Calibration and maintenance should be routinely performed on all instruments per manufacturers' recommendations. Improperly calibrated and maintained instruments will result in inaccurate measurements, negating all the efforts to obtain representative samples.*
- ***Cooler Cleaning.*** *Periodic cleaning of the cooling-waterside of the coolers may be required to maintain proper heat transfer and sample temperature. Cleaning frequency depends upon the scaling properties of the cooling water.*
- ***Sample Tube Cleaning.*** *Sample tubing should be periodically cleaned by flushing or acid cleaning, or it should be replaced. Cleaning frequency depends on the amount of impurities in the sample streams.*
- ***Safety.*** *The sampling nozzle, weld boss or flange, valves, valve connecting pieces, and all welds should be periodically inspected for cracking and other forms of damage. For sampling wet steam and water, the pipe section after the sampling nozzle should be periodically inspected for thinning caused by flow-accelerated corrosion (erosion-corrosion), and for cavitation in installations where liquid water is sampled.* PE

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