Keys to On-line Monitoring in Steam Generating Systems

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Summary: Successful on-line monitoring in steam generating systems requires conditioning a sample, selecting the correct analyzer, compiling the data in a useful format, interpreting the trends and using the information to identify problems and optimize system efficiency.

INTRODUCTION

On-line monitoring is becoming very common in many steam generating systems. The trend of installing analytical instruments with continuously flowing samples has been driven by improvements in analyzer technology, availability of electronic communication networks and new data acquisition and data management software. Successful transition from using periodic grab samples to using continuous on-line analyzers requires an understanding of the key variables in the sampling, measurement and data management processes.

Obtaining a representative sample on a consistent basis requires equipment to control sample flowrate, temperature and pressure. The basic measurement principles have not changed even though analyzer technology has been transformed by the microprocessor. For example, pH measurements are very temperature-dependent and the sample should be cooled to a standard 25 degrees Centigrade. Often the sample temperature is reported with the pH to ensure correct interpretation of the data. The area of data management is undergoing the greatest transformation as process control systems are linked to desktop personal computers, allowing many users to access data.

This paper will discuss the key issues in the design of sample conditioning systems, the fundamentals of analyzer technology, and the operational improvements resulting from integrating reliable sampling systems with plant processes.

ON-LINE MONITORING ISSUES

SAMPLE CONDITIONING SYSTEM (1, 2, 3, 4, 5, 6, 7)

The purpose of sample conditioning systems is to ensure that the analyzed sample has the proper temperature, flowrate and pressure required for accurate measurement. As processes are automated and monitoring equipment is installed to measure variables "on-line," without an operator handling the sample, the sample conditioning systems become critical to both the accuracy of the analyzer measurement and the automation of that process.

Design Considerations The design of sample conditioning systems has evolved to meet the needs of automating plant processes. Sample conditioning systems can consist of a single line assembly for location in remote parts of the plant or they may be part of the central water quality monitoring panel.

Material compatibility is critical, because contamination of the sample or failure of the component may occur if the incorrect materials are selected. It is common practice to use stainless steel, since it resists erosion, can tolerate high sample temperature and pressure, and will not contaminate the sample. After the sample temperatures and pressures are reduced to controlled levels, it is possible to use inert plastic materials such as those found in many rotameters and analyzer sensors.

Controlling sample flowrate requires devices that are different from those required for controlling pressure. Since flow and pressure are interdependent, design criteria for both parameters are discussed together. Inadequate

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pressure control will affect the sample flow rate and consequently the accuracy of the measurement. Additionally, excessive sample pressure will result in failure for most analyzers and rotameters as well as a risk of injury to operators.

For high pressure samples, a rod-in-tube flow controller (a.k.a. VREL) is often used; a backpressure valve should follow it. If inlet pressure fluctuates in systems with high pressure samples, pressure reduction can also be done using a two-stage pressure regulator followed by a backpressure valve. For intermediate pressure, a needle valve or self-adjusting pressure regulator followed by a backpressure valve is sufficient. Following the pressure reduction, a rotameter is used to control the flowrate to an analyzer.

Temperature reduction is essential to protect the operator, achieve accurate analysis and avoid damage to the analyzer sensor. On most sample conditioning panels, a temperature indicator will allow the operator to confirm the sample stream temperature. The accuracy of most on-line analyses is greatest when the temperature is controlled to a standard 25 degree Centigrade.

To accurately control sample temperature, most plants use plant cooling water for primary cooling and a separate chilled water system for precise cooling to 25^o C +/- 1^o C. Although some analyzers have an automatic temperature compensation feature, this feature is designed to correct for the effects of off-specification temperatures on the sensor's electrode, not the temperature dependence of the analytical test result.

Reliability has become more important as plants reduce operating staff and as on-line measurement is integrated into process control systems. To ensure reliable sample measurements, sample conditioning systems typically incorporate devices that compensate for changing sample conditions and prevent system damage in the event of equipment malfunctions. Often these devices are described as "fail-safe" features.

Fail-safe features are critical to protect the operator and the components of the sample conditioning system from exposure to high temperatures and pressures. In the event of a loss of cooling water or sample cooler failure, a temperature sensor/solenoid shut-off valve can stop the sample flow and trigger an alarm. Often fail-safe features require specific operator intervention to return the sample conditioning system to operation, ensuring that all abnormal conditions are corrected. To protect operators from injury due to failure of a high pressure component, all high pressure components should be located behind the panel front, allowing only the low pressure components to be located on the front of the sampling station.

<u>Panel Construction</u> Sample conditioning systems are typically in service for 15 to 20 years. Panel construction should use stainless steel or steel with corrosion resistant paint. High quality valves and rotameters, and welded, not bolted or fabrication methods should be used to maximize panel integrity, minimize maintenance and extend the system life. Proper design and fabrication has important consequences for safety, maintenance and durability.

<u>Maintenance</u> Sample conditioning equipment should be designed to minimize maintenance; however, these systems have cation columns, filters or rotameters that require periodic maintenance. These components which require periodic maintenance should be easily accessible in the sample panel. Additional maintenance requirements occur at start-up, where the sample conditioning system can be subjected to abnormal operating conditions and high contaminant loading. Panels with in-line filtration should be carefully monitored during system start-up when they are vulnerable to plugging. Sample conditioning systems are not configured for bypassing plugged filters.

<u>Installation Issues</u> The location of the sample conditioning systems should be determined during the design process. If the panel is located in the operating area rather than in a controlled enclosure or control room, the design should incorporate applicable NEMA enclosure standards to provide protection for panel components. The plant may need to add lights, electrical service for analyzers, chilled water and drain lines. In all cases, the environment is a significant factor in ensuring the proper operation and durability of the sample conditioning system. In addition, provisions should be made for easy accessibility to the components for operations and maintenance purposes.

<u>Start-up and Training</u> Ensuring proper start-up and training is important to obtain reliable systems operation. Personnel should be familiar with the operation and maintenance manual for each analyzer prior to system start-up. Ideally the manufacturer of the sample panel will participate in the start-up and training process.

ANALYZER CONSIDERATIONS (8)

Analyzers in steam generating systems are precision instruments, designed to measure very low concentrations of contaminants. Typically, measurement values are in parts per billion (ppb) or micromho range. Obtaining accurate, low level measurements requires both a good analyzer and a well-designed sample conditioning system.

<u>Sample Conditioning System - Analyzer Interaction</u> An illustration of the interaction between the analyzer and the sampling system is the issue of compensation for off-specification conditions. Although some analyzers have compensation for off-specification conditions, this automatic adjustment is usually not sufficient to ensure an

accurate measurement. A good example is an in-line pH meter that has automatic temperature compensation. This temperature compensation, like most compensation systems, is designed to correct for the temperature-dependent changes in the electrode. This compensation does not adjust for the temperature dependent changes in the ionic dissociation that occurs in the solution. To correct for the temperature dependence of the ionic dissociation, the concentration and identification of each contaminant would be required, creating a very complex algorithm. For aqueous solutions that have a single, known contaminant, these algorithms have been created, and programmable pH meters are available with various correction factors.

A slightly less complex situation exists for analyzers whose measurement accuracy is flow-dependent or pressure-dependent. For optimal performance, the sample conditioning system must deliver a sample at the standard temperature, flow and pressure conditions required by the analyzer.

<u>Reliability and Maintainability</u> The two most important characteristics of analyzers for plant personnel are reliability and maintainability. The evaluation of reliability is dependent on the analyzer design, the analyzer's mechanical and electrical integrity, and correct installation, operation, and periodic maintenance. Operators and instrumentation personnel often use personal experience as a strong factor in evaluating reliability. Recent advances in solid state electronics and fail-safe designs have significantly improved the reliability of most analyzers.

Some analyzers, such as reagent-based units like silica analyzers, have historically required a high level of maintenance. Manufacturers have reduced maintenance in more recent versions of these analyzers; however, some maintenance is expected in systems with precision mechanisms such as low flow pumps and when measuring ultra low concentration of contaminants. To improve analyzer maintainability, most analyzers have automatic or in-line calibration, self-diagnostics and error codes that identify problems. Like other process control equipment, manufacturers have begun to standardize different analyzers to reduce the complexity of operation, improve the repair processes and reduce maintenance. Again, the incorporation of microprocessor technology has enabled plant personnel to perform maintenance more quickly and with less training.

<u>Improved Operator Interface</u> The operator-analyzer interface can be improved by using alarms and built-in "intelligence." Analyzers can be programmed to evaluate abnormal operating conditions and notify the operator only when the situation absolutely requires "human" intervention. Built-in intelligence also allows sequential or multi-stream sampling protocols, or simultaneous measurements for process control systems.

<u>Integration of Analyzers into Process Control Systems</u> Analyzers have traditionally been "stand-alone" units located at either a remote sampling point or in a central sampling location. Occasionally data acquisition and analysis would be done on a microprocessor that was not connected to the plant's process control system.

Recently, analyzers have been integrated into the central process control system. These process control systems receive the analyzer output, perform a complex algorithm and automatically signal for a system correction. With increased automation, operator intervention is reduced. For example, installing a process control system on the chemical feed to a boiler allows the automatic adjustment of the internal treatment chemical feedrate based on an analyzer signal. A wide range of system operating variables can be recorded and off-specification conditions can be reported via a system alarm. These changes provide plant personnel with useful information to evaluate current and historical operation and make changes based on that data.

SPECIFIC MEASUREMENT REVIEW

There are many measurements that can be made using on-line analyzers in steam generating systems. Each measurement requires specific sample conditioning to ensure accurate results. The sample conditioning needs of each parameter are summarized in Table 1.

<u>pH</u> On-line measurement of pH in high purity samples requires an electrode that is designed specifically for flowing samples. Accurate measurement of pH is very dependent on having a strictly controlled sample temperature. The most complex pH meters have solution temperature compensation that can be adjusted based on the identity of the specific contaminant. For example, for samples in which ammonia is the primary contaminant, the pH meter could be programmed using an empirically derived value for the change in pH as a function of the change in solution temperature.

<u>Dissolved Oxygen</u> There are two different technologies used for dissolved oxygen analyzers; polaragraphic and galvanic. Both technologies have merit and both methods use a semi-permeable membrane and an electrochemical cell that reduces oxygen at the cathode. The polaragraphic method applies a constant voltage across the electrode and measures the resultant current that is proportional to the partial pressure and hence the concentration of oxygen. The galvanic method measures the resultant voltage (which is proportional to the partial pressure, and hence the concentration of oxygen) created across the electrode

by the reduction of oxygen. Oxygen permeable materials such as Tygon®[*] tubing should not be used in the sampling system.

Table 1 - Sample Conditioning Needs for On-line Analyzers

Parameter	Analyzer Methodology	Reagent-based	Flow Sensitivity	Temperature Sensitivity
Dissolved Oxygen	Electrochemical	No	Moderate	Low
pH	Electrochemical	No	Moderate	High
Ortho-phosphate	Colorimetric Reaction	Yes	None	High
Silica	Colorimetric Reaction	Yes	None	Moderate
Iron	Colorimetric Reaction	Yes	High due to reactive suspended iron particulates	Moderate
Total Hardness	Colorimetric Reaction	Yes	Low	Moderate
Conductivity	Electrochemical	No	Low	High
Cation Conductivity	Ion Exchange + Electrochemical	No	Low	Moderate
Sodium	Selective Ion Electrode	Yes	Low	High
Total Organic Carbon (TOC)	Oxidation	No	Low	None

Colorimetric Methods Several analyzers use a colorimetric method to create a highly colored complex. A spectrophotometer is used to measure the percent absorption of a specific wavelength of light that is proportional to the concentration of the ion of interest. Analyzers that use spectrophotometric methods include silica, iron, total hardness, and ortho-phosphate. All of these methods consume reagents that must be replenished on a scheduled basis.

Conductivity and Cation Conductivity Conductivity meters are based on the principle that ionic contaminants, or "salts" will conduct electricity. A standard voltage is applied to the electrode, and the resulting current is measured. This method does not measure the concentration of the non-ionic solids. Conductivity does not correlate to dissolved solids when there are non-ionic or very weakly ionic species or suspended materials. Unlike pH, there is no temperature compensation for the sensor; all temperature compensation is for solution effects. The algorithm is complex since the relationships between sample temperature and conductivity and sample temperature and concentration of the contaminant are non-linear.

The most complex conductivity meters have compensation for solution effects; however, they are approximations when measuring samples with contaminants such as ammonia. Cation conductivity measurements use a cation column upstream of the conductivity probe to exchange cations such as aminium ions (i.e. from ammonia) for hydrogen. This exchange converts a weak acid into a strong acid, creating a solution that has a known correlation between conductivity and the ion concentration.

Sodium Sodium analyzers use an ion-selective electrode. These electrodes are very similar to pH electrodes that respond proportionally to the log of the hydrogen ion concentration. The logarithmic response of the electrode to the concentration of pH or sodium is the reason that sodium analyzers have excellent accuracy at low concentrations of sodium (1 ppb). To reduce the interference of hydrogen ions on the sodium measurement, the pH of the sample stream is adjusted using ammonia prior to measuring the sodium. For low sodium concentrations, (1 ppb and lower) a stronger base such as an amine is used.

Total Organic Carbon (TOC) TOC analyzers are designed to measure the concentration of organic contaminants in the sample. Although there are a variety of methods, all of the analyzers oxidize the organic contaminants, providing a measurement of the total carbon from organic sources. Unfortunately, TOC measurements cannot give specific information about the organic compounds that were present in the steam. Oxidation can be performed with chemical oxidizers, UV radiation or thermal energy.

INTEGRATION OF ON-LINE MONITORING INTO OPERATING SYSTEMS (9, 10)

Measurement Redundancy Measurement redundancy is important for confirming the accuracy of the control systems which use on-line monitoring in the control of a process. For critical systems, the redundancy is usually on-line, using a second, independent analyzer. For most steam generating systems, the redundancy is manual, wherein the operator confirms the accuracy of the on-line measurement with a grab sample analysis.

Maintenance The ease of maintenance of these systems has become more important because the measurement is used on-line in the process control algorithm. Simplifying maintenance procedures reduces the time that analyzers are out of service and reduces the impact on the automated control. Newer analyzers are designed to hold the last value or a pre-programmed value during maintenance or

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[*] Tygon® is a registered trademark of the Norton Company, Akron, OH

calibration. The local output will reflect the measured value; however, the output to the controller or process control system will be fixed at the reading at the initiation of maintenance or calibration.

Some of the routine maintenance required for on-line analyzers includes calibration, probe cleaning and reagent replenishment. Because the system control is dependent on the accuracy of the independent variable measurements, failure to perform this routine maintenance will result in a loss of system control.

Corrective Action Every on-line monitoring system must have specific corrective action prescribed for abnormal operating conditions. As systems are automated, the role of the operator is transformed from a “controller” role to a “supervisory” role. The operator now has responsibility for analyzing the current and historical data and making decisions on how and when to intervene in the automated process.

Future Trends of Process Control These trends can be seen as plants upgrade their distributed control systems to incorporate processes such as the water treatment into the process control systems. Historically, the processes on the “water-side” of the steam generating systems did not require the high speed, fast sampling rate, and complex data analysis required for other processes. However, the trend towards greater automation and integration of all plant processes supports the need for merging the data acquisition and control of the water chemistry with plant processes.
As shown in the following case history, the combination of a sample conditioning system, on-line analyzers, data acquisition and analysis was used to identify the root cause of a problem and allowed plant personnel to return their system to optimum operation.

PLANT EXPERIENCE

BACKGROUND

A mid-Atlantic power plant has 4 boilers totaling over 1000 MW generating capacity. Three boilers are drum units; one boiler is a supercritical unit and the operating pressures of the boilers range from 1900 psig to 3600 psig. Typical of most power plants, the plant has installed on-line analyzers throughout the boiler system. A list of analyzers is shown in Table 2.

Each of these analyzers requires a conditioned sample to maximize the accuracy of the analyzer measurement. Accurate measurement is essential for proper corrective action and maximum unit reliability.

KEY ISSUES

During the process of upgrading the sample conditioning systems and the analyzers, plant personnel learned several key lessons. They were:

1. An adequate cooling water supply is critical. Primary cooling is normally supplied by plant component cooling or service water. If that water is high in dissolved solids, an isolation heat exchanger is used to separate the cooling water from the sample cooler and to protect the sample cooler from excessive fouling. These isolation heat exchangers should be oversized for additional protection against fouling, especially in the summer months. A closed loop chilled water system was installed in each of the three sampling systems for secondary cooling and final sample temperature control. The chiller should also be slightly over-sized to accommodate unusually hot conditions experienced during peak summer operation.

Table 2 - On-Line Measured Parameters

Stream	On-Line Analyzer
Condensate Pump Discharge Economizer Inlet Boiler Water Saturated Steam	Cation Conductivity
Condensate Pump Discharge Boiler Water Condensate Polisher Inlet (1 unit) Condensate Polisher Outlet	Specific Conductivity
Economizer Inlet Boiler Water	pH
Condensate Pump Discharge Economizer Inlet	Dissolved Oxygen
Condensate Pump Discharge Saturated Steam (1 unit)	Sodium

2. Preventative maintenance is critical to maintain system reliability and sampling accuracy. The operators found that the following maintenance is especially important.
    a. Carefully wiping pH probes clean once per week.
    b. Occasional cleaning of rotameters is recommended to ensure that settings are easily read. Rotameters that can be disassembled to clean the accumulation of iron oxide on the internal surfaces should be selected.
    c. Blowdown of the sample lines once per week is important. The lines from the source to the sample panel should be configured to be safely and easily blown down.

3. The installation of filters on sample lines should be done selectively, with consideration given to flowrate through the filter, the filter element size and the micron size. Installation of a large in-line filter slows the response time due to the residence time or the time to purge the volume of sample in the filter housing. Dissolved oxygen (D. O.) and sodium analyzers benefit from in-line filtration due to the sensitivity of the D.O. probe surface and the sodium analyzer electrode to damage by particulates.
4. The backpressure regulator should be a device separate from the sample relief valve. The backpressure regulator maintains a constant pressure and a stable flow to the analyzer. This is especially important in a system that serves a group of analyzers and a grab sample location. For example, boiler feedwater may have a grab sample and several analyzers on the same distribution header, including pH, specific conductivity, hydrazine, and sodium.
5. Special procedures are required for units operating in peaking or cycling mode.
    a. Constant sample flow maximizes the reliability of most analyzers. During periods when there is no sample available, demineralized water should be circulated through the analyzer. This is especially important for reagent-based analyzers. A stagnant sample in a sodium analyzer will result in the pH adjustment reagent diffusing into the sample cell and etching the glass of the measuring electrode.
    b. Some analyzers should not have demineralized water circulated when there is no sample available. For analyzers such as dissolved oxygen, there should be no demineralized water flow when the unit is off-line. The high dissolved oxygen in the demineralized water will shorten the life of the electrode.
    c. Analyzers which have cation columns upstream of the conductivity sensor should be configured for upflow rather than downflow service. This configuration improves the rinse time, purges any air trapped in the line and permits the system to deliver an accurate signal more quickly upon start-up without technician intervention. In downflow units, the technician must manually rinse the column and purge trapped air during system start-up.
6. A self-adjusting pressure regulating device together with a rotameter, provides a steady flow from a sample source which has varying pressure during normal peaking service (i.e. variable steam loads). Blowdown systems should allow the sample lines to be purged of any settled particulates. Sample line blowdown systems must be configured to allow total isolation of the sample conditioning systems during blowdown. A typical sampling and sample line blowdown configuration is shown in Figure 1.

CASE HISTORY

An example of the value of on-line analyzers occurred on the once-through unit, a base-loaded unit that follows electricity demand. The cation conductivity in the condensate sample peaked each night after the unit had reduced load. The cation conductivity would be between 0.10 and 0.20 μmhos during the day and at night it would rise as high as 0.40 μmhos. To accurately measure and identify the differences between these low values required accurate instrumentation and reliable sample conditioning systems.

A review of the on-line cation conductivity measurements indicated that there was a gradual rise in cation conductivity throughout the period of low steaming rate. The plant's maintenance personnel found no evidence of air inleakage that would have increased the cation conductivity.

The plant's response to the high cation conductivity values was to place the in-line deep bed polishers in service, removing the contaminants causing the high conductivity as well as the ammonia which was being fed for condensate and feedwater pH control. Using these deep bed polishers resulted in higher costs due to additional regenerations and higher ammonia feed rates.

<u>Root Cause</u> The process to identify the root cause of this problem started with a set of observations and a hypothesis. In this case, the plant observed a very small but significant difference in cation conductivity of the condensate: 0.20 μmhos to 0.40 μmhos. The plant had to be confident that this observation, i.e. a 0.20 μmho difference in cation conductivity, was real. The sensitivity of the cation conductivity instrument had been confirmed by the plant through an intensive calibration and measurement validation program. In addition, there are many variables which can affect the accuracy of on-line measurements, including sample temperature and flowrate. In this unit, the variables such as flow and temperature are measured and tightly controlled by a new sampling system to minimize their effects on measurement accuracy. After installing the new instruments and sample conditioning systems, the cation conductivity measurements showed that the phenomenon was repeated each 24-hour cycle and that the cation conductivity profile was not an aberration of the sample conditioning system or the analyzer.

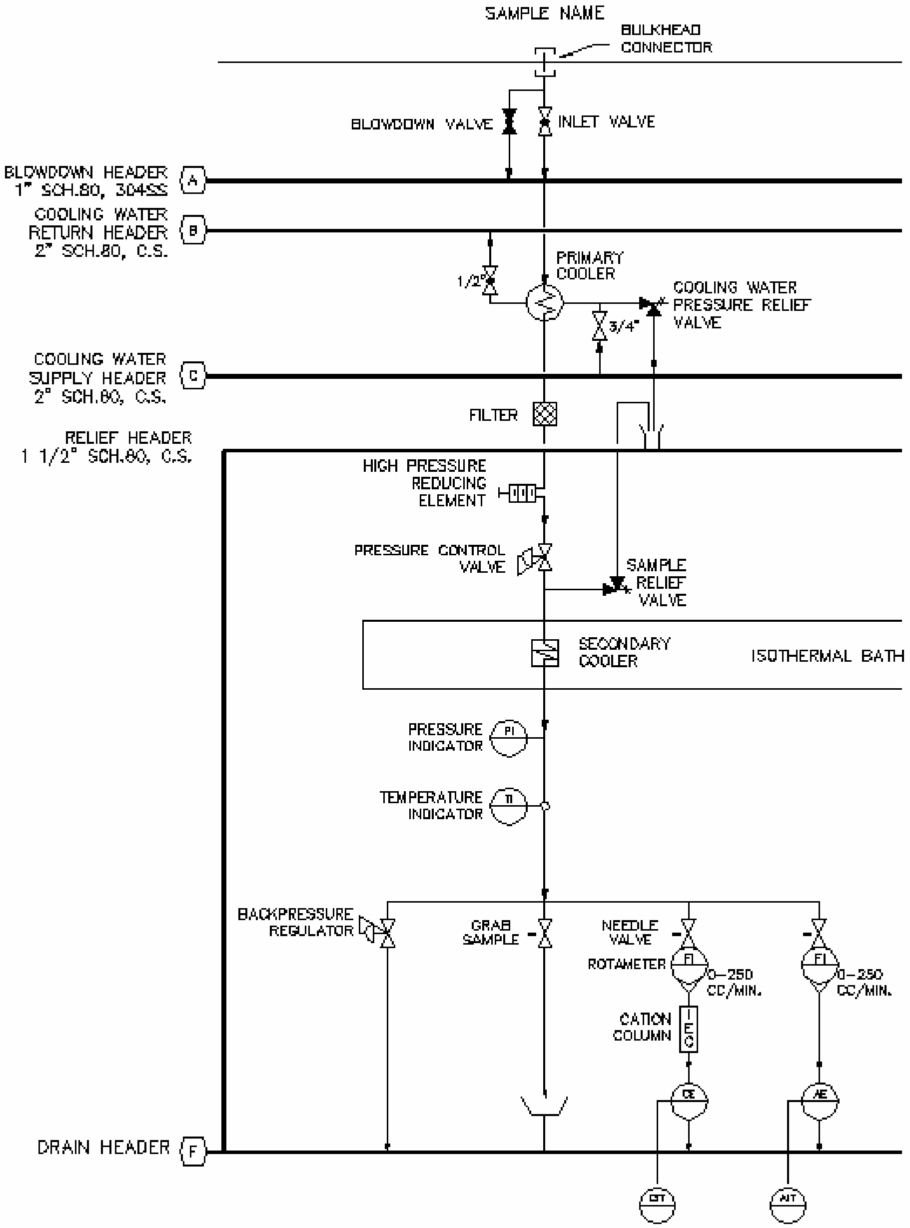

Figure 1 - Typical Sample Conditioning Design

Hypothesis A control room operator made another important observation: there was a negative pressure reading on several of the feedwater heaters during the reduced load period (Figure 2). Feedwater heaters are assumed to be under positive pressure during all operating conditions. Based on this observation, a hypothesis was formed that air was leaking into the feedwater heater during reduced load operation. The carbon dioxide in air was dissolving in the feedwater, increasing the cation conductivity.

Data Gathering To substantiate this hypothesis, the plant had to correlate the unit operating parameter (feedwater heater pressure) with the chemistry measurement (high cation conductivity). Both the cation conductivity, (i.e. the water chemistry data) and the pressure on each of the feedwater heaters, i.e. plant operations data, are recorded on the central data acquisition unit. This common database

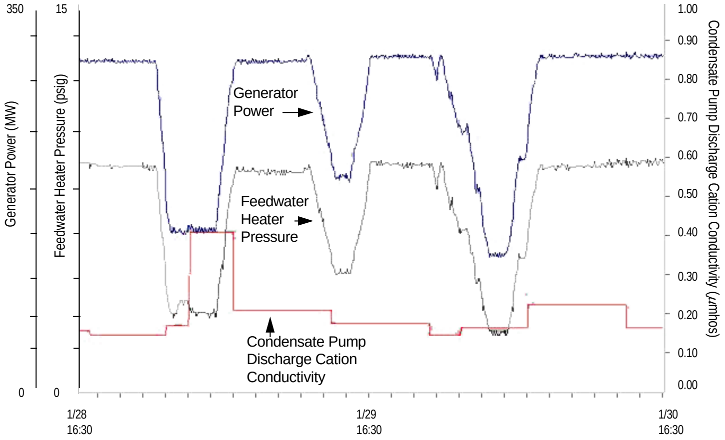

Figure 2 - Historical Trend Chart of Plant Operating and Water Chemistry Data

reports the information on the same time scale allowing correlations to be drawn between the water chemistry and the plant operating parameters. A review of the trend information showed that these heaters were under slightly negative pressure, or a vacuum during reduced loads.

Proof To prove this hypothesis, the plant had to find the root cause of the problem, take corrective action, and re-examine the process. On the day shift, plant operations found a leaking bonnet on a drain valve on one of the feedwater heaters. During normal steaming loads in the daytime, the feedwater heater had positive pressure and this leak dripped water on the floor. The plant conducts periodic air in-leakage audits during the day shift at full load when the feedwater heaters are pressurized. At night during reduced load when the feedwater heater pressure was negative, the water stopped leaking and a significant amount of air in-leakage occurred.

Resolution Repair of the leaking bonnet on the valve eliminated the air in-leakage. The cation conductivity declined to the daytime value of less than 0.20 μmhos at all operating conditions. This proved the hypothesis that air in-leakage (i.e. carbon dioxide) was the cause of high conductivity readings. Without the plant's confidence in the analyzer readings, the cation conductivity profile may not have been identified as a problem and may have been described as a sampling or analyzer system anomaly. The combination of a sample conditioning system, on-line analyzers and comprehensive data acquisition and analysis enabled the plant to identify the root cause of the problem very quickly. Solving the problem eliminated the extra operating costs for the deep bed cation polishers and minimized the ammonia feedrates.

Summary A well designed sampling system, a properly maintained analyzer with the appropriate data acquisition system and a database will permit more rapid identification and correction of chemistry excursions.

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