White Paper

Improve Cooling System Performance with Liquid Analytics

Water analysis and treatment makes the difference for yielding profitable and productive processes

EMERSON

Using liquid analytics to improve recirculated water system and scrubber performance

Two major water-intensive utilities in a refinery or chemical plant – cooling and scrubbing – depend on water quality analysis to deliver effective performance. Selecting the right instrumentation makes all the difference.

Introduction

Refineries and large-scale chemical processing plants often incorporate support systems using large volumes of water, specifically cooling systems and scrubbers. The nature of these vary from location to location but, in many facilities, production depends on the ability to use recirculated water to reduce the volume of fresh water consumption for cost, availability, and environmental reasons. A common characteristic of recirculated systems is the increasing volume of minerals and general contaminants that end up in the water, changing its "chemistry" as it is in constant use.

Some changes in the water are benign and have little effect on efficiency or overall operations. Others can cause fouling, corrosion, and even breed bacterial disease within a facility, resulting in increased maintenance costs, reduced effectiveness as well as personnel or public health concerns. This white paper will examine cooling system and scrubber installations, look at how they operate, what happens to the water they use, and how instrumentation can help monitor and control remediation efforts.

Heat exchangers and cooling systems

Most processing units in a refinery or chemical plant involve temperature change. The product stream must be heated, cooled, or both, potentially multiple times, to facilitate reactions or separations. Heating is a major part of the picture, but for purposes of this discussion, we'll focus on the cooling side and how heat gets removed from product process fluid.

A refinery or chemical processing unit will typically cool a liquid product stream by feeding it through the tubes of a shell-and-tube heat exchanger, while cooling water surrounding the tubes and inside the outer shell is pumped through the exchanger. The cooling water becomes hotter as the product's heat transfers through the tube walls, and in turn needs to be cooled by transferring heat to the atmosphere via an air-cooled heat exchanger, which in many situations is an open-circuit cooling tower.

These water-cooling systems typically scale up to become plant-wide utilities supporting multiple process heat exchangers served by many cooling towers so the amount of cooling can be regulated. This minimizes operating costs since the need for cooling capacity varies based on which units are running, production rates, and even local weather conditions. Multiple-unit cooling towers provide capacity and maintenance flexibility since individual sections can be run or shut down as needed.

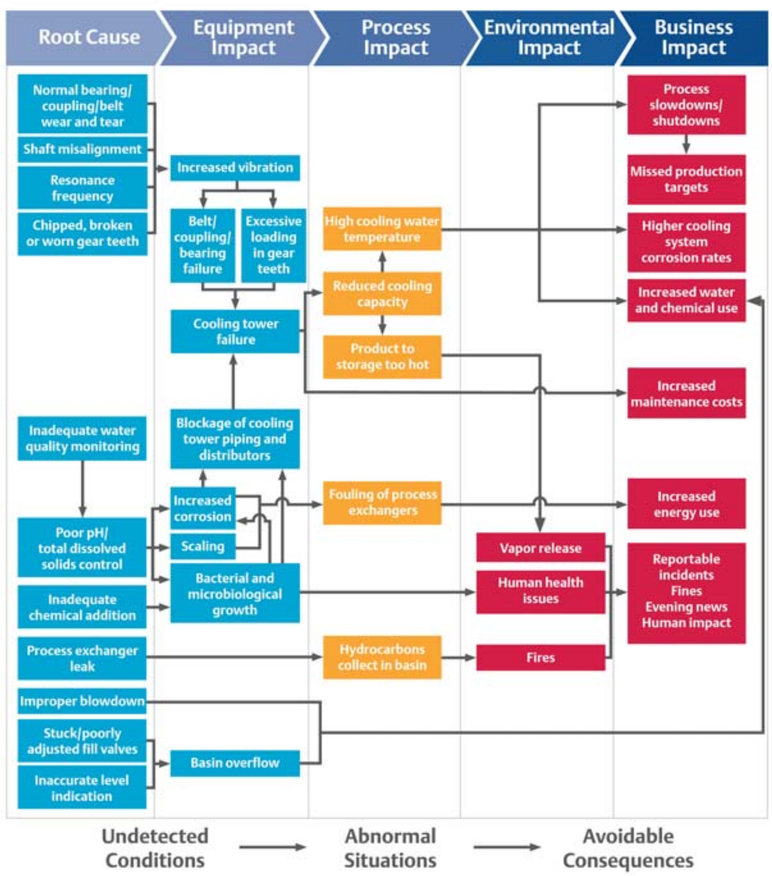
Open-circuit cooling towers are available in countless sizes and configurations but perform a common function of spreading out water over packing, or some surface, so it comes into direct contact with ambient air flow pulled through using a fan. The water cools by transferring heat to the air and by evaporation, resulting in water loss. Air flow is controllable using dampers and variable-speed fans to provide the required degree of cooling without wasting energy and losing excessive amounts of water.

Living with cooling towers

As the chart (Figure 1) shows, open-circuit cooling towers are complex and there are many things that can go wrong. To those responsible for maintaining them, there are two main areas of concern:

- Mechanical – Equipment such as blowers, valves, piping, dampers, etc.
- Water – Characteristics such as chemistry, sediment, deposits, etc.

Figure 1. Anatomy of a Cooling Tower Failure



Cooling towers are complex, and something starting as a small problem may initiate a chain of effects costing a facility production capacity and money.

These two are vastly different areas in concept and practice, but either can cause increased operating costs, lower cooling efficiency, and create potentially hazardous conditions both for people and equipment. Emerson has a variety of sensors, analytical tools, and resources to characterize mechanical performance, but this paper will concentrate on concerns related directly to water quality.

Water chemistry and contamination

An industry rule-of-thumb says it takes 1.5 barrels of cooling water to process one barrel of oil. Given the production of a typical refinery, unless it is located on a major body of water and it is permitted to use the water, recirculating systems are necessary. Recirculating the same volume as much as is practical minimizes drawing from local supplies and the associated effluent treatment costs.

However, with recirculating systems, anything getting into the water tends to stay there since filtration beyond coarse strainers at this scale is rarely practical. As some water volume is lost to evaporation, contamination levels only increase. This is made worse since the water and air flow in a typical cooling tower makes it a very effective collector of airborne dust, bacteria, spores, seeds, bugs, and anything else pulled into the airstream. Such systems can even become breeding grounds for legionella bacteria.

Given these circumstances, water treatment is critical to avoid a range of contamination-related operational problems including:

- Tube leaks in heat exchangers, which can release hydrocarbons and other chemicals into the water
- Evaporation leaving behind scale, which can clog pipes and deposit on heat exchanger surfaces
- Biological organisms growing and depositing on internal surfaces resulting in hydrogen sulfide production
- Poor control of chlorine and other additives causing corrosion or inadequately eliminating biologicals
- Poor control of blowdown and makeup water allowing problems to grow or wasting fresh water

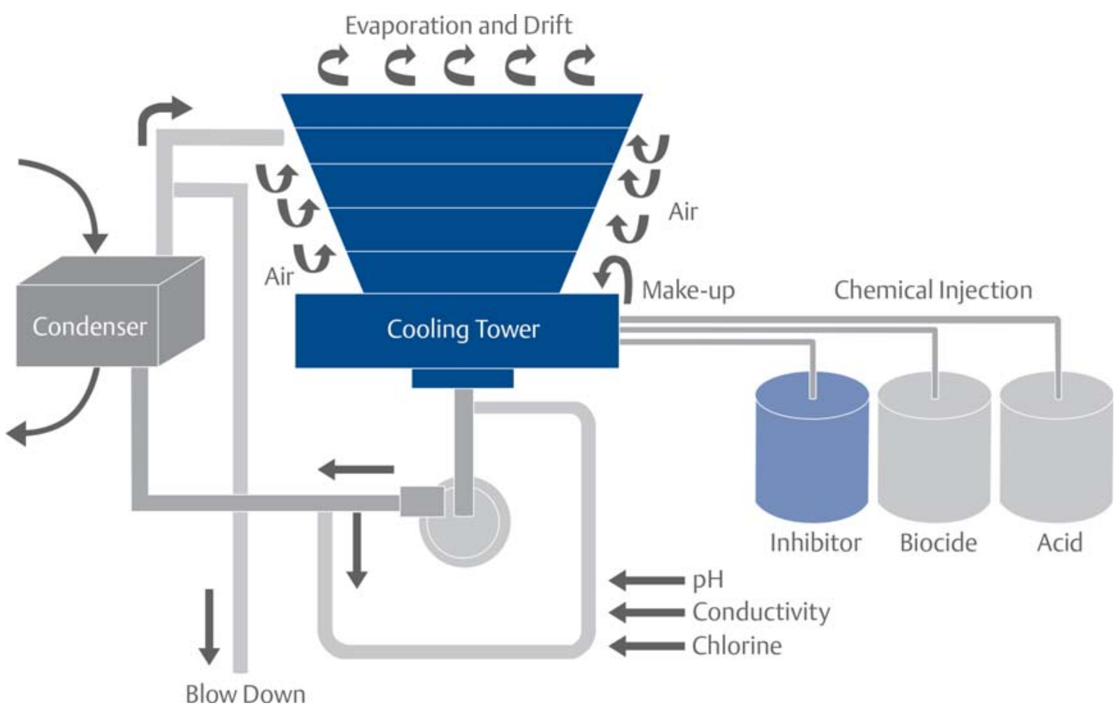
All these water quality problems, if left unaddressed, rob a cooling tower of its ability to dissipate heat. Since a cooling tower cannot reduce water temperature below the ambient wet-bulb temperature under the best conditions, a hot and humid day reduces capacity. A poorly performing cooling tower compounds the issue, and production problems in the facility's units will certainly result.

Water analysis and treatment

Water used in these systems must be treated (Figure 2) to avoid the problems just discussed. Cooling towers encourage a portion of the water to evaporate to increase cooling, further concentrating dissolved solids. This is mitigated by removing some of the circulating water via the blowdown valve so it can be replaced by fresh water. It is critical to establish and maintain specific chemical characteristics, which can help optimize cooling tower performance for the following conditions:

- Minerals must be kept in solution to avoid scaling
- pH must be controlled to avoid unwanted reactions and corrosion
- Biologicals must be killed off or at least suppressed

Figure 2. Water Treatment Systems



It is critical to establish and maintain specific chemical characteristics of the water used in the cooling system.

Cooling water systems should include continuous routine monitoring of specific conditions such as pH and conductivity at a minimum. Most of the impurities in cooling water are alkaline, such as calcium carbonate, and are therefore less soluble at high pH values. Most facilities add small amounts of sulfuric acid to the circulating water to lower the pH value and thus prevent formation of scale. A general-purpose pH sensor (Figure 3) can be used by a control strategy adjusting the rate of acid addition to maintain the correct range. A general-purpose conductivity sensor (Figure 4) provides additional information, supplementing the pH reading.

Figure 3. Emerson's Rosemount 3900 General Purpose pH/ORP Sensor

Emerson's Rosemount™ 3900 General Purpose pH/ORP Sensor is an appropriate choice for this application. It uses a double junction to protect the reference element from poisoning ions.

Figure 4. Emerson's Rosemount 400 Contacting Conductivity Sensor

Emerson's Rosemount 400 Contacting Conductivity Sensor can control blowdown cycles when conductivity becomes too high.

Conductivity can be a useful tool, in some circumstances, for detecting and locating tube leaks throughout a larger cooling system. A leak that allows process fluid to bleed into the cooling water will tend to change conductivity more than one of the other values. (The main exception is where the process fluid is organic without being particularly acidic or basic, which rules out many oil products.) Multiple conductivity sensors placed at strategic locations up- and down-stream from critical heat exchangers can spot where changes are occurring and alert maintenance to which exchangers might be leaking. Adding greater numbers of sensors increases the specificity of the location.

If the fresh water source already has a high level of suspended solids, the overall level of mineral and other contaminants will be high under all conditions, presenting a challenge for the instrumentation. When working at high levels consistently, a toroidal conductivity sensor (Figure 5), and a fouling-resistant pH sensor (Figure 6) are recommended for their ability to measure accurately under such conditions.

Figure 5. Emerson's Rosemount 228 Toroidal Conductivity Sensor

Where suspended solids levels are high, Emerson's Rosemount 228 Toroidal Conductivity Sensor may be necessary.

Figure 6. Emerson's Rosemount 396P pH/ORP Sensor

Conventional pH sensors can be fouled when suspended solids levels are high, so a fouling-resistant sensor, Emerson's Rosemount 396P pH/ORP Sensor, can reduce

Data to control additives

A group of sensors working together supply variables needed to calculate the Langelier Index, which is a composite value indicating the water's tendency to be corrosive or cause scaling. The formula considers measurements of calcium hardness, alkalinity, pH, conductivity, and temperature measurements for determining the overall scaling potential. It looks primarily at the degree of saturation of calcium carbonate in water, which under ideal conditions should be right at the saturation point, resulting in a zero value on the index. If under-saturated (a negative value), the water will be corrosive. If over-saturated (a positive value), it will cause scale formation.

A variety of chemical scale and corrosion inhibitors may be injected in addition to sulfuric acid. These additions are initiated and dosed by other system measurements, such as moving in parallel to acid demand or adding a fixed amount of additive per unit of new make-up water. Dispersants may be necessary to prevent coagulation or flocculation of suspended solids drawn in with the air flow, including dust and living microorganisms. These additives are normally injected along with the other inhibitors.

The warm water and air produce an ideal environment for airborne spores and seeds drawn in, and for common algae and slime. Biocides such as chlorine or bromine are typically added on a fixed dosage basis at specific time intervals and can also be monitored using a free-chlorine sensor (Figure 7). Measuring free or total chlorine in cooling water provides feedback to the chlorination system.

Figure 7. Emerson's Rosemount 499ACL Free Chlorine Sensor Family

Chlorine necessary to suppress biological growth can be monitored using Emerson's Rosemount 499ACL Free Chlorine Sensor family. Various models can measure free chlorine, total chlorine, and monochloramine.

Ozone treatment to control biological growth is a cost-effective solution for many applications. Ozone is a powerful alternative to chemical biocides and can reduce operating costs while eliminating the need for hazardous chlorine storage. Unlike most chemicals, ozone has a half-life of only 20 minutes and will not be found in blowdown water. A dissolved-ozone sensor (Figure 8) provides a continuous measurement so a control loop can maintain a level between 0 and 10 ppm.

Figure 8. Emerson's Rosemount 499OZ Ozone Sensor

Ozone treatment to reduce biological growth is growing in popularity but requires continuous concentration monitoring, which can be provided by Emerson's Rosemount 499AOZ Dissolved Ozone Sensor.

When the concentration of impurities reaches a specified level, the blowdown valve must be opened to release some amount of used water. This is typically controlled by a contacting conductivity sensor (Figure 3), which opens the valve automatically. Discharging blowdown water causes a demand for make-up water, which is less concentrated in impurities, and thus lowers conductivity.

Wet scrubbers

Various pollutants need to be removed from flue gas streams or other gas flows released from chemical processes. In most applications, this capture takes place by causing the pollutant to react with some other chemical reagent to produce a third product, typically a solid, which remains behind. The scrubbed gas stream can be released to the atmosphere without violating relevant regulations while the spent sorbent product can be disposed of or even sold as a byproduct.

A common example is removing sulfur dioxide (SO2) from various combustion processes, particularly burning coal and petroleum products. This flue-gas desulfurization (FGD) process can take various forms depending on the application, but according to the U.S. Environmental Protection Agency (EPA), approximately 85 percent of the systems installed in the U.S. are wet scrubbers.

A typical scrubber is a large vessel the process flue gas passes through. Inside are header pipes equipped with nozzles for spraying fluid to fill the interior with falling droplets, which interact with the gas. The sprayed liquid is typically a slurry of water mixed with an alkaline sorbent designed to react with the SO2 to produce a solid compound. Common reagents include magnesium oxide, lime, and limestone. The nozzles are designed to create droplets of this slurry with specific diameter and density to optimize the liquid surface area for the two-phase reaction to take place as effectively as possible. Most flue gas also contains some chlorine content, which also reacts with the reagent to form magnesium chloride or calcium chloride.

The slurry falls to the bottom and moves to an absorber tank where the reaction is completed, forming a neutral salt or gypsum. Agitation keeps the slurry in suspension, so it can be pumped through the nozzles again. The reacted sorbent is removed, so the slurry can recirculate.

Naturally, the chemical balance of the slurry is critical to an effective reaction and scrubbing action. Overuse of the reagent increases costs while too low a concentration reduces removal rates.

Evaluating scrubber water

The most critical characteristic of scrubber water is pH, and any unit should monitor it continuously (Figure 9). The slurry's pH value is the primary method to determine how much fresh sorbent needs to be added to maintain correct reactivity. The appropriate operational pH level depends on which reagent is in use. For example, lime slurry is more alkaline, so a desired level is around 12.5. Limestone is more neutral and operates around 5.6 to 5.8. Without sufficient sorbent, the recirculating water will quickly become acidic.

Figure 9. Emerson's Rosemount 3400HT PERpH-XTM pH/ORP Retractable Sensor

Emerson's Rosemount 3400HT PERpH-X™ pH/ORP Retractable Sensor is designed to maintain a long service life in difficult, hot processes such as a scrubber.

Given the low solubility of calcium compounds used in scrubbers, solids tend to accumulate in recirculation loops and can result in scale buildup. Scale deposits on the spray nozzles affect the internal geometry, negatively impacting droplet formation and distribution. When this moves out of the desired range, the scrubber loses efficiency. Scale on the return pipes also reduces overall flow, changing thermal balance in the system. The tendency to form scale can be reduced by using additives, such as chelating agents and phosphates, but these are generally only effective at higher pH levels. Consequently, pH control is necessary to avoid scale buildup since preventing scale is much easier than removing it.

Other acid gases

While FGD processes are common, they are not the only scrubbing applications. Many chemical processes and incinerators can create a variety of acid gases which need to be abated in keeping with environmental regulations. Other scrubbers using alkali reagents perform similar functions depending on the context.

Some use recirculated liquid, while others spray a more finely atomized reagent solution, so the droplets evaporate in mid-air leaving the spent sorbent as a dry powder. Both recirculating and spray-dry scrubbers need to monitor pH of the sorbent solution to ensure effective and economic performance.

Sour water stripping

Water used in refineries, and some chemical plants, can become contaminated with hydrogen sulfide and possibly ammonia, making it "sour" water. Environmental regulations in most areas require removal and capture of these contaminants before water can be treated further and released back into the local ecosystem.

The stripping process uses a gas stream to force both the hydrogen sulfide and ammonia out of solution and into the gas phase, allowing it to be captured. Some systems use air injection, but steam stripping is more effective due to its higher temperature. The ideal pH for stripping H2S is below 5, since above 5, sulfide is primarily found in the form of ions (HS- or S-2). Conversely, efficient ammonia stripping requires a pH above 10 to prevent the formation of ammonium ion ($NH_4^{(+)}$) that cannot be stripped. Where separate stripping towers are not practical, a compromise solution using a pH around 8 usually allows adequate removal of both gases.

This is a difficult challenge for measuring pH due to the temperatures involved and the tendency for the chemicals involved to poison the sensor. Effective operation depends on a sensor (Figure 10) able to survive and continue reliable operation under these conditions.

Figure 10. Emerson's Rosemount 3500P PERpH-Z pH/ORP Sensor

Sour water stripping calls for the long operational life available from Emerson's Rosemount 3500P PERpH-X pH/ORP Sensor technology with its rebuildable double junction.

Combining sensor and transmitter

The discussion, so far, has emphasized the specific sensors used for these applications, but proper sensor selection is only part of the picture. Like any process instrument, the raw analog signal from an analytical sensor must be processed and converted to relevant engineering units. At the very least, this requires the help of a transmitter (Figure 11), but feeding the signal to an advanced transmitter (Figure 12) can provide additional capabilities such as sophisticated data storage and calibration history.

Figure 11. Emerson's Rosemount 5081 Explosion-Proof Transmitter

Emerson's Rosemount 5081 Explosion-Proof Transmitter is a single-channel loop-powered device that can accept input from pH/ORP sensors, conductivity (contacting and toroidal) sensors, and amperometric (dissolved oxygen, chlorine, and ozone sensors).

Figure 12. Emerson's Rosemount 56 Dual Channel Transmitter

Emerson's Rosemount 56 Dual Channel Transmitter serves as a two-input transmitter for pH/ORP sensors, conductivity (contacting and toroidal) sensors, and amperometric (dissolved oxygen, chlorine, and ozone sensors) with an unrestricted choice of dual measurements.

SMART transmitters and sensors can eliminate field calibration, which is one of the largest problems when measuring pH. Traditional calibration methods require pulling the sensor from its mount and using buffers and rinse solutions there at the installation point. SMART sensors have factory calibration specs embedded in their memory, which can be accessed by a SMART analyzer. This simplifies the calibration process since the settings can be transferred automatically.

Evaluating condition and performance

All the data generated by these instruments calls for effective analysis so it can be interpreted as useful information for providing input to decision making. Fortunately, traditional wired and *Wireless*HART® transmitters can be combined with data gathering and analysis software apps designed to perform specific asset monitoring and evaluation functions.

These apps can send alarms when certain conditions are met, such as a change in conductivity or if pH crosses a threshold where scaling and fouling could become an issue. Different individuals in different departments can access the same information in real time on a smartphone or tablet via the web. These industrial internet of things (IIoT) concepts are quickly gaining ground with industrial users thanks to their sophistication and ease-of-use. The idea of pervasive sensing delivers the means to gather more information and automate analysis along with a process.

The value of diagnostics

Given the cost of operating cooling and scrubber systems and their importance in the overall production picture, taking action to add the kinds of instrumentation just discussed is really a very modest investment capable of delivering major returns:

- Avoid Unplanned Shutdowns – When a cooling tower isn't running, for any reason, it isn't earning its keep. Unplanned shutdowns are particularly costly since they may cause other equipment to stop as well. Timely information on cooling tower health is needed to avoid delays and failure.
- Improve Asset Performance and Reliability – Reduced cooling or scrubbing capacity due to water quality problems limits production from process units. Poor water quality can necessitate frequent shutdowns for cleaning. Online asset health information can alert maintenance before problems with pH imbalance or scaling impair performance.
- Mitigate Safety and Environmental Risks – Hydrocarbon leaks contaminating the cooling water can cause safety as well as environmental concerns. Water quality monitoring can include hydrocarbon detection, which warns of malfunctions in production unit heat exchangers and allows maintenance to remove hydrocarbons safely and initiate repairs.

All these elements working together, guided by data gathering and effective data analysis, can improve performance of these critical and costly water systems, and therefore overall plant profitability. This digital transformation is becoming reality, which will make and keep refineries and chemical plants viable going forward.

For more information, see www.Emerson.com/RosemountLiquidAnalysis

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