Originally appeared in:
November 2019, pgs 75-79
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HYDROCARBON PROCESSING®

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Improved cooling system performance begins with data

Refineries consume large amounts of energy and water to refine crude oil into products. Up to 10% of crude oil's energy content is consumed during processing, and it takes 1.5 bbl of water to process one barrel of crude oil. Refining processes also generate large quantities of excess thermal energy that needs to be expelled into the environment using a once-through or recirculating cooling system. A once-through system draws water from a raw water source and pumps it through process heat exchangers where it absorbs heat and is then sent back to the source. These systems are cheaper to construct and consume significantly less water than recirculating systems, but they may also require more water treatment chemicals and pose environmental risks.

Unless a raw water source is abundant and readily available, recirculating cooling water as much as possible is critical not only to reduce the cost of water treatment, but also to conserve the water supply. Unlike once-through systems, recirculating systems reuse the cooling water and employ evaporative cooling towers (FIG. 1) to transfer heat from the process to the atmosphere. Evaporative cooling towers have high construction, operational and maintenance costs, while consuming large quantities of water, often as much as 90% of the total water consumption in a refinery.

Cooling water availability is critical for refining operations. It is highly dependent on maintaining cooling towers and the rest of the cooling water system at peak performance. Equipment failures within a cooling tower can be costly to fix, can potentially lead to unplanned downtime, and may create an unsafe environment for plant personnel. As shown in FIG. 2, there are many things that can go wrong with a cooling tower. To those responsible for maintaining them, there are two main areas of concern:

- Problems with mechanical components, such as fans, pumps and valves
- Cooling water quality and integrity of the distribution system.

FIG. 1. Cooling towers are often used to transfer heat from processes to the atmosphere, but they have high construction, operational and maintenance costs.

Problems with mechanical components. Cooling towers incorporate a variety of mechanical equipment—most notably pumps and fans—that are susceptible to problems common to rotating equipment, but with a unique set of challenges. These challenges include:

- Cooling tower fans operate under variable load conditions with differing stresses over a prolonged period, putting them at higher risk of structural failure.
- Bearings and gears can fail due to misaligned drive shafts, and high vibration is common.
- Vibration data from a cooling tower's gearbox is difficult and dangerous to collect without permanently installed sensors.
- Mechanical components are often difficult to access, and thus are undermaintained.
- Failure of a fan requires a crane to remove and fix or replace, which costs time and money and is a potential safety hazard.

By installing wireless sensors on cooling tower pumps, fans and gear boxes to monitor vibration and temperature, a facility can automate data collection for asset health evaluation—increasing worker safety, saving time and freeing technicians for performing repairs prior to failure and other higher-level tasks. Furthermore, continuous monitoring can enable con-

dition-based maintenance, which is more effective than time-based maintenance or reactive maintenance that addresses a failure after the fact.

Cooling water quality. The measure of cooling water recirculation is defined as cycles of concentration (COC), which is the ratio of dissolved minerals in the recirculating water to dissolved minerals in the makeup water. It can be calculated using Eq. 1:

$$COC = \frac{\text{Total dissolved minerals in blowdown water}}{\text{Total dissolved minerals in makeup water}} = \frac{\text{Evaporation rate} + \text{blowdown rate}}{\text{Blowdown rate}} \quad (1)$$

Increasing COC introduces several problems that can impact cooling system performance, such as corrosion, scale deposition, fouling from airborne contaminants, microbiological growth and degradation of a cooling tower's structural integrity. The severity of these problems depends on multiple parameters, such as chemical composition of the makeup water, cooling tower location, cooling system materials of construction and operating conditions. In addition, these problems are interrelated, and addressing one may exacerbate the other. For example, lowering pH of the cooling water by adding acid can help control scale deposition, but may intensify corrosion and make controlling certain types of microbiological growth more difficult.

It is critical to establish and maintain a program of corrective measures to maintain optimal cooling system performance. Concentration of dissolved minerals and pH of cooling water must be carefully monitored and controlled to avoid excessive scale deposition while maintaining acceptable corrosion rates. Organic and inorganic contaminants must be removed through side-stream filtration and prevented from depositing on heat-transfer surfaces. Finally, microbiological growth must be controlled with biocides. Some of these microbiological contaminants may include harmful bacteria such as *Legionella,* which causes Legionnaires' disease.

Preventing scale while controlling corrosion. As COC increases, more water evaporates, and additional minerals enter the system via makeup water. The recirculating water becomes supersaturated with dissolved minerals and precipitation begins to occur, resulting in formation of scale deposits, such as calcium carbonate and magnesium silicate, on heat-exchange surfaces. While small amounts of scale can be beneficial for corrosion protection, if left unchecked, scale deposits will start to impede heat

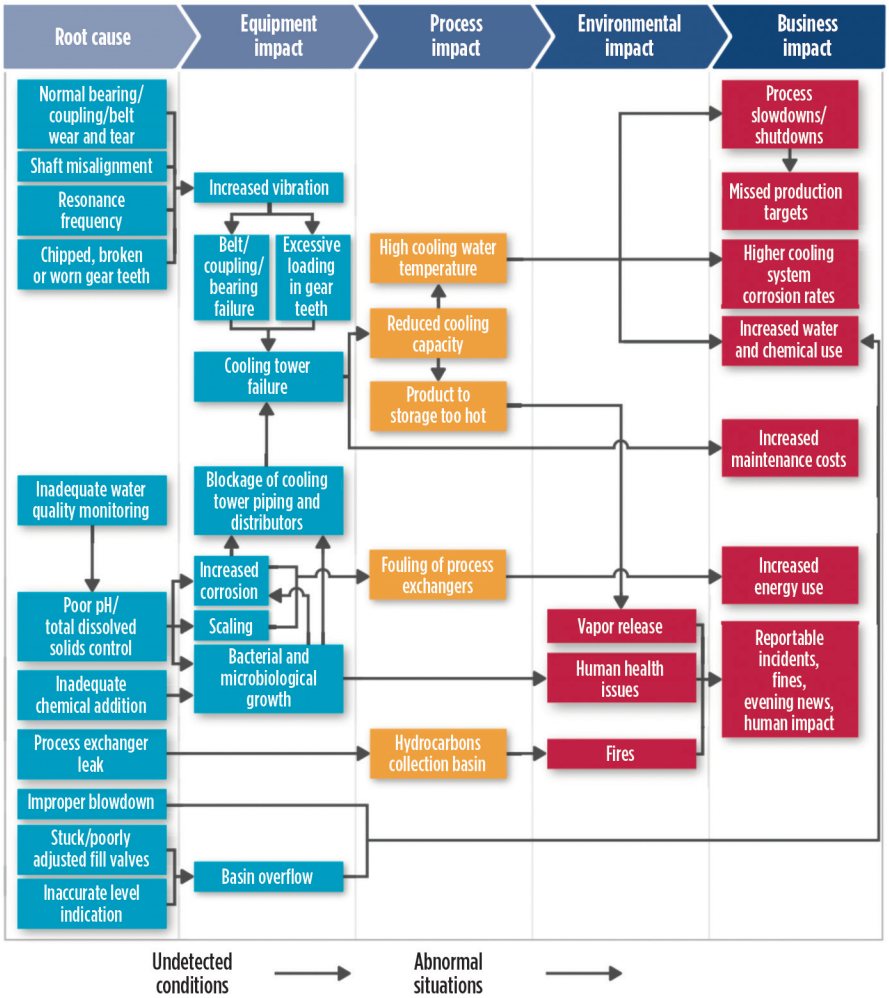

FIG. 2. Following the chain of effects of a problem shows how a small issue can escalate if not addressed quickly.

FIG. 3. A general-purpose pH sensor[a] is an appropriate choice for this type of application.

FIG. 4. A conductivity sensor[b] can control blowdown cycles when conductivity becomes too high.

transfer and significantly increase the risk of localized corrosion.

In addition, some carbonate deposits may accelerate delignification of cooling tower lumber and undermine structural integrity. Scaling is typically controlled by blowing down (bleeding off) some of the recirculated water from the system to reduce concentration of dissolved minerals. This may be sufficient for operation at low COC, however; at high COC, reducing alkalinity by adding sulfuric or hydrochloric acid and dosing chemical scale inhibitors may be required to control scale deposition.

Corrosion in a cooling system is a factor of temperature, pH, concentration of dissolved minerals, water flow velocity and extent of microbiological fouling. Three main types of corrosion exist: general, localized and galvanic. Localized corrosion is the major concern with these systems because it may lead to a rapid metal failure and is often hidden from sight under deposits.

Corrosion effects are widespread and often result in unscheduled downtime and costly repairs. These include:

- Fouling of heat exchangers and distribution piping by corrosion products (e.g., rust)
- Leaks in heat exchangers resulting in contamination of the process fluid by cooling water or vice versa
- Decrease in heat transfer efficiency.

pH control, along with chemical anodic and cathodic corrosion inhibitors such as chromates, nitrites, polyphosphates and bicarbonates, are commonly used to maintain corrosion within acceptable limits. Corrosion inhibitors must be carefully chosen for the specific metallurgy of the cooling system.

Controlling fouling and microbiological growth. During normal operations, cooling water becomes contaminated by organic and inorganic matter. Dosing of dispersants may be necessary to prevent coagulation or flocculation of suspended solids, which are drawn in with the outside air. Warm water also produces an ideal environment for algae, slime and bacterial growth. If left untreated, microorganisms form a gel-like substance called biofilm that allows them to attach to heat-transfer surfaces and protects them from biocides. Biofilm also prevents corrosion inhibitors from reaching the metal surfaces and may accelerate corrosion.

To control microbiological growth, non-oxidizing and oxidizing biocides, such as chlorine, bromine or ozone, are typically added on timed intervals. Some of these are highly toxic and pose a significant safety risk. Ozone is an effective alternative to traditional chemical biocides and has the following advantages:

- More effective than chlorine or ultraviolet light at destroying bacteria and viruses
- Does not produce harmful residuals that need to be removed from effluent water
- Reacts with iron, manganese and sulfur in the water to form insoluble metal oxides or elemental sulfur
- Can be generated onsite, eliminating the risks of storing and handling toxic chemicals
- Does not increase corrosion.

Cooling water monitoring. Effective control of COC and chemical treatment to maintain water quality requires continuous online measurement of water quality. Nonetheless, many facilities operate based on daily or even weekly analysis of their cooling water. Online monitoring of cooling water quality can help optimize cooling system performance and lower water and chemical usage.

At a minimum, plants should continuously monitor their cooling water pH and conductivity, using temperature-compensated pH sensors (**FIG. 3**) to monitor the alkalinity of the cooling water, along with conductivity sensors (**FIG. 4**) to monitor the concentration of dissolved minerals to maintain an optimal COC. General-purpose pH sensors and contacting conductivity sensors are suitable for most cooling water systems; however, for systems with a high degree of fouling, pH sensors resistant to fouling (**FIG. 5**) and toroidal conductivity sensors (**FIG. 6**) are recommended.

Measuring free chlorine in cooling water provides feedback to the chlorination system on biocidal efficacy to control and optimize dosing. To obtain accurate measurement of chlorine concentration in the cooling water, a free chlorine measurement (**FIG. 7**) compensated by a pH sensor should be used.

FIG. 5. Conventional pH sensors[c] can be fouled when suspended solids levels are high, so a fouling-resistant sensor can be used to reduce maintenance requirements.

FIG. 6. Where suspended solids levels are high, a toroidal conductivity sensor[d] may be necessary to make the measurements used to reduce the level.

FIG. 7. Chlorine necessary to suppress biological growth can be monitored using a sensor[e].

FIG. 8. Ozone treatment to reduce biological growth is growing in popularity but requires a specific sensor[f] to monitor concentration.

When utilization of a free chlorine measurement system is cost prohibitive, an oxidation reduction potential (ORP) measurement may serve as an alternative. The effectiveness of chlorine depends on its ability to oxidize water to produce hypochlorous acid, a strong oxidizing agent. ORP measurement—also compensated by a pH sensor—may be correlated to the amount of hypochlorous acid and may be used as a proxy to a free chlorine measurement for controlling the chlorination. If ozone is used to control biological growth, a dissolved-ozone sensor (FIG. 8) may be used to provide a continuous measurement of ozone concentration to control and optimize dosing.

FIG. 9. Measuring total suspended solids requires a sensor[g]. Data from this can be used for regulatory compliance reporting.

A blowdown stream turbidity measurement (FIG. 9) provides a way to monitor suspended solids and can be used to control sidestream filtration and for reporting of effluent total suspended solids levels to government regulators.

Cooling water return temperature is a good indicator of cooling performance and can be monitored easily with the temperature sensor incorporated into most pH or conductivity sensors, eliminating the cost of an additional temperature measurement point.

Cooling water treatment control. Since chemical water treatment is one of the largest variable cost components in cooling tower operations, automated control of blowdown and chemical dosing is important for cost-efficient operation.

In addition to monitoring and communicating various cooling water parameters, some liquid analytical transmitters may offer alarm relays, as well as proportional integral derivative (PID) and time proportional control (TPC) functions. These functions allow the transmitter to direct control of the cooling tower's makeup and blowdown valves, heaters and chemical treatment dosing pumps.

PID control can be applied to any of the sensor measurements connected to the transmitter, as well as to external analog and digital signal inputs. The output signal of a PID controller can vary its output from 0%–100% in response to the measured variable.

TPC is more commonly known as duty cycle or pulse-width modulation. It applies PID control to a relay, rather than using an analog current output. The TPC output is defined as the percent of time that a relay is activated.

The following alarm relay functions are common for cooling towers:

- **High/low concentration:** Primary and secondary measured variables (such as pH, conductivity and temperature) can be used to drive outputs to control concentrations. These outputs have an adjustable dead band and perform on/off control of pumps and valves. A typical application is control of blowdown.
- **Delay timer:** A delay timer can be used in a concentration control scheme to delay measurement following dosing of treatment chemicals. This ensures enough mixing time in a cooling water recirculation loop before performing a measurement, preventing unmixed readings that might cause overshooting. This function can be utilized when adding acid or inhibitors.
- **Bleed and feed:** This approach is typically used to replace chemicals lost during blowdown and involves two or more relays. Once the bleed relay deactivates, one or more feed relays activate for a percentage of the time the bleed relay was on. Bleed and feed support continuous monitoring of blowdown water conductivity to determine the point of excessive conductivity. At a programmable maximum concentration value,

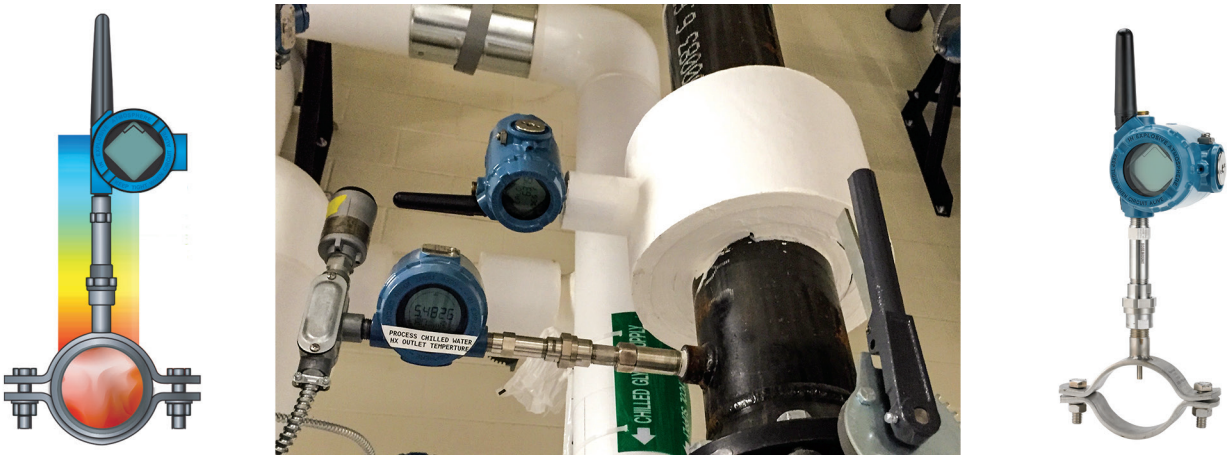

FIG. 10. Where it is not practical to add a permanent temperature measurement point, a transmitter[h] can infer the water temperature without a process penetration.

bleeding of blowdown water is triggered. Subsequently, pumping to feed additional makeup water chemicals is enabled to account for lost blowdown water. Through level control, makeup water is added in proportion to the volume of water lost through blowdown and evaporation.

- **Totalizer-based relay activation:** This approach feeds chemicals for a preset period every time a programmed volume of liquid has been added or removed. The relay energizes when the volume has been reached and remains energized for a fixed time. The process repeats once the volume has been reached again. The scheme uses pulse inputs from a flow meter or 4-20 mA current input from a flow transmitter to calculate a volumetric total flow. A typical application is chemical dosing control.
- **Interval timer:** When a sensor needs to be cleaned or the process requires adjustment, an interval timer turns on to begin the cycle. When the interval time has expired, the analyzer deactivates the "hold" mode on the assigned measurement and the relay is energized for the on-time period.
- **Date and time activation:** This relay feature allows programming of relays to activate on an assigned day of the week and time of day or night for an assigned interval, functioning like a sprinkler timer. The programmable timeframe cycle is typically two weeks. A typical application example is daily biocide dosing.

Evaluating condition and performance. In addition to liquid analytical measurements used for monitoring and control of cooling water quality and COC, continuous measurements of other parameters—such as flow, temperature, level and pressure—at various points throughout the cooling system work together to monitor performance and further optimize efficiency. Typical points of measurement include:

- A cooling tower's exhaust air temperature
- Ambient air dry-bulb and wet-bulb temperatures
- Cooling water supply and return temperatures
- Level measurements in water and chemical storage tanks
- Water flowrates
- Pressure differential across heat exchangers.

The data generated by these instruments can be recorded and analyzed by preconfigured applications to continuously monitor the cooling tower and its related equipment health. This can enable:

- Tracking and optimizing cooling tower efficiency
- Monitoring and optimizing water and chemical usage
- Monitoring heat exchanger performance
- Monitoring rotating equipment for condition-based maintenance to mitigate asset failures
- Alerting operators when something abnormal is detected
- Training operators to act on this new information and to update procedures as needed.

Wireless products are supported by, and are fully compliant with, the IEC 62591 standard, making this kind of monitoring much easier and less expensive than with wired instruments. All the types of instruments necessary for monitoring a cooling tower are available with either native *Wireless*HART transmitters or with adapters to connect to *Wireless*HART networks. This makes installation easier, and, if added to existing networks, the cost is especially low. Some things to consider:

- Surface-mounted temperature sensors do not require thermowells, and are able to accurately measure water temperature through the pipe wall (**FIG. 10**).
- If it is practical to use conventional temperature sensors, a single transmitter (**FIG. 11**) can send data from up to four sensors on one wireless signal.
- Vibration and bearing temperature sensors can be added to fan and pump motors and gear boxes to warn of developing mechanical problems.
- Wireless pressure sensors may be installed on the inlet and outlet of a heat exchanger to measure differential pressure and to monitor fouling.
- Liquid analytical transmitters can connect to a *Wireless*HART network with an adapter.

FIG. 11. Some temperature transmitters[i] can send data from up to four sensors on one channel.

All these elements working together, guided by data gathering and analytical apps, can improve cooling tower performance and plant profitability. HP

NOTES

[a] Refers to the Emerson Rosemount 3900 general-purpose pH/ORP sensor
[b] Refers to the Emerson Rosemount 400 contacting conductivity sensor
[c] Refers to the Emerson Rosemount 396P/396PVP pH/ORP sensor
[d] Refers to the Emerson Rosemount 228 toroidal conductivity sensor
[e] Refers to the Emerson Rosemount 499ACL free chlorine sensor
[f] Refers to the Emerson Rosemount 499AOZ amperometric ozone sensor
[g] Refers to the Emerson Rosemount T1056 Clarity II turbidimeter
[h] Refers to the Emerson Rosemount X-well technology
[i] Refers to the Emerson Rosemount 848T wireless temperature transmitter

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