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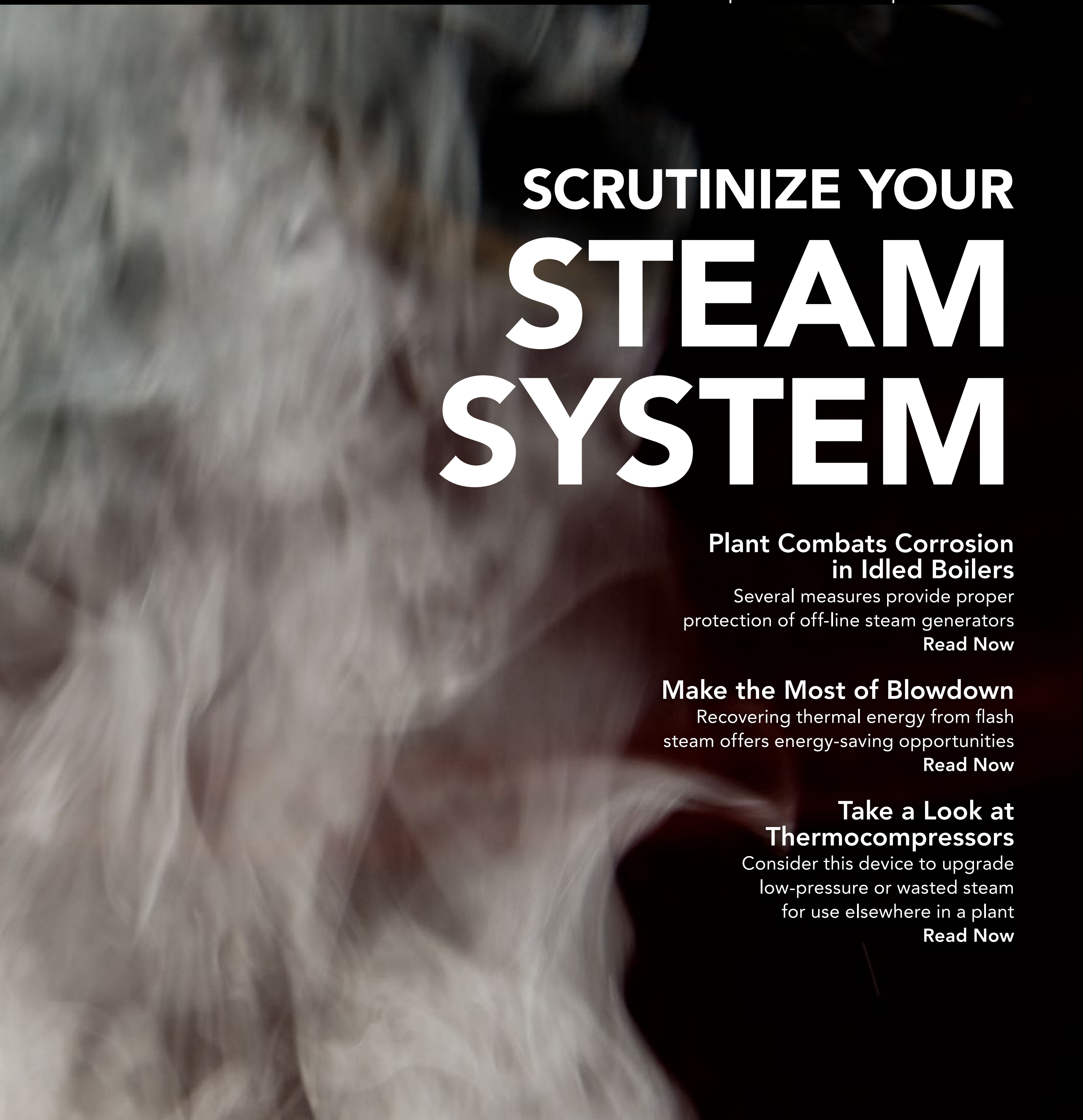

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Plant Combats Corrosion in Idled Boilers

Several measures provide proper protection of off-line steam generators

By Brad Buecker, Kiewit Engineering and Design Co., and Dan Dixon, Lincoln Electric System

Steam generation plays a critical role at many industrial facilities. Unfortunately, the high-temperature and high-pressure environment of large steam generators makes them susceptible to corrosion. Even seemingly minor impurity ingress can cause problems [1]. Fortunately, plants can take advantage of a lot of lessons learned about preventing corrosion in boilers. However, an often overlooked issue is the risk of severe corrosion occurring during those times when a steam generator is down due to lack of steam demand or for maintenance. This article outlines several techniques for protecting steam generators at these times. Our examples come from a power plant, Lincoln Electric System's Terry Bundy Generating Station in Lincoln, Nebraska, but the technologies suit process plants as well.

BACKGROUND

The Terry Bundy plant has three GE LM6000 combustion turbines, two of which are equipped with heat recovery steam generators (HRSGs) that drive a supplemental steam turbine. Total plant capacity is 170 MW. The units cycle on and off, often on a daily basis during the summer, according to the requirements of the South West Power Pool. At other times, a unit may be down for several days or perhaps even weeks during periods of mild weather or for maintenance outages.

For normal operating chemistry, the HRSG feedwater is on an all-volatile treatment oxidizing [AVT(O)] program, with ammonium hydroxide injection to maintain feedwater pH within a 9.6–10 range. High-pressure evaporator chemistry complies with the Electric Power Research Institute's phosphate guidelines, with trisodium phosphate as the only phosphate species and control within a 1–3 ppm range. The high-pressure evaporator pH control range is 9.5–10. Free caustic concentrations are maintained at or below 1 ppm to minimize the risk of caustic gouging.

For short-term outages, the HRSGs must remain full of condensate to enable quick start-up. On the other hand, a maintenance outage requires draining of the unit, preferably while it is hot so it flash-dries. However, even such drying still leaves some areas exposed to moist conditions and, thus, vulnerable unless additional protective methods are used.

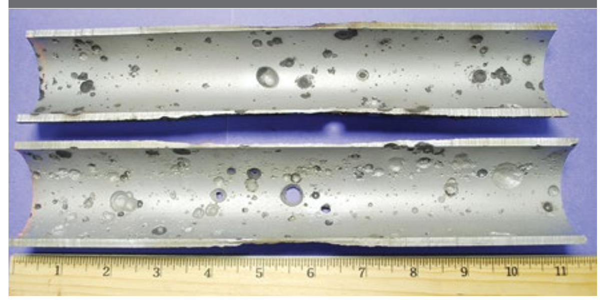
The equipment and processes outlined below all are designed to protect the unit from oxygen corrosion during any outage. Oxygen attack is extremely serious.

The corrosion mechanism can induce severe metal loss in those areas of high oxygen concentration. The attack often takes the form of pitting (Figure 1), where the concentrated corrosion can cause through-wall penetration and equipment failure in a short period of time.

In addition, oxygen attack will generate corrosion products that then carry over to the steam generator during startups. Deposition of iron oxides in the waterwall tubes leads to loss of thermal efficiency and, most importantly, establishes sites for under-deposit corrosion, such as very insidious hydrogen damage, acid phosphate corrosion (in units

OXYGEN CORROSION

Figure 1. Oxygen can cause severe pitting that can penetrate the wall of a steam generator tube. *Source: ChemTreat.*



with poorly maintained or monitored chemistry — see: "Don't Get Steamed," http://goo.gl/XPhl7s), and caustic gouging [2].

Oxygen also can infiltrate steam generators at startup when collected condensate or fresh demineralized water is needed for filling or boiler top-off. These high-purity waters typically are stored in atmospherically vented tanks. The water absorbs oxygen and carbon dioxide, often to the saturation point, which may be up to 8 ppm in the case of oxygen. When the makeup is injected into a cold steam generator, significant oxygen attack is possible.

KEY MEASURES

To prevent oxygen ingress and corrosion, the Terry Bundy combined-cycle plant relies on four of the best techniques: nitrogen blanketing; periodic water circulation; dissolved oxygen removal from makeup condensate and demineralized water; and warm air recirculation to protect the low-pressure turbine.

Nitrogen blanketing. The first and foremost measure is nitrogen blanketing during shutdown and subsequent short-term layups. Experience has shown that introducing nitrogen to key points in the system before the pressure has totally decayed will minimize ingress of air. Then, as the system continues to cool, only nitrogen enters, not oxygen-laden air. Key points for nitrogen protection in HRSGs include the evaporator, economizer and feedwater circuits.

The nitrogen blanketing system was installed in 2005, just a few years after the steam generators' startup, when plant personnel discovered oxygen pitting in one of the high-pressure evaporators as well as other corrosion.

One question that often arises is how best to supply nitrogen. Certainly local gas-supply or welding firms can provide bottles of compressed nitrogen. Liquid nitrogen is another possibility. Terry Bundy personnel selected a different method, nitrogen generation via a pressure-swing adsorption (PSA) system. (For more on such units for nitrogen generation, see: "Rethink Nitrogen Supply for Chemical Blanketing," http://goo.gl/btiSw3.)

The process relies on a carbon molecular sieve that, when compressed air is introduced at high pressure, adsorbs oxygen, carbon dioxide and water vapor but allows nitrogen to pass through (Figure 2). The nitrogen then can be collected in a receiver for use as needed. At a preselected interval, pressure is released from the unit; O_2, CO_2, and H_2O desorb from the material and are vented to atmosphere. The nitrogen purity from this system depends upon production rate, and ranges from 1,000 scfh at 99.5% purity to 248 scfh at 99.99% purity.

NITROGEN GENERATOR

Figure 2. Unit uses a carbon molecule sieve to separate nitrogen from air. *Source: Lincoln Electric System.*

The Terry Bundy N_2 generator supplies 5-psig nitrogen to the low-pressure and high-pressure drums during wet layups; the nitrogen also serves to "push" water from an HRSG during dry layup draining. A nitrogen pressure of 5 psig is maintained during the dry layup, provided no major tube work is required.

An obvious major concern with nitrogen blanketing — and why some plants don't use it — is safety. Nitrogen is an asphyxiating agent and requires strict adherence to confined-space entry procedures and proper ventilation of the space.

Periodic water circulation. This is another important point with regard to wet layup chemistry. Regular water movement minimizes stagnant conditions that can concentrate oxygen in localized areas to cause pitting. Both Terry Bundy HRSGs have circulating systems installed on the high- and low-pressure circuits for use during wet layups. Each circuit uses one of two redundant preheater recirculation pumps, which normally are in service during HRSG operation to mitigate acid dew point corrosion of external circuits. Each pump provides approximately 100 gpm per circuit. Valves and piping have been added to enable seamless transition from layup circulation to normal operation. Sample/injection systems allow operators to test the layup chemistry for pH and dissolved oxygen (using colorimetric ampules), and to inject ammonium hydroxide if the pH must be raised. In addition, modifications made in each boiler drum permit the layup water to bypass the drum baffle, promoting circulation and minimizing short-circuiting via the downcomers. The pumps typically are started once drum pressure drops below 50 psig, and remain in service for the duration of the layup.

Dissolved oxygen removal from condensate and makeup water. Because demineralized water commonly is stored in atmospherically vented tanks, oxygen-laden water enters the steam generator during normal operation and, even more critically, during boiler filling. In the latter case, the influx

DISSOLVED OXYGEN REMOVAL

Figure 3. Hollow-fiber membranes eliminate oxygen in condensate return and makeup water. ***Source: Lincoln Electric System.***

of cold oxygen-saturated water can cause severe difficulties. One possible method to minimize this problem is to limit oxygen ingress to storage tanks — but this typically is a difficult proposition. So, instead, Terry Bundy personnel selected a gas-transfer membrane technology to treat condensate return and makeup water (Figure 3).

The oxygen-laden water flows along hollow-fiber membranes that let dissolved gases pass through but not the water. A sweep gas, often nitrogen, flows along the opposite surface of the membranes and carries away the gases. The technology can reduce the dissolved oxygen concentration from saturated conditions to less than 10 ppb.

DON'T FORGET THE STEAM TURBINE

Far too often in the power industry, plants allow the condenser hotwell to remain moist or even contain standing water during outages in which the condenser vacuum was broken and air entered the condenser and low-pressure turbine. The low-pressure blades in steam turbines typically collect salts that carry over with steam from boiler drums. The combination of a moisture-laden atmosphere and these salt deposits can foster pitting and stress corrosion cracking.

A very practical method to combat this corrosion, and the one adopted at Terry Bundy, is injection of desiccated air into the condenser during all but short-term, i.e., <72 h, layups.

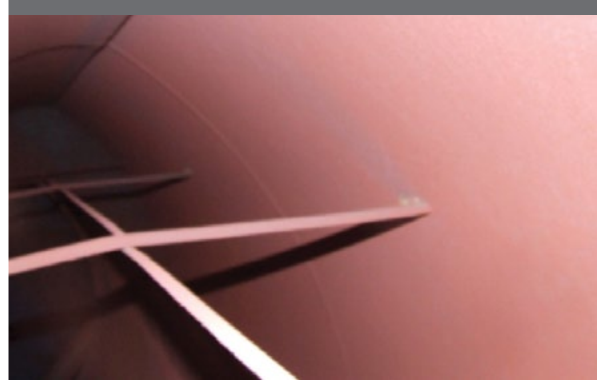
DEHUMIDIFIER

Figure 4. Desiccant wheel unit provides air with only 10% humidity to condenser and low-pressure turbine. *Source: Lincoln Electric System.*

This system uses a desiccant wheel dehumidifier (Figure 4) to provide 700 scfm of 100°F air at 10% humidity to the condenser and low-pressure turbine. This flow can lower the relative humidity from nearly 100% to less than 30% in just a few hours.

FOLLOW-UP INSPECTION

Figure 5. Check conducted three years after measures were implemented showed no new pitting. *Source: Lincoln Electric System.*



IMPRESSIVE RESULTS

In 2005, drum inspections showed significant pitting. This prompted implementing the changes we've outlined. A repeat inspection in 2008 showed no new pitting (Figure 5). Subsequent inspections continue to show little to no additional pitting.

Iron level monitoring, via particulate collection on 0.45-micron filters, showed a significant decrease in samples from the condensate pump discharge and both low-pressure and high-pressure drums.

Quicker startups than in the past are now commonplace. In addition and of significant importance, the units can be left in wet layup for extended periods, which saves the plant six hours (over dry layup) to reach full load when needed.

BRAD BUECKER is a process specialist for Kiewit Engineering and Design Co., Lenexa, Ks. **DAN DIXON** is supervisor, inter-local projects, for Lincoln Electric System, Lincoln, Neb. E-mail them at Brad.Bueker@kiewit.com and ddixon@les.com.

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Make the Most of Blowdown

Recovering thermal energy from flash steam offers energy-saving opportunities

By Riyaz Papar

Irrespective of how steam is produced in our process plants, several aspects of steam generation are common; we should apply standard best practices to them. This column specifically addresses the blowdown stream as well as both the flash steam recovery and heat recovery that we should implement in our steam systems.

Every steam system has a water treatment plant; feedwater is made up of treated makeup water, returned condensate and directly injected steam (in the deaerator). Although the condensate and steam are clean, the treated makeup water still brings in dissolved impurities. Because these impurities are not soluble in steam, they remain in the boiler. As a result, their concentration builds and can lead to serious operational problems such as scaling on the water-side of the tubes resulting in tube leaks and failures, foaming resulting in liquid carryover, loose sludge in the boiler water, etc. All of these problems could damage boiler integrity. Blowdown is the primary mechanism that controls the water chemistry of the boiler water. It regulates the concentration of dissolved and precipitated chemicals in the boiler and, thus, ensures steam generation equipment functions reliably.

Generally, boiler water conductivity or total dissolved solids is used to control blowdown, but as our steam systems get more complex, other parameters — pH, silica, iron, etc. — also are used as secondary control points. In the past 25 years, I have seen blowdown rates as low as 1% and in some instances as high as 15%. Blowdown rate depends on several factors; however, I will not be covering blowdown rate in this column. Please work with your water chemist to ensure you have everything in place to minimize blowdown.

CAPTURE THERMAL ENERGY

Blowdown, because it is saturated liquid water at steam generation pressure, contains a significant amount of thermal energy. The higher the steam generation pressure, the higher the saturation (blowdown) temperature and the higher the thermal energy (Btu/lb) associated with the blowdown. As blowdown is discharged from the boiler, this thermal energy (provided by the fuel or from another source) is lost. Therefore, reducing the amount of blowdown to the bare minimum is an excellent best practice; beyond that we need to look at other mechanisms to capture lost energy.

So, that brings us to creating and recovering flash steam from blowdown and then, if economically justifiable, recovering heat from the liquid water before discharge. The simplest configuration is to first take the blowdown stream into a flash tank whose pressure is slightly higher than either the deaerator pressure or the lowest-pressure steam header in the steam generation area. The blowdown flashes and produces low-pressure steam that can be recovered and used within the steam system to offset deaerator steam demand. Recovering flash steam accounts for 65–70% of the total blowdown stream energy that would otherwise have been lost. Interestingly, the flash tank is a simple piece of equipment with no moving parts. On several occasions, I have been able to source it from within a plant's operations that are no longer in service. The remainder of the liquid water from the flash tank is still hot (>225°F) and can be used to exchange heat in a simple one-pass shell-and-tube heat exchanger or a plate-and-frame unit, etc. This can be used to heat the makeup water going to the deaerator, thereby saving on overall steam demand from utilities.

Also, I have faced some challenges in plants when I tried implementing blowdown thermal energy recovery. Most relate to past incorrect applications, such as a large U-tube heat exchanger used to recover heat from blowdown that fouled and eventually was taken out of service because it became a maintenance headache. In other plants, because there is so much excess low-pressure steam, managers claim there's no benefit of low-pressure, low-temperature heat recovery. This is not necessarily true; technologies exist to upgrade low-pressure steam and make use of every Btu that would otherwise be lost. I realize the overall blowdown energy recovery and cost savings may not be huge (<2%) but, as one of the simplest and most cost-effective best practices, it should never be ignored! (For more on improving boiler management to help save energy, see "Optimize Boiler Loads," http://goo.gl/z9c1M1 and "Don't Get Steamed," http://goo.gl/xoUQSM.)

RIYAZ PAPAR is a former Energy Saver columnist for *Chemical Processing*. Email him at rpapar@hudsontech.com.

Take a Look at Thermocompressors

Consider this device to upgrade low-pressure or wasted steam for use elsewhere in a plant

By Riyaz Papar

Many sites, including petrochemical plants and refineries, often have a lot of low-temperature heat (waste heat, low-pressure steam, etc.) available; in most cases, it is rejected in fin-fans, cooling towers, exhaust stacks, etc. While identifying and recognizing these sources of low-temperature heat is easy, sometimes economically justifying using such heat in process or utility areas is difficult. I will attempt to shed some light on one potential technology that can be used effectively to capture low-temperature heat (most often in the form of low-pressure steam).

Most of us who have had to deal with thermodynamics extensively realize that the variation in steam enthalpy (energy content) doesn't significantly differ between pressure levels. For example, saturated steam enthalpy at 20, 200 and 600 psig is 1,167, 1,200 and 1,203 Btu/lb, respectively. The superheat in the steam at the different pressures will drive the enthalpy up but for all practical heating applications — excluding power generation — saturated steam is all that's needed at the appropriate heating temperature.

So, if we have excess low-pressure steam currently being vented or sent to the fin-fans (or a cooling-tower water condenser) for condensation, investigating upgrading this steam to a higher pressure may be worthwhile. As I mentioned, the enthalpy isn't that different, but a pressure upgrade also includes an inherent temperature upgrade and that's where the second law of thermodynamics comes into play. Several methodologies exist to upgrade this low-pressure steam, including the use of a thermocompressor.

From a layman's perspective, a thermocompressor is an extremely well-designed converging diverging nozzle that requires high-pressure steam to absorb (or suck in) low-pressure steam to create medium-pressure steam useful for process heating. The high-pressure steam is known as the "motive or live steam" and the low-pressure steam is known as "suction steam." The medium-pressure steam is generally referred to as "discharge steam." Apart from the specific pressures, the main design parameter is the mass ratio of the suction steam to motive steam. All thermocompressor designs start with identifying the amount of low-pressure waste steam available for recovery and then identifying the high-pressure motive steam that could be used to create the medium-pressure steam. Generally, for a given discharge pressure, the higher the pressure ratio between the motive steam and suction steam, the higher the mass ratio of the suction steam to motive steam (note the inverse relationship here). So, always try to use the highest pressure steam available in the plant as the motive steam!

Industry long has used thermocompressors, which are a time-tested technology. They have no moving parts, although control valves are used to regulate pressures if the steam requirement varies. Several applications exist in process plants for thermocompressors; the most common include:

1. Flash steam recovery from condensate tanks.
2. Multi-effect evaporators and other processes that sequentially remove water from products.

Thermocompressors also can be applied effectively in several other places. I came across one such application about six years ago when I was working on a steam system energy assessment at a refinery. We had a reboiler steam requirement at ~400 psig and the refinery was letting down high-pressure steam at ~800 psig through a pressure-reducing valve to provide steam to the reboiler. Interestingly, we had a 250-psig header in the vicinity. A thermocompressor fit perfectly well in that application; the refinery installed it, thus upgrading the 250-psig steam to 400-psig using the high-pressure (800-psig) steam. The energy and cost savings along with a higher overall energy efficiency came from:

1. a reduction in 800-psig steam generation (natural gas savings).
2. more power production from the existing 800/250 backpressure steam turbine generator (electrical power savings).
3. the elimination of steam flow through pressure-reducing/letdown stations.

In summary, review your plant's steam system to identify vented and low-pressure steam that can be upgraded with thermocompressors. In addition, challenge yourself to think out-of-the-box to identify applications that integrate the process requirements and lead to significant energy and cost benefits!

RIYAZ PAPAR is a former Energy Saver columnist for *Chemical Processing*. Email him at rpapar@hudsontech.com.

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