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Downcomer and furnace wall water supply pipes for a radiant boiler. Photo Babcock & Wilcox Power Generation.

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POWER Engineering

Opinion

Purgatory of Maybe

By David Wagman, Chief Editor

Now that the Democrats have lost their super majority in the Senate it seems more likely that carbon regulation rules will come from the U.S. Environmental Protection Agency rather than Congress.

This is contrary to what many in the power generation industry had hoped. A congressional approach might make it more likely that an economy-wide strategy would be adopted. As a rulemaking agency the EPA is more narrowly confined. Its approach, although still likely to be far-reaching, will nonetheless fall short of the scale and scope that Congress could address.

Uncertainty over carbon has left much of the industry in a state of paralysis. Perhaps the only happy outcome of the recession is that electricity demand has dropped, easing many timetables for building new fossil-fired power plants. Given the long lead time needed to permit, build and commission a new baseload plant, however, the industry can't wait indefinitely for a decision on carbon.

Complicating matters is the global muddle that resulted from last December's Copenhagen climate change talks. Little consensus emerged on how the world will address the issue of global climate change. Behind it all are the climate change skeptics whose doubts still needs to be listened to: are regulations truly necessary?, is climate change a phenomenon that humankind can control? and so on. Answering "yes" assumes agreement on a host of scientific and political factors. Saying "no" assumes agreement on a different list. Still to be considered are legal challenges that may result from new rules.

All this points to a purgatory of "maybe" that does no one any good. Trying to figure out how to value the cost of carbon has turned into such a fundamental issue that it affects capital spending decisions from nuclear power plants to solar rooftop installations. Either Congress or the EPA must act swiftly to resolve the impasse and allow the industry to move on. pe

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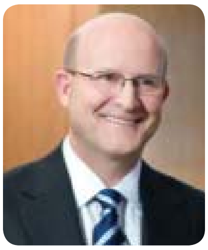
Infrastructure Retrofits

By Dan Heintzelman, GE Energy Services



Power plant managers continually face the challenge of increasing efficiency, extending asset life and simultaneously optimizing power operations. No matter the external conditions, reaching optimum power levels with the least cost, effort and emissions is critical to continued business success.

Today, a growing urban global population and a business footprint that demands more power, while companies rely on fewer people and constrained capital resources to deliver it, further compounds this challenge.

But responding by simply purchasing more new plant assets doesn't always translate to improved business or bottom-line efficiency. What may make more sense for some utilities and industrial energy suppliers is to pursue a strategy based on utilizing the best available technology to maintain and improve existing assets and infrastructure.

This strategy can be accomplished through a mix of equipment upgrades and more intelligent operational and maintenance programs. With much of the dialogue about energy efficiency today focused on demand side management, it is equally important that energy producers consider the energy supply side. In fact, much of the energy generated is lost before the electricity passes to the grid. Three solutions for improving supply-side energy generation efficiency are as follows:

- **Retrofitting technology to upgrade gas-fired, combined-cycle power plants**

Simply making what we already have more efficient seems a smart place to start. For example, gas turbines retrofitted with new compressors or rotors, advanced combustion systems and newly updated emissions and controls packages can help extend unit life by up to 25 years, in addition to providing the owner and operator with better performance, operational flexibility and often improved efficiency.

The benefits of upgrading existing gas-fired, combined-cycle power plants could be considerable given the global installed capacity base. Even a small percentage change in efficiency gained through retrofitting these gas-fired plants can create large results. For example, a one-percentage-point efficiency improvement in the GE fleet of F-Class gas-fired turbines could reduce carbon dioxide emissions by 4.4 million tons a year.

- **Improving controls to reduce VARs in electrical transmission and distribution**

Today's electric grid is inefficient. Losses occur throughout the system, from generation, through transmission to consumption. Making the grid 10 percent more efficient could save more than 27 GWh of energy. That's equivalent to the power output from 56 coal-fired power plants.

Reliability issues also are problematic and these challenges cost businesses money. Across business sectors, the U.S. economy loses $104 to $164 billion a year to outages and another $15 to $24 billion to power quality phenomena.

These examples make it easy to see why improved controls can be valuable. When utilities are equipped with the proper controls, they can respond in real-time to power demands and power pricing to reduce cost. For example, line losses can be minimized by using VAR Control and, at the same time, power quality can be improved.

Further, peak-period voltage control could help reduce peak load, lowering peak generation costs and deferring capital expenditures for generation, transmission and distribution. Continuous voltage controls also help reduce overall load, lowering generation operating costs and reducing base load capital expenditures.

- **Installing monitoring and diagnostic software and hardware**

For many electrical utilities, there's a focus on distributing power at the lowest cost with manageable reliability risk. Utilities using a time-based maintenance approach can have the unintended consequence that the reliability and availability of machinery is actually reduced. This affects the experience of customers and unnecessarily increases the overall lifecycle cost of the asset.

It can be far more efficient to install monitoring equipment that give up-to-the-minute reports so that current conditions can be assessed and the concept of condition-based maintenance can be applied, resulting in significant savings to the owner.

A monitoring solution provides accurate, real-time condition data. In some cases, that allows for an 80 percent increase in time between outages and a 60 percent decrease in outage durations. The right monitoring hardware along with diagnostics software in some cases can help decrease asset downtime by nearly 4 percent.

Early detection of asset performance degradations and malfunctions also helps extend asset service life and reduce maintenance costs, and reduces the overall likelihood of a significant event. Meanwhile, lessons learned could be embedded in the system as knowledge-based rules to continuously improve, automate, and validate diagnostics that can help predict future events.

Smart technology can be used to monitor and diagnose aging operating assets and is critical for achieving improved efficiency. A three-pronged approach of retrofitting older technology, installing the latest in controls and monitoring systems and a relentless focus on operational optimization will result in an increase in equipment reliability, improved performance, and in many cases, enhanced efficiency.

Taking these strategies into consideration afford power producers the opportunity to be cleaner, smarter and more efficient. pe

Dan Heintzelman is president and CEO of GE Energy Services based in Atlanta.

Atoning for Non-Attainment

By Robynn Andracsek, P.E., Burns & McDonnell and Contributing Editor

How do you know if the air around your facility is "clean"? And what are the consequences if it is not clean enough?

As one of its basic tenets, the Clean Air Act (CAA) directs the U.S. Environmental Protection Agency to establish National Ambient Air Quality Standards (NAAQS) as federal health standards for outdoor air. Ambient air monitors operated by each state measure the actual air quality in each area. These measurements are then compared to the numeric NAAQS limits. The CAA's goal is for every part of the country to meet these standards. Attaining and sustaining NAAQS compliance is the driver behind the New Source Review, Acid Rain program, emission inventories and almost every other air regulation that applies to a power plant. (Okay, there are a few other regulations that deal with hazardous air pollutants like mercury.)

Of the six criteria pollutants for which EPA has established NAAQS, ground-level ozone is the one with the most non-attainment areas. Ozone is almost entirely a secondary pollutant formed when volatile organic compounds (VOCs) and nitrogen oxides (NO_x) react under conditions of high temperatures and direct sunlight. With ozone, it's all about location: ground-level ozone (smog) can adversely affect human lungs and plant life while upper air ozone protects life from the sun's harmful rays. However, it sometimes takes a degree in statistics to know if an area is in attainment or not. Compliance with the 8-hour ozone standard is based on the 3-year average of the 4th-highest daily maximum 8-hour ozone reading from each monitor. What's more, non-attainment is divided into five categories: marginal, moderate, serious, severe and extreme.

Let's say you are in an ozone non-attainment area. Your state must develop a State Implementation Plan (SIP) to bring the area back into attainment. Since both NO_x and VOC are precursors to ozone, the SIP can address one or both. Reducing NO_x or VOC emissions to the atmosphere removes the ingredients required for ozone formation. The consequences for a SIP failing to achieve attainment can be stifling as well as costly. If the EPA thinks a SIP is not sufficiently strict, responsive or timely it will impose a Federal Implementation Plan. Sanctions can include loss of federal highway dollars and EPA funds. Worse yet, the area can be reclassified to a worse category of non-attainment. The most common non-attainment classifications (marginal, moderate or serious) put the area at risk for limitations on projects such as new road construction.

One of the biggest concerns to existing power plants is the imposition of Reasonably Available Control Technology (RACT). Here, specific facilities and operating units are identified and required by the SIP to install retrofit controls. This is costly for power plants and other large emitters such as refineries, glass manufacturers and steel mills.

The story doesn't end once an area achieves attainment. Safeguarding is required to ensure the area doesn't slip back into non-attainment. Designating an area as being "in attainment" requires that emissions be less than or equal to NAAQS, that a fully approved SIP be in place, that substantial proof exists the air quality has improved due to permanent and enforceable emission reductions and that an EPA-approved "maintenance plan" is in place. Within three years of the redesignation, the state must submit a 10-year maintenance plan detailing plans to preserve the attainment status.

In March 2008, EPA lowered the ground-level ozone standard from 80 parts per billion (ppb) to 75 ppb over an 8-hour period. Based on estimates from 2004 to 2006 data, 345 monitored counties violate the 2008 8-hour ozone standard of 75 ppb. This included 74 counties that were in attainment with the 80 ppb standard. EPA will likely designate areas as non-attainment based on data from 2006 to 2008 or later, which is expected to show improved air quality.

In January 2010, EPA proposed to lower ozone even further, to 60 70 ppb, "to ensure they are clearly grounded in science" since 75 ppb was "not as protective as recommended by EPA's panel of science advisors." This is yet another step back from Bush-era EPA policy.

Additionally, EPA is proposing new 1-hour NAAQS for both SO_2 and NO_2. Adding this 1-hour standard will work against the ability of power plants to recover from short-term emission upsets. EPA is proposing the NO_2 1-hour standard at 0.080 to 0.100 ppm and the SO_2 1-hour standard at 0.050 to 0.100 ppm.

These proposed changes in NAAQS for ozone, SO_2 and NO_2 will lead to even more areas designated as non-attainment and even more power plants called to task.

Thanks to Whitney Smith, Burns & McDonnell, for her input to this column. pe

Examining the Evidence

By Nancy Spring, Senior Editor

"I guess I'd be more concerned if there was complete agreement on whether we are in the midst of a nuclear renaissance in the U.S.," said Chris Gadomski, managing editor, nuclear, New Energy Finance. "One minute I'm optimistic, the next minute I'm less so, but at least the discussion is still ongoing."

Gadomski took part in a panel discussion on the economics of nuclear power at the NUCLEAR-POWER International conference in December and we talked after the session about the "evidence" pointing toward or against new nuclear projects in the U.S.

He was one of five nuclear power experts on the panel, each of whom had a different take on trends affecting the U.S. nuclear renaissance.

Energy generation has followed a decarbonization trend for 150 years and energy density has been one of the primary drivers of the change from one fuel to the next, said Robert Preston, portfolio manager, Merrill Lynch. With 200 years of history behind this trend, Preston is confident that "the decarbonization vector will not deviate significantly from its path." Nuclear power's fuels, uranium and thorium, have 2 million times the spatial energy of wood and no carbon, making the move to nuclear power the natural next step.

Nuclear power has a positive effect on local economies, said Mark Fecteau, managing director, global growth and innovation, Westinghouse, and chairman of the Carolinas Nuclear Cluster. The goal of the "cluster" companies is to make the "New" Carolinas the center of nuclear activity in the U.S., "like the wine industry in California."

In the Carolinas, 51 percent of the electricity is generated by nuclear power and the nuclear industry there employs 37,000 people, in good, well-paid positions. Fecteau hopes that number will double in 20 years and said currently interest is strong. "There was standing-room-only at the four supplier information sessions we have held since 2007."

We have knowledge and experience building and operating nuclear plants and now we must show we can do it, said Bryan Erler, Erler Engineering, and ASME vice president of Nuclear Codes and Standards. What ended nuclear power in the '70s was the (un)economics of the projects and this time around "we'll have to rebuild our credibility."

Erler is optimistic but said we still have to be careful. The U.S. must have standards that are consistent and quality in every aspect of construction is critical. "We must lock in the design before construction and fabrication" or cost and scheduling problems will plague us again.

Ed Kee, vice president, NERA Economic Consulting, said nuclear energy today is a very valuable commodity because its fuel costs are low—the marginal cost is zero—and nuclear plants have such a long operating life. "The new plants being built today could even last forever," he said.

On the other hand, constructing a nuclear power plant has a long lead time, said Kee, with about 10 years of delay before the operator sees any financial benefit, and "something that far out is not desireable."

Two of the four plants being considered for the U.S. Department of Energy loan guarantee, UniStar's Calvert Cliffs and NRG's STP 3&4, are merchant plants and "never in the whole world has there been commercial nuclear power," Kee said.

The move toward a carbon-free society is usually a big plus for nuclear power but if carbon prices aren't high enough, they may not give nuclear the push it needs.

The supply of experienced workers is limited and the cost and availability of commodities is troublesome. "We can't even fabricate a reactor in the U.S.," said Erler.

In other parts of the world, the government's role is key to making new nuclear projects work. As Kee said, it's not about anything but building something big and if the government said it would do it, it could be done. That kind of radical departure from the norm in this country is unlikely to happen.

Perhaps most worrisome is recent talk about tying the decision to build nuclear power plants to the price of natural gas.

"This shale-gas bubble thing is happening," said Kee. "It's amazing that a short-term gas price is driving people away from nuclear."

When I add up most of the pros and cons mentioned here and include other factors, such as early site approval, standardized nuclear power plant designs and construction experience in other parts of the world, I am optimistic that we will be building new nuclear plants soon. By some estimates, we need to build 70 reactors by 2053 in the U.S. just to replace our current fleet of 104, so the sooner the better.

But when I consider short-term thinking like tying nuclear power to natural gas, I'm less encouraged. "Letting the markets work" based on short-term price signals is not likely to result in multi-billion dollar investments in projects with 10-year-plus timelines. Until our system changes, my bet's on natural gas. pe

What Works

Major Babbitt Bearing Repair Completed at Power Plant

By Pat Trentler, Quadna branch manager, Casper, Wyo., and Jim Jenkins, Quadna area manager, Salt Lake City, Utah

Babbitt bearings are frequently found in large steam turbines and generators in major power plants. A Babbitt bearing is made of Babbitt metal, a soft alloy of tin, antimony and lead, and when properly maintained, Babbitt bearings can provide years of service.

To ensure a long service life, it is imperative that during the casting process new Babbitt material is free from contamination and meets stringent specifications. Specific temperatures for both the Babbitt and bearing must be maintained to prevent the removal of tin and oxidation to the shell. Specific revolutions per minute also must be maintained during the spin cast process. Other critical elements are good bonding of the Babbitt to the bearing shell, as well as ensuring proper outside dimensions, joint line contact and pin alignment.

While Babbitt bearings are durable, like any bearings, they can fail over time when operated in adverse conditions or when catastrophic occurrences take place within rotating equipment. The latter is what happened to one U.S. power plant.

Power Plant Reliability

A coal-fired power plant operated by one of the largest electric generation and transmission cooperatives in the U.S. experienced a problem with a turbine that forced its shutdown. Through a series of simultaneous and unlikely events, both the primary and back-up oil lubrication pumps became inoperable, causing a loss of lubrication supply to all of the critical Babbitt bearings within the turbine and generator set. The loss of lubrication resulted in significant damage to the turbine and generator Babbitt bearings.

Babbitt, like most bearing types, requires lubricant to reduce friction and remove heat from the bearing, rotating shaft and stationary housing. Babbitt bearings are a fluid film, or hydro-dynamic, type of bearing, meaning that a fluid film of lubricating oil is required between the bearing surface and shaft. The oil film actually supports the shaft as it lubricates, reduces friction and removes heat. This type of bearing is used in critical equipment because of its unique ability to handle high shaft speed and vibration.

Immediately following the forced shutdown, Quadna was put on stand-by to assist with upcoming repairs. Due to the potentially significant financial impact to the plant from lost production, the repairs required an around-the-clock effort to meet necessary deliveries and restore power generation capabilities.

Once the cooperative was able to fully assess the damage, it found there was significant damage to nine bearings, four of which ultimately required a complete rebuild of the bearing shells as well as rebabbitting. Nine oil deflectors required rebuilding as well.

The most serious damage to bearings and deflectors came from the turbine journal contacting the bearing shell once it had worn through the Babbitt lining. The excessive heat built up caused warping in all of the critical fit areas.

Damage to a 20+ -inch turbine bearing caused by loss of lube pumps at coal-fired power plant. Photo, Quadna.

Restoring these bearings to a usable condition required a weld build up of the spherical bearing seat on the bearing outside dimension and stress relief of the shell followed by the centrifugal casting of the Babbitt. In addition, prior to final machining, it was necessary to mill the split lines to restore flatness and to re-drill and pin all of the alignment holes.

After repairing the bearing bore, the final restoration step was machining the spherical bearing seat on the outside dimension of the bearing that had been welded previously. Because this is a critical surface and must be exact in its size, the ball seats were finish-machined on a computer numerical controlled (CNC) lathe, then hand-fit to their housings to ensure they met the original equipment manufacturer (OEM) specifications.

The project, from initial contact through completion, took approximately five weeks and required multiple overnight bearing shipments, which weighed up to three tons each. Most of the work was performed by Quadna professionals in Salt Lake City, but due to the extent of the machine work required and the rush nature of the project, other resources and vendor partners were called upon to assist. pe

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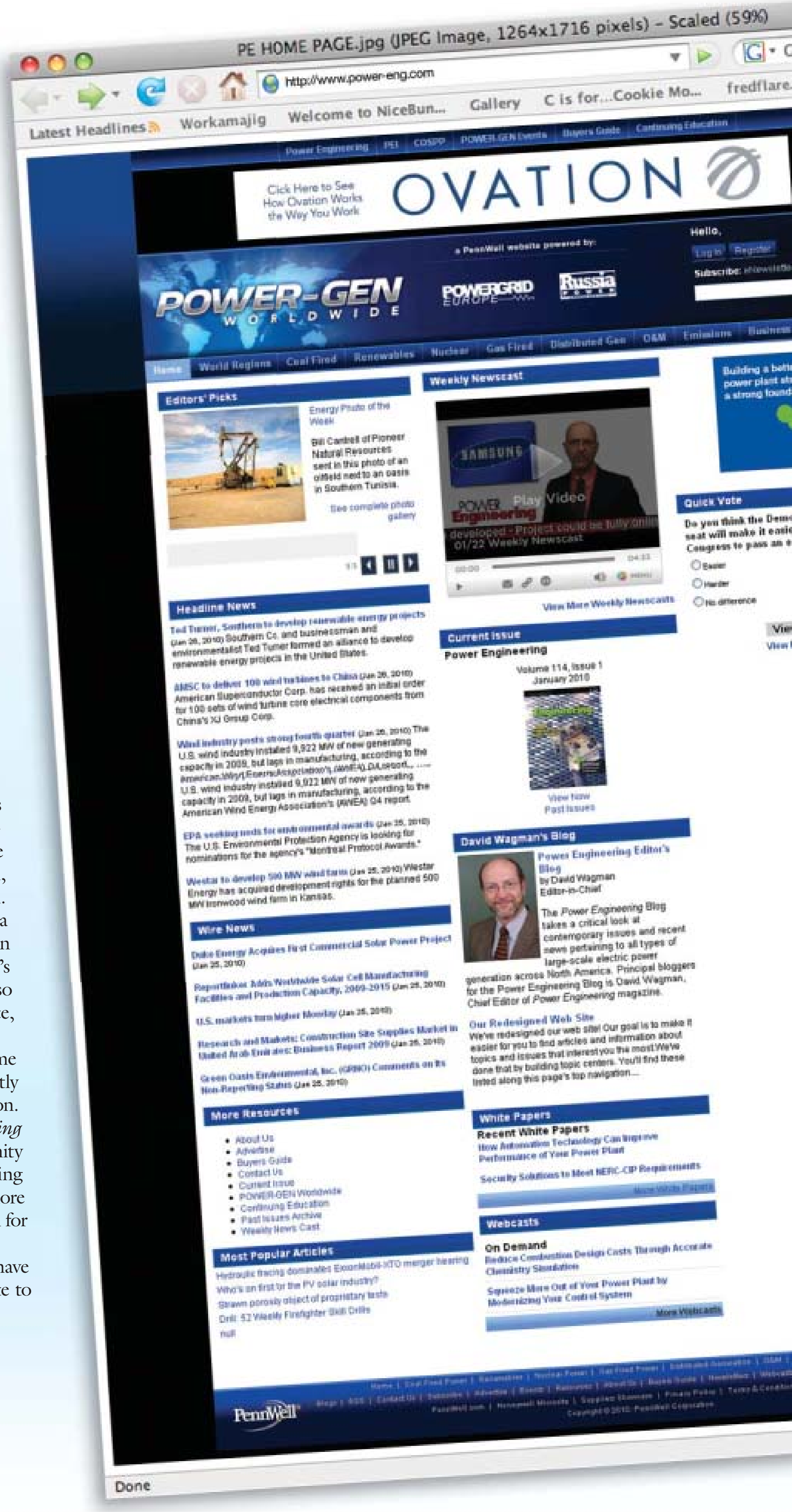
We hope you like what you see. If you have questions, comments or suggestions send a note to pe-editor@pennwell.com.

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ABMA Special Section

Controlling Steam Generator Waterwall Deposition

By Brad Buecker, Contributing Editor

A single waterwall tube failure in a steam generator often will cost a utility at least six figures in lost production, labor and startup costs. If the failure occurs during the hot summer months, the penalty can be even greater. And if the difficulties trigger a chemical cleaning or multiple tube replacements, watch out!

Typically, the single most common failure mechanism of waterwall tubes is under-deposit corrosion. Significant strides have been made in reducing under-deposit corrosion incidents, but not all issues have been resolved, particularly with regard to iron deposition following major maintenance outages.

Iron Deposition on Waterwall Tubes

During normal steam generator operation, condensate/feedwater piping and boiler tubes develop a layer of iron oxide, which, while being a corrosion product, protects the underlying base metal against further corrosion. This protective layer may be very tight, especially where all-volatile oxygenated treatment [AVT(O)] or especially oxygenated treatment (OT) is utilized. During periods of chemistry upsets, thermal transients, and forced outages, additional corrosion products are generated. And, from the major work often performed during scheduled maintenance outages, literally hundreds to thousands of pounds of loose particulates, primarily composed of iron oxides, may collect in the condenser hotwell, condensate and feedwater systems. As these particulates enter the boiler, they precipitate on the tubes. Because the transported deposits are porous, they establish wick boiling. In this mechanism, the bulk boiler water enters the deposits and migrates toward the tube surface where the water flashes to steam while any contaminants remain behind.

Consider what can happen during times of a condenser tube leak, even if the leak is considered small. Several under-deposit reaction mechanisms are possible, but very common is the reaction shown below.

$$MgCl_2 + 2H_2O + heat \rightarrow Mg(OH)_2\downarrow + 2HCl$$

Magnesium salts react with water to produce a magnesium hydroxide precipitate, plus hydrochloric acid. While HCl may cause general corrosion in and of itself, the compound will concentrate under deposits where the reaction of the acid with iron generates hydrogen, which in turn can lead to hydrogen damage of the tubes. In this mechanism, hydrogen gas molecules (H_2), which are very small, penetrate into the metal wall where they then react with carbon atoms in the steel to generate methane (CH_4),

$$2H_2 + Fe_3C \rightarrow 3Fe + CH_4\uparrow$$

FIGURE 1 HYDROGEN DAMAGE FAILURE OF A WATERWALL TUBE. NOTE THE THICK-LIPPED FRACTURE WITH LITTLE NOTICEABLE METAL LOSS.

Photo courtesy of ChemTreat.

continued on page 24

Robinson Fans

Robinson Fans in the Power Industry:

A New Facility and The Development of Better Exhaust Solutions

After tipping its hat to Robinson Fans numerous times in the fan company's 118-year history, the power industry has a new reason to thank forward-thinking Robinson Fans: its participation in clean coal generation.

Robinson Fans and Robinson Service drew upon their innovative multi-stage design, manufacturing and "any-fan" service expertise to install new induced-draft fans as part of an emissions upgrade project for Tampa, Florida-based Seminole Electric Cooperative, Inc. Seminole Electric is one of the largest generation and transmission cooperatives in the United States and relies on two 650-megawatt pulverized coal boilers for base-load generations.

Begun in 2006, the details of the project required the installation of selective catalytic reduction for the generating station's coal boilers. After successful implementation, Seminole Electric became one of the cleaner coal facilities in the United States in terms of regulated emissions.

Like most power industry projects, on-time delivery was essential for reduced costs and accurate power generation projections. Therefore, a very specific schedule was put into place once design and engineering began. Under a tight timeline, Robinson Fans was challenged to respond with eight completely designed and manufactured induction draft fans. Thanks to exceptional project management, Robinson met its delivery and installation deadlines—a rarity for other fan manufacturers. And Seminole Electric now enthusiastically reports itself a very satisfied Robinson Fans customer.

Innovation in Repair, Rebuild and Upgrades

Recently, a mid-Atlantic utility company realized that its paddle-wheel, or "whizzer wheel" exhausters were wearing too quickly, producing energy inefficiently and moving air at rates that weren't up to snuff. The utility company's primary need was to increase power output by increasing air and particulate flow rate from coal mill exhausters with increased wear resistance. Searching for a custom solution, the utility partnered with Robinson Fans.

To solve the utility's problem, Robinson replaced the whizzer wheel design with an enhanced backward-curved fan and added non-structural inlet dust deflectors, which are miniature fan blades placed between the main blades to direct heavy particulate airflow between the main blades of the fan wheel.

Robinson also improved the traditional paddle-wheel design by developing a narrower, shrouded wheel design, which improved energy efficiency via a 3,000 acfm increase in volume and a 7.0 inch wg increase in static pressure.

To ensure extended wear resistance, Robinson lined the fan's interior with a lightweight, extremely durable ceramic tile. Through a proprietary testing method, Robinson identified the exact fan locations where particulate contact would be greatest. On these places only, Robinson used tungsten carbide for superior durability.

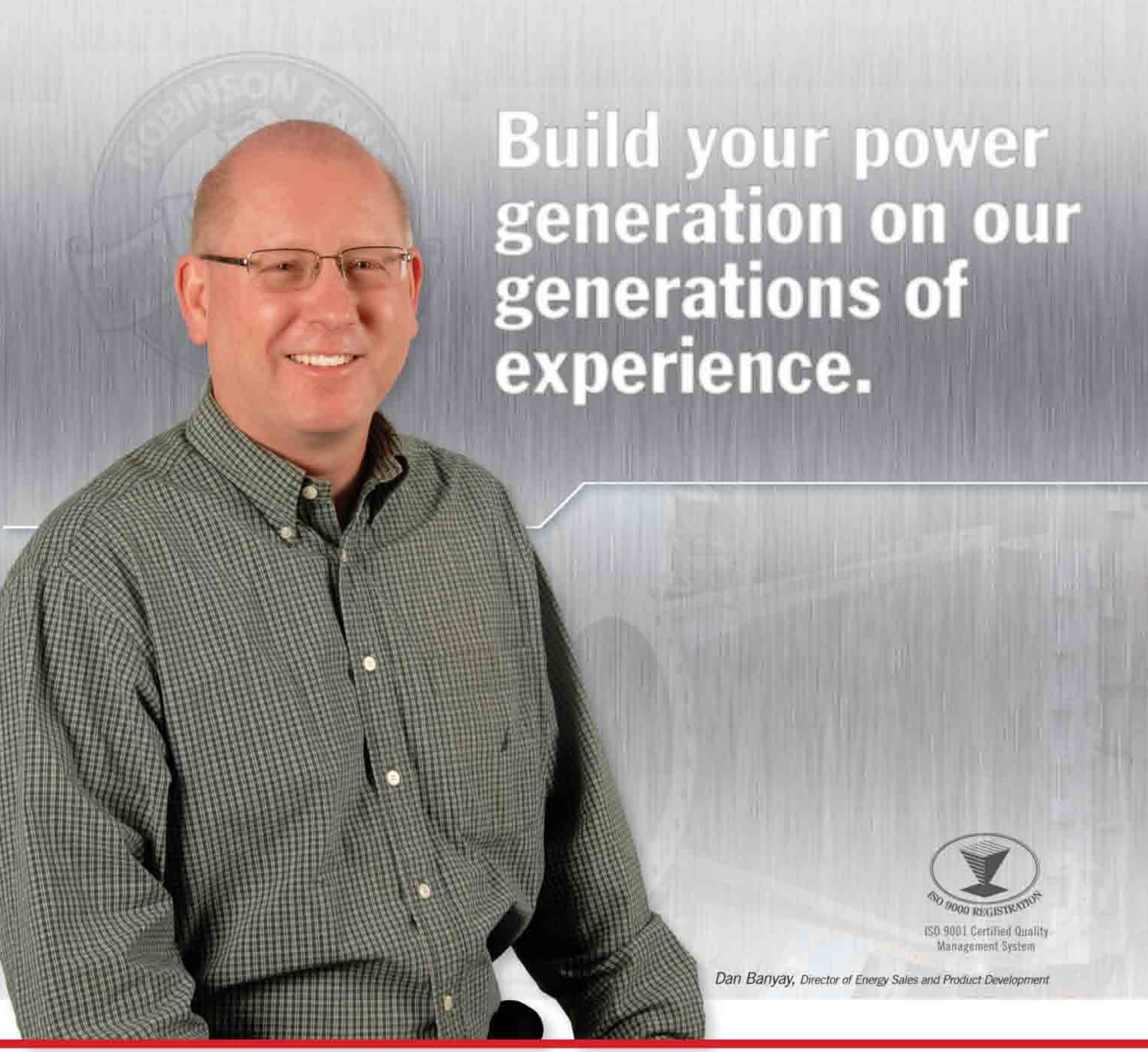
After 20 weeks in operation at the power station, the Robinson backward-curved fan was opened and inspected. Little or no wear was detected. The fan is expected to exceed the utility's requirement for an energy-efficient, cost-effective fan that will last at least two years without excessive wear.

Unparalleled Response and Service

Robinson Fans offers extensive repair and rebuild capacities at many of its facilities. All of its facilities are dedicated to minimizing downtime by expediting repairs and meeting any need. No matter what the make, model, type or design of your equipment, Robinson Fans will repair and rebuild it.

Robinson Service also offers on-site repair and rebuild service. With a 24-hour hotline and 24-hour technician availability, Robinson Service can analyze, service and keep your equipment running at maximum efficiency.

To contact Robinson Fans with fan design, manufacturing, implementation or service needs, call the Sales Department at (724) 452-6121, email *sales@robinsonfans.com* or visit *www.RobinsonFans.com.*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Dan Banyay, Director of Energy Sales and Product Development

continued from page 20

Formation of the gaseous methane and hydrogen molecules causes cracking in the steel, greatly weakening its strength. Hydrogen damage is troublesome because it cannot be easily detected. After hydrogen damage has occurred, the plant staff may replace tubes only to find that other tubes continue to rupture.

Hydrogen damage failures may occur in a matter of days, without any appreciable metal loss, following a significant condenser tube leak. The Electric Power Research Institute (EPRI) recommends immediate boiler shutdown if the pH drops to 8.0. The following case history illustrates the rapidity with which contaminant in-leakage can affect boiler water chemistry.

This first example comes from personal experience. An 80 MW unit supplied by a 1,250 psig coal-fired, cyclone boiler had just been returned to service from a scheduled autumn outage. Laboratory personnel discovered a condenser leak was allowing contaminants to enter the system, such that condensate total-dissolved-solids (TDS) concentrations at times reached 0.75 parts per million (ppm). Although lab staff requested that the boiler be taken off line immediately, operations managers declined due to load demand issues.

The boiler was on congruent phosphate control (this was in the early 1980s), so the lab staff increased monitoring frequency and attempted to maintain phosphate and pH levels within recommended guidelines. After approximately three weeks, operators discovered the source of the leak and corrected the problem. Two months later, boiler waterwall tubes began to fail with alarming frequency. The unit came off numerous times for tube repairs and in at least one instance had only been back on-line for a few hours when another tube failed. Failures happened so regularly that plant management scheduled an emergency tube replacement during the upcoming spring outage. The repairs cost over $2,000,000. The mechanism attributed to these failures was under-deposit corrosion and hydrogen damage caused by excessive sludge and scale formation.

Interestingly, the leak was not from a failed condenser tube. The condenser hotwell is equipped with a drain line that discharges to the cooling water outlet tunnel. During the autumn outage, an operator opened the line to drain the hotwell but then forgot to close the isolation valve before startup. Once the unit went on-line, the strong condenser vacuum pulled cooling water into the hotwell. Stopping the leak was easy; repairing the waterwall tubes was not.

This example is a drastic example of under-deposit corrosion, but serious difficulties may still arise although the deposits are "simply" iron oxides. Impurities from even small condenser leaks may concentrate due to wick boiling and generate acidic conditions in localized areas. A common perception is that deposition is most prevalent on the hot side of waterwall tubes, and indeed in general this is true. However, the following example shows the unpredictability of where fouling might occur.

Because deposit-forming materials typically accumulate more rapidly and in greater depth on the hot side of tubes and in areas where the flow acquires some horizontal tangent such as nose tubes, common sampling points for deposit density analysis are the areas 20 to 30 feet above the top burner elevation and/or the nose tubes themselves. However, with steam generation always expect the unexpected. In a conversation with a power plant colleague in 2009, I learned that two boilers at a plant had experienced failures of lower waterwall tubes. Tube analyses indicated overheating due to localized iron oxide buildups generated during oil firing at startups following major outages. Certainly, the total heat load in the boiler with oil guns in service is much lower than at normal, coal-fired operation, but the oil fires generated hot spots that caused substantial iron oxide deposition; a phenomenon exacerbated by the high concentrations of particulates following outages. Condensate/feedwater chemistry is AVT(O), which, during normal operation, maintains feedwater iron concentrations below 2 parts per billion (ppb). Thus, the iron deposition has been an outage/startup problem in this case.

Iron Oxide Deposit Control

At many plants the transition in condensate/feedwater chemistry from all-volatile-reducing treatment [AVT(R)], which utilizes a reducing agent, to AVT(O) or OT has greatly reduced iron corrosion and transport during normal operation. It is not uncommon to see economizer inlet iron concentrations of less than 1 ppb. But what about iron oxide control during startups?

An equipment investment that can pay for itself several times over with just the first use is a condensate particulate filter. These straightforward mechanical devices can be easily equipped with filter cartridges that remove particulates down to 1 micron in size.

The common location for a particulate filter is just after the condensate pumps, with the filter placed in a valved, bypass loop around the main condensate feed line. The device need not be full flow, as at start-up the condensate circulation is often restricted to half the full-load flow rate or perhaps even less. A filter will remove iron oxide particulates and other "crud" within a short period of time, allowing for potentially significant reductions in hold periods, as illustrated below.

At another utility, we once started up a supercritical unit following a boiler chemical cleaning. Following the standard rinses, the only method to remove remaining iron oxide and other particulates from the condensate was filtration through the deep-bed condensate polishers. Not only did this process significantly foul the polisher resin, but four days of filtration were required to reduce the suspended solids, whose original concentration was greater than 1 ppm, to the relatively low ppb concentration necessary to fire the boiler.

To alleviate this difficulty for future startups after maintenance outages and chemical cleanings, we ordered a condensate particulate filter designed to handle half of the full-load flow. The vessel, equipped with 6-micron (absolute) filter elements, was placed ahead of the condensate polishers. The filter was first utilized in 2008 at startup following another chemical cleaning, where again the initial iron oxide concentration in the condensate was above 1 ppm. Although two filter element change-outs were required to clean the condensate, the cleanup time was reduced from four days to one. The three-day startup savings paid for the filter vessel and elements several times over after just the first use.

Phosphate Deposition

It has become well known among power plant chemists that the traditional phosphate treatment programs of the 1960s through 1980s for drum units have fallen out of favor due to the tendency of sodium phosphates to directly precipitate on waterwall tubes. The phenomenon is commonly known as "hideout." Not only does hideout cause difficulties with bulk boiler water chemistry and its control, but the old congruent and coordinated programs allow precipitation of acidic phosphates that directly corrode the tube metal. Furthermore, phosphate carryover into main and reheat steam caused problems, not least of which was overheating in U-bends due to phosphate collection. At most plants, and especially those with steam generators operating at 2,000 psi or greater, the favored programs now are EPRI's phosphate continuum (PC), caustic treatment (CT), or in some cases AVT or OT. Space limitations prevent a comprehensive discussion of these alternatives, but in each case only a small amount of alkalinity is available to counteract the acidic conditions generated by even a small condenser tube leak.

While these programs have minimized or eliminated hideout issues, their use

continued on page 28

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further emphasizes the need for control of iron oxide deposition. Of course, a condenser leak could quickly generate acidic conditions, but alkaline corrosion is also a possibility. Phosphate continuum and caustic treatment operate with a small amount of free sodium hydroxide, where guidelines recommend a maximum concentration of 1 ppm free caustic with PC and 1.5 to 2 ppm with CT. When waterwall tubes are clean, the small concentration of caustic is not problematic. However, an accumulation of porous iron oxide deposits can lead to under-deposit caustic gouging, where the caustic attacks both the protective iron oxide layer and the base metal underneath.

$$Fe_3O_4 + 4NaOH \rightarrow 2NaFeO_2 + N_2FeO_2 + 2H_2O$$

$$Fe + 2NaOH \rightarrow Na_2FeO_2 + H_2\uparrow$$

This phenomenon can be particularly problematic if a chemistry change is made without first chemically cleaning the boiler.

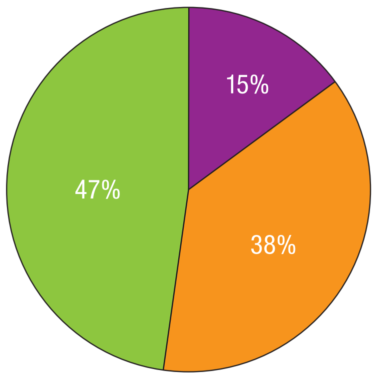
Control of deposition in steam generators can pay big dividends in reliability and availability of the unit. Deposit prevention often requires a combination of good chemistry control and modern equipment utilization. pe

Author: Brad Buecker is a contributing editor for Power Engineering.

Reference: [1]. *B. Buecker, "Condenser Chemistry and Performance Monitoring: A Critical Necessity for Reliable Steam Plant Operation"; Proceedings of the 60th Annual Meeting, International Water Conference, October 18-20, 1999, Pittsburgh, Penn.*

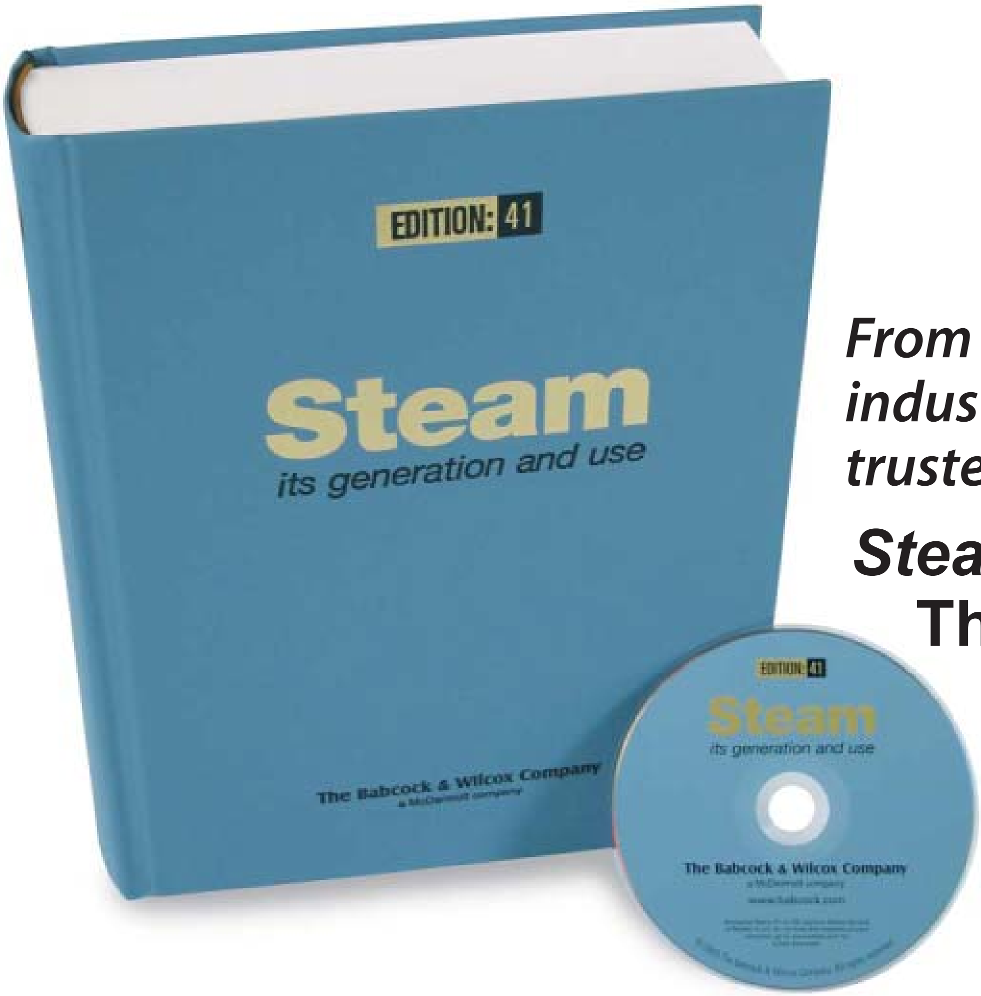
PE Online Question of the Week

For the upcoming spring outage season, what does your scope of work look like?



- Routine maintenance, no change from previous years
- Routine maintenance plus deferred projects from 2009
- A smaller scope of work is planned due to budget issues

(For more Questions, visit www.power-eng.com.)



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ABMA Special Section

Deaerator Pressure Transient – Can Your Boiler Feed Pump Handle It?

By S. Zaheer Akhtar and Magdy Mahmoud, Power Generation Engineering and Services Co.

In a typical thermal power plant, the boiler feed water (BFW) pump takes suction from the deaerator and discharges to the boiler through the feedwater heaters. During normal operation, the deaerator is supplied with extraction steam from the steam turbine and serves to provide a) net positive suction head (NPSH) for the BFW pump and b) a continuous supply of feed water to cope with surges in boiler demand.

The intent of this article is to provide the feedwater system designer with the methodology required to evaluate adequacy of the feed water system and determine whether the BFW pump is capable of handling a deaerator pressure transient or not. In this context, a deaerator pressure transient refers to a rapid loss of deaerator pressure as experienced during a steam turbine generator trip (boiler remaining in service) or sudden load reduction on the steam turbine generator.

If the results obtained from this methodology indicate that the BFW pump is not capable of handling the pressure transient, then it is probable that the pump internals will suffer cavitation damage during the transient event. Alternatively, the pump could shut down on a trip and lead to a total plant shutdown. In any case, some system-design changes would be required to ensure trouble-free operation during pressure transients.

The methodology presented in this article is useful for checking the adequacy of new system-design under development as well as those designs already installed and in-service.

NPSH and NPSH Margin

The deaerator is installed at an elevation to provide the NPSH to the BFW pump. By definition, the NPSH is the total suction head over and above the vapor pressure of the liquid pumped.

The deaerator elevation minus the dynamic losses in the BFW suction piping provides the net positive suction head available (NPSHa) to the pump. The difference between the value of the NPSHa and the net positive suction head required (NPSHr) by the pump gives the NPSH margin.

The NPSH margin or the NPSH margin ratio (NPSHa/NPSHr) is an important factor in ensuring adequate service life of the pump and minimizing noise, vibration, cavitation and seal damage. The NPSH margin requirements increase as the suction energy level (for example, high suction specific speed, high peripheral velocity of impeller and so on) of the pump increases. In case of the BFW pump, this ratio could be in the range of 1.8 to 2.5.

Additionally, the NPSH margin enhances the capability of the BFW pump in handling a deaerator pressure transient. This aspect of the system design is the main topic of this article and the methodology presented facilitates efforts to determine if the NPSH margin is adequate to handle the transient.

Deaerator Pressure Decay and Effect

Immediately after a steam turbine generator trip, turbine extraction steam is no longer available to the deaerator resulting in pressure decay in the deaerator. Also during a sudden steam turbine generator load reduction, the extraction steam pressure decreases and a point is reached when the extraction stage supplying the deaerator has insufficient pressure to feed the deaerator. This also results in deaerator pressure decay as the condensate continues to enter the deaerator and provide a cooling effect. The decrease in deaerator pressure causes some of the water in the storage tank to flash to steam until saturation is attained at the new pressure.

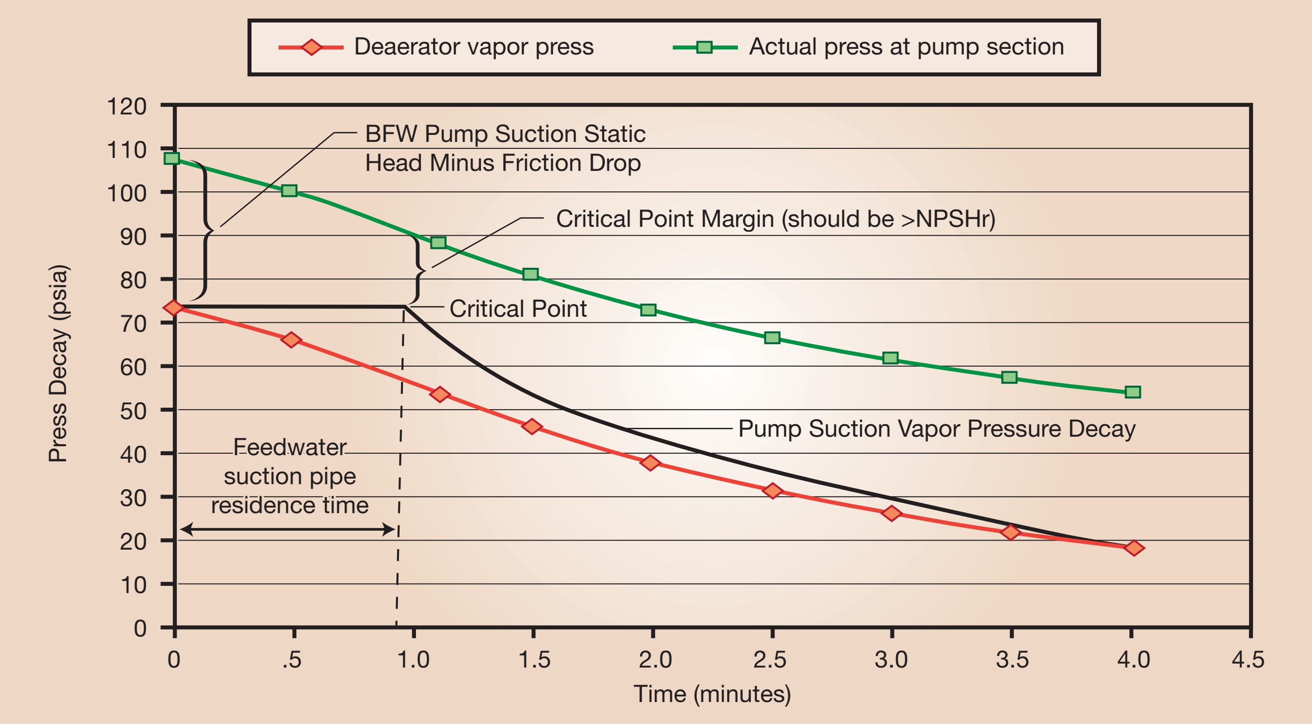
The water in the BFW pump suction line has a static head exerted on it by the level in the storage tank, preventing it from flashing immediately. Therefore, the water in the suction line can be considered as a slug of hot fluid which is trapped and has to be moved through the pump. In other words, the pump will not perceive a decrease in vapor pressure (or a decrease in water temperature) until the entire slug of hot water has passed through the pump.

During the passage of the hot-water slug, the combination of high vapor pressure at the pump suction along with a decrease in pump suction pressure (due to deaerator pressure decay) leads to a critical point at which the suction pressure may drop below the minimum required pressure (that is, the vapor pressure of the hot-water slug plus the pressure equivalent of the NPSHr). This low suction pressure could result in cavitation damage to the pump internals due to insufficient NPSHr.

Residence Time

The time required for passage of the hot-water slug through the pump suction line is known as the residence time. It can be expressed as the suction line volume divided by the volumetric flow rate (or alternatively as the mass of liquid in the suction line

Figure 1 DEAERATOR PRESS DECAY & BFW PUMP NPSH MARGIN



Source: S. Zaheer Akhtar and Magdy Mahmoud

divided by the mass flow rate). Note that since the vapor pressure at pump suction is considered to decay only after the residence time has elapsed, the critical point occurs at the end of the residence time interval.

A simplified expression for the deaerator pressure decay can be expressed by the exponential decay equation for corresponding enthalpy as follows:

$$h_d = h_{hc} + (h_1 - h_{hc}) e^{\left(\frac{-Wc}{M}\right)t} \qquad \text{Eqn (1)}$$

where,
hd = enthalpy of deaerator water storage tank at any time t, Btu/lb
hhc = enthalpy of condensate in condenser hotwell
h1 = initial enthalpy of deaerator water storage tank, Btu/lb
Wc = condensate flow after steam cut-off, lbs/min
M = mass of water in deaerator storage tank, lbs

Eqn (1) is given in terms of enthalpy. The corresponding deaerator pressure is the saturation pressure at the enthalpy established by Eqn (1).

This equation is a simplification as it does not consider the warm condensate contained in the low pressure heaters and the condensate piping. However, it is adequate for our use as it is conservative.

If the use of Eqn (1) indicates a problem with the BFW pumps' capability in handling the deaerator transient, the system designer can redesign the system or re-check the calculations using the more exact equations available in published literature (Ref. 1). Note that the condensate flow to the deaerator (Wc) after steam cut-off needs to be established correctly, based on subsequent boiler load and spray water consumption in the steam attemperaters. The boiler load at this stage is expected to be limited to the capacity of the turbine bypass system.

Establishing the Curve

The actual pressure at BFW pump suction is simply the deaerator vapor pressure as computed by using Eqn (1) plus the deaerator static head less the frictional pressure drop in the BFW pump suction piping.

Figure 1 shows a plot of the actual pressure at BFW pump suction and the deaerator vapor pressure. The difference is the available net positive suction head (NPSHa) at pump inlet.

During a deaerator pressure transient, the actual pressure at pump suction decreases as the deaerator vapor pressure decays. However, due to hold-up of the hot-water slug in the pump suction line, the pump suction vapor pressure does not decrease until after the residence time has elapsed. This results in a critical point corresponding to the BFW pump suction pipe residence time where the NPSHa is at a minimum. If the value of NPSHa at this point (critical point margin) falls below the pump NPSHr, the system design is inadequate and the pump could be damaged due to cavitation during the transient. In this case, one of the solutions would be to install a low NPSH booster pump upstream of the BFW pump.

Booster Pump Upstream

The main BFW pumps are generally large, high-energy pumps needing large values of NPSHr. This requires raising the elevation of the deaerator which is costly and sometimes not practical. In such cases, low-speed, low-NPSH booster pumps are used upstream of the BFW pump. The booster pump discharge head then provides the necessary NPSH to the BFW pump.

Although the above discussion on critical point and critical point margin is presented here with reference to the majority of installations where the main BFW pump takes suction from the deaerator, it is equally applicable to the case where a booster pump is installed upstream of the main BFW pump. The only difference is that in case of the booster pump arrangement, the critical point and the critical point margin needs to be evaluated at the booster pump suction as well as the BFW pump suction.

Additional Transient Condition

An additional transient condition which the system designer should be aware of is that which could occur during a hot start. In this case also, steam flash (water-steam mixture) can occur at pump suction and cause cavitation damage to the pump internals. However, the mechanism causing steam flash is slightly different.

On a plant trip, the deaerator pressure and the water temperature both drop. However, the pump and suction piping near the pump remain at a higher temperature due to mass of the metal. As a result, when the pump is operated on a hot restart of the plant, steam flash and cavitation is likely to occur at the pump suction.

Solved Example

A solved example explaining the methodology for evaluating the effect of the deaerator pressure transient on the BFW pump NPSH is presented below.

(Note that the hot re-start transient is not a part of this calculation).

A. Input Data:

- Deaerator pressure @ instant of steam cut-off, p1: 73.20 psia
- Saturated water enthalpy @ instant of steam cut-off, h1: 275.86 Btu/lb
- Final deaerator pressure, p2: 18.50 psia
- Saturated water enthalpy @ end of transient, h2: 192.11 Btu/lb
- Condensate flow after steam cut-off to deaerator, Wc: 29,265.00 lbs/min
- Warm condensate enthalpy @ time of load reduction, h4: 202.00 Btu/lb
- Hotwell condensate enthalpy, h5: 69.80 Btu/lb
- Mass of water in deaerator storage tank, M: 20,3958.00 lbs
- Mass of warm condensate in LP htr & conn. piping, Mw: 32,849.00 lbs

ABMA Special Section

TABLE 1 PREDICTED DEAERATOR PRESSURE COMPARISONS

Time after steam cut-off (t, mins)	Deaerator water enthalpy, Btu/lb, per simplified, conservative correlation (Eqn 1)	Deaerator water enthalpy, Btu/lb, per complex, non-conservative correlation (Ref 1)	Deaerator pressure, (Psia corresponding to enthalpy per simplified, conservative correlation) (Eqn 1)	Deaerator pressure, (Psia, corresponding to enthalpy per complex, non-conservative correlation) (Ref 1)
0.00	275.86	275.86	73.20	73.20
0.50	261.59	268.78	59.45	66.10
1.00	248.31	254.85	48.54	53.70
1.50	235.95	245.15	39.87	46.20
2.00	224.45	233.00	32.96	38.00
2.50	213.74	221.78	27.41	31.50
3.00	203.78	211.38	22.96	26.30
3.50	194.50	201.44	19.35	22.00
4.00	185.87	192.11	16.42	18.5

The table shows that for the case considered, the predicted deaerator pressure using the simplified, conservative correlation is about 10 percent lower than that obtained from the more complex, non-conservative correlation (Ref. 1).

- Time required to replace warm condensate, tw=Mw/Wc 1.12 mins
- Residence Time (time required to replace warm feed water in BFW pump suction line): say 0.5 mins

B. Computation:

- Using the above data along with Eqn (1), Table 1 can be developed.

For the case under consideration, the residence time is estimated at 0.5 min and this becomes the critical point. At this point, Table 1 shows a reduced deaerator pressure of 59.45 psi (or 66.1 psi depending upon the correlation used). The actual pressure at pump suction then corresponds to deaerator pressure of 59.45 psi + 34 psi (where 34 psi equals the static head minus friction loss) = 93.45 psi. However, the pump suction vapor pressure during the residence time remains unchanged at 73.2 psi. This provides a margin above the pump suction vapor pressure of 93.45-73.2=20.25 psi (equivalent to 52 ft of NPSHa).

If this calculated value of NPSHa = 52 ft. is less than the NPSHr provided by the pump vendor, the pump is expected to cavitate during the transient and such a design would therefore be considered as inadequate.

The NPSHr provided by the vendor can be based on 3 percent head loss or 1 percent head loss. It is more conservative to have the vendor provide the NPSHr based on 1 percent head loss. pe

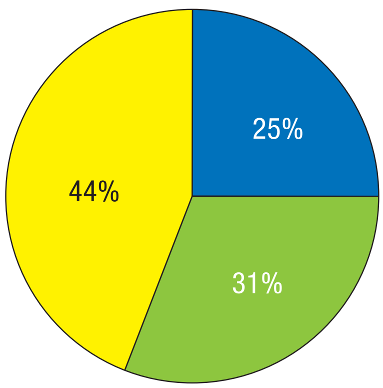
References:

[1]. *Liao, C.S., and Leung, P "Analysis of Feedwater Pump Suction Pressure Decay", ASME J. Eng. Power, April 1972*

[2]. *Karassik, I.J., Messina, J.P., Cooper, P., and Heald, C.C. "Pump Handbook" 4th Edition, Chapter 12.*

PE Online Question of the Week

How does your company's 2010 capex budget compare with 2009?



- Higher than 2009
- Lower than 2009
- The same as 2009

(For more Questions, visit www.power-eng.com.)

A Double-Hybrid Approach to Fuel Efficiency

Ethanol plants are a good CHP application, but the selection process often involves choosing between a GT/HRSG and a boiler/ST design.

By Drew Robb, freelance writer

Gas-electric hybrid engines are gaining popularity as a way to boost fuel efficiency. Automotive fuel producers are also adopting a hybrid approach to improve the efficiency of their plants – using combined heat and power (CHP) to cut fuel costs and emissions.

"Ethanol plants are a very good application for CHP, since they need a lot of steam and a lot of electricity," says John Cuttica, director of the Midwest CHP Application Center, which the U.S. Department of Energy established at the University of Illinois at Chicago in 2001. "There is a good coincidence between the electric and thermal requirements and when that happens, it can be a good environment for CHP."

While efficient, CHP is not always the most cost-effective choice. It depends on the cost of electricity from the utility, properly sizing the equipment to the needs for steam and electricity and the reliability of the equipment selected. The selection process is generally one between a gas turbine/heat recovery steam generator (HRSG) or a boiler/steam turbine design. This article covers the factors to consider in making the choice and gives an example from a site which selected a modular boiler by Rentech Boiler Systems.

The Need for Higher Efficiency

Brazil had long been the world leader in ethanol production, with an automotive fuel program dating back 30 years. Over the past decade, however, the United States has taken over the top spot. According to the Renewable Fuels Association's Outlook 2009, the number of ethanol plants in the U.S. had more than tripled since the start of the millennium, from 54 in January 2000 to 170 in January 2009. Plant capacity over that same time frame had grown six-fold—from 1.75 billion gallons a year to 10.57 billion gallons.

And that is just the beginning. The EPA's Renewable Fuels Standard, in accordance with the Energy Independence and Security Act of 2007, calls for 36 billion gallons of renewable fuel to be blended with gasoline by 2022.

This rush to increase ethanol production, however, has its critics. One bone of contention is that ethanol is derived mainly from a food source (corn) which led to rising food prices. This problem has a solution: a switch from corn starch to cellulose derived from grass or waste as a feedstock for the ethanol plants. The downside, however, is that currently it costs about twice as much to produce cellulosic ethanol as it does to produce corn ethanol.

Another criticism is that ethanol production requires high energy inputs. According to a report published in the January 2006 issue of *Science* magazine, it takes 0.76 joules of fossil fuels to produce 1 joule of corn ethanol.[1]

Those figures, though, are improving. May Wu of the Center for Transportation Research at Argonne National Laboratory looked at 2006 data covering 22 corn ethanol facilities with a combined 1.813 gallons of annual fuel ethanol production ("Analysis of the Efficiency of the U.S. Ethanol Industry 2007"). She compared those statistics with data compiled by the U.S. Department of Agriculture in 2001. Wu found that over that five-year period, total energy usage had decreased 21.8 percent at dry mills and 7.2 percent at wet mills. Dry mills also reported a 15.7 percent decrease in grid electricity use.

A modular boiler prior to being lifted into place. Photo courtesy Rentech Boilers.

Boiler or HRSG

A key factor in reducing energy usage is to use CHP at the ethanol plants. There are two main approaches to this: using a boiler to create process steam along with a steam turbine generator set or a combustion turbine to generate electricity and a HRSG to convert the exhaust heat into process steam.

The largest corn ethanol plants use the wet mill process which entails soaking the grain in water and sulfurous acid for up to two days to separate the grain into its component parts. The parts are then separately processed into products such as corn oil, corn syrup, corn starch, ethanol and protein. Dry milling plants, on the other hand, grind and process the entire grain without separating its parts.

According to Wu, the dry milling process requires considerably

less energy input than wet milling (a mean of 31,070 Btu per gallon of ethanol vs. 47,409 Btu/gal). Figures vary widely, with the most efficient plants using less than half the amount of energy as the least efficient.

That doesn't mean however, that wet mill ethanol production is more expensive than at dry mills. Large wet mills primarily use coal-fired boilers to produce steam and generate most of their electricity on site. The smaller dry mill plants tend to use more natural gas and make less use of cogeneration.

Archer Daniels Midland Co., one of the largest ethanol producers with a capacity of 1.65 billion gallons a year, runs coal- and biomass-fired cogeneration plants ranging up to several hundred megawatts at several of its ethanol production facilities in Illinois and Iowa.

Smaller dry mill plants tend to use a gas turbine/HRSG set up rather than a boiler/steam turbine system. For example, POET LLC of Sioux Falls, SD, which produces over a billion gallons of ethanol at 26 plants, runs a Solar Turbines GT genset at its 56-milion-gallon-a-year plant in Ashton, Iowa. Operating at 69 percent efficiency, the CHP system produces up to 7.2 MW of electricity and 56,000 pounds of steam per hour.

Ken Ulrich, an engineer for ICM Inc., which provides the technology in use at more than 100 dry mill ethanol plants says cogeneration, says his firm has installed Dresser Rand steam turbines at nine of those plants.

"It is all about economics," he says. "Typically the ethanol plants are in the corn belt, where there is a lot of reasonably priced, coal-generated electricity, so they don't pay for themselves easily. But they are cost effective out west in places like Kansas and Colorado where electricity costs are higher."

The ethanol plant ICM built for East Kansas Agri-Energy LLC uses cogeneration effectively. The 35 million-gallon-a-year dry ethanol plant has a natural gas boiler producing about 7 million pounds of low pressure (150 psi) steam daily. Since most of the production process uses steam at near-atmospheric pressures rather than passing through a pressure-reducing valve, some of the steam goes through a Dresser Rand KD2 backpressure steam turbine genset which converts the pressure to electricity before the steam is used for the ethanol process. Though the generator is capable of generating 1.6 MW, the plant's steam requirements limit the electrical output to 750 kW. Nevertheless, that is more than enough to make it viable. According to plant manager Doug Sommer, the generator provides close to a third of the plant's electrical needs, saving the company $15,000 a month.

Sizing the Solution

Whether one goes with a GT/HRSG or boiler/steam turbine design, the economics depend on correctly sizing the equipment to meet the plant's needs. Bruce Hedman, director of distributed generation market and technology for Energy and Environmental Analysis Inc. advises against getting too large a GT. He says it should be large enough that, with supplemental duct firing, it meets most of the plant's steam needs. But it shouldn't go above the plant's electrical needs, since selling power back into the grid can be difficult.

Boiler/ST units are more flexible, but again the boiler needs to be sized properly. Jim Lopata, owner of Lopata Technical Services in Chicago, tells of a boiler he specified for a large dry mill plant. The job specs called for 290,000 lbs of steam per hour at 250 psig and 555 F superheat. In addition, the boiler needed to be able to rapidly ramp up or down in response to demand. These requirements created certain problems.

"The proper design of a boiler that will cycle rapidly up and down is to have a maximum heat release of less than 80,000 Btu per hour per cubic foot," says Lopata. "That limits the size of a boiler that can be shipped on a truck or rail to about 200,000 pounds per hour, but they needed 290,000 pounds."

One option was to buy two smaller package boilers which could be shipped. A second was to buy one package boiler that was undersized and then put a larger burner in it.

"That would be like putting a Dodge hemi engine into a Volkswagon," says Lopata. "It will fly like the wind until it tears itself apart."

A third option was to erect a custom, stick-built boiler on site. This would meet the performance requirements, but not the budgetary ones.

The solution finally selected by Lopata was a modular boiler from Rentech Boiler Systems. Rentech built the convection section and the mud and steam drums in the shop and shipped them to the field for installation. The tubes were then attached in the field.

"That process turns out to be about half the price of a stick-built boiler of the same size," says Lopata.

A low purchase price and high efficiency, however, are only important if the equipment can reliably meet the production needs.

"The most important thing when you are talking about efficiency is that it runs all the time and doesn't break down," he continues. "The Rentech boiler can swing loads very quickly, from 20 percent maximum continuous rating (MCR) to 100 percent in about five minutes without damaging the boiler."

He says that several features in the boiler allow it to achieve these swings without breaking down due to the thermal stress. One is that there is no refractory in the boiler, which eliminates the largest maintenance problem. The boiler also has oversized downcomers that are out of the heat path. This eliminates deviation from nucleate boiling—where steam goes up the downcomers and fights with the water coming down—which is the most common cause of rupture in steam boilers. Finally, the boiler comes with an oversized steam drum.

"This is a safety factor," says Lopata. "If there is an unscheduled power outage or incident, since you have a lot more steam in the drum, you have more time to do an orderly shutdown."

As a result of those features, the Rentech boiler proved to be the most reliable boiler in the plant. And because of this, the plant owner ordered a second, identical boiler to replace another boiler in use at the facility. pe

"That would be like putting a Dodge hemi engine into a Volkswagon."

Reference: [1]*(Farrell AE, Plevin RJ, Turner BT, Jones AD, O'Hare M, Kammen DM "Ethanol can contribute to energy and environmental goals".* Science *311: 506–508)*

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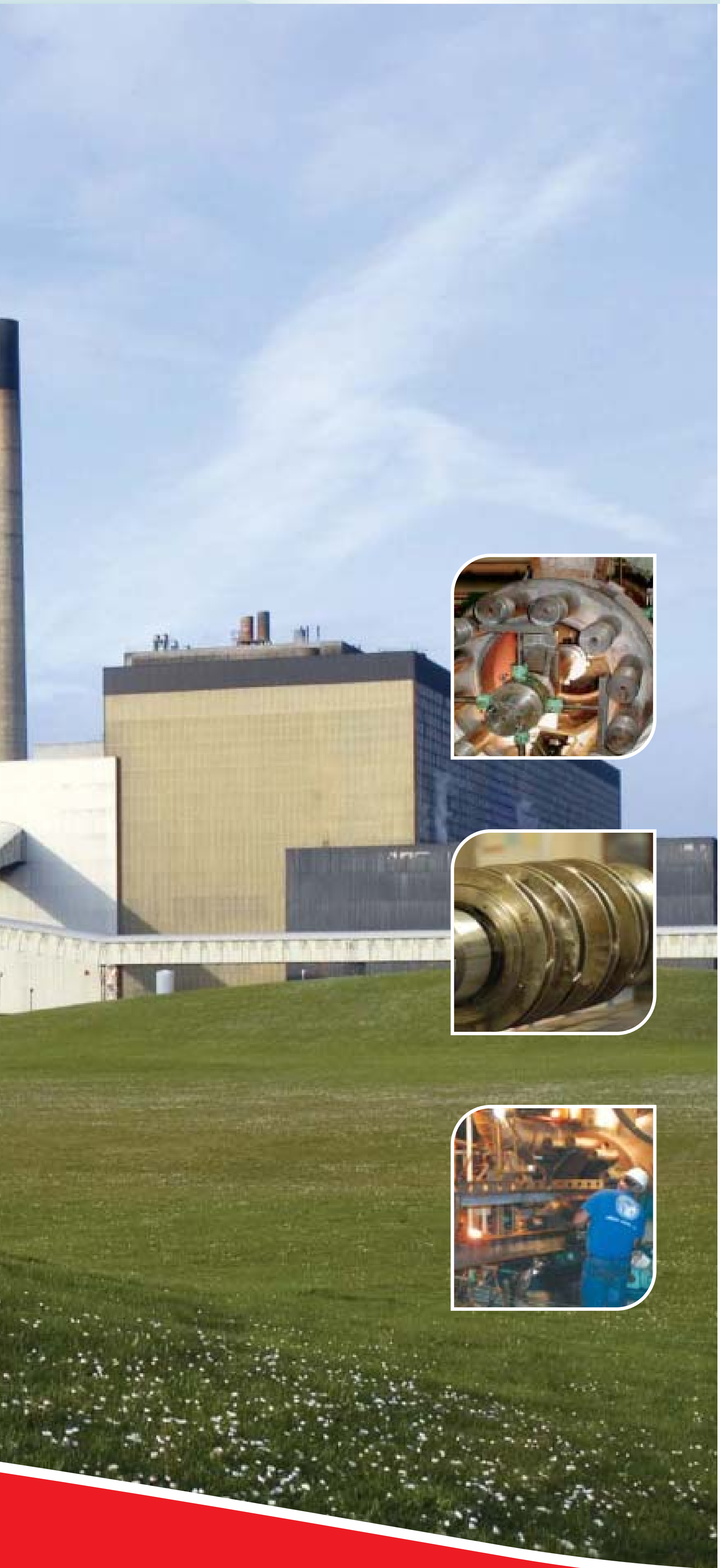

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Supplemental Cooling of Turbine Lube Oil

Larry Denk, P.E. and Michael Karlin, Aggreko Process Services;
and Daniel Earnest and Loren Bartlett, Allegheny Energy

Coolers are utilized on lubricating oil reservoirs of large rotating equipment to control viscosity and reject heat. Lube oil cooler performance is impacted by a number of plant-specific variables, such as ambient temperature, plant utilities, equipment condition, and the like. This article presents design considerations, an engineered approach and plant case project for cost-effective, temporary, supplemental heat rejection from large lube oil reservoirs.

The success of the approach depends, in large part, on an accurate engineering understanding of heat transfer in lubricating oil systems. Performance predictions from commercially available computer models had been found to be misleading. A spreadsheet-based model that included mass/heat transport in viscous, laminar flow was found to be quite accurate. Field data taken during operation confirmed the conclusions and validated the spreadsheet model.

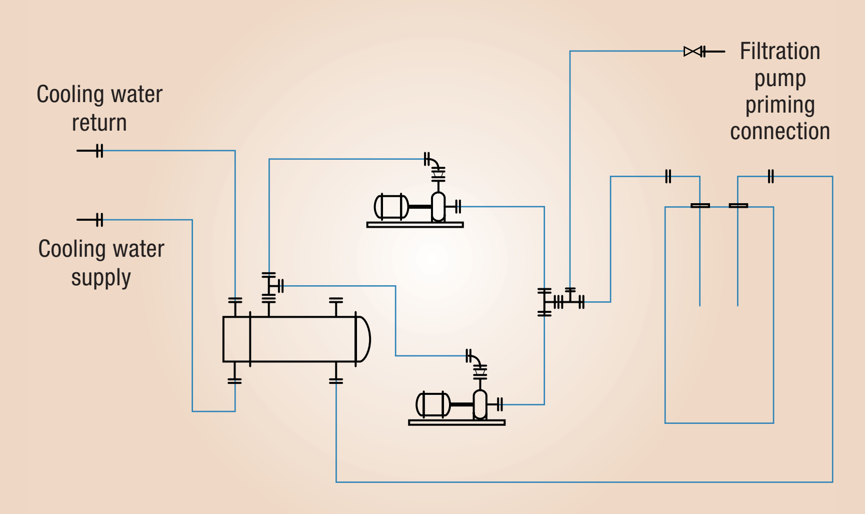
In a full scale application, Allegheny Energy collaborated with Aggreko to provide temporary, supplemental lube oil cooling for the No. 1 and No. 2 turbines at the Pleasants, W.Va., power station. Each of two temporary systems was designed to reject an additional increment of about 2 MMBtuH from the lube oil reservoirs to the plant cooling water system. The projects were installed and on-line within 11 days following the decision to proceed.

The success of the projects confirms that temporary, supplemental cooling can be rapidly and safely implemented. This also permits conservation of capital and avoids permanent equipment that would only be used during a small portion of the year.

Viscosity (and thus lubricity) control of lubricating oil in large rotating equipment service is important for bearing life, controlled maintenance and operating costs and machine reliability. The generally accepted practice for high horsepower motors and turbines is to install a reservoir of reasonable capacity and some means of continuously removing heat from the circulating lubricating oil system. This practice is found in machines performing service in the power, refining, petrochemical, pulp and paper and other industries.

The design of every system is unique to the conditions of that system. Every design represents a compromise among a number of elements, including available utilities, ambient conditions, cost, anticipated needs, machine mechanical condition and others. The nature of a compromise is that it generally does not completely satisfy all of the elements. Furthermore, some of the elements change over time. One result is that the lubricating oil cooling system can become, under some conditions, limited and unable to achieve the desired oil temperature.

Figure 1 FLOW SKETCH FOR LUBE OIL RESERVOIR COOLING



Heat Transfer in Lube Oil Cooling

Purposes of lubricating oil include reducing rolling and sliding friction in bearings, providing a seal/fluid barrier to prevent mass transport from inboard (process) environment to the outboard environment and removing unwanted heat from the bearing zone.

The suitability of lubricating oil to perform its tasks depends on its thermophysical properties at point-of-use. The user can control one important property—viscosity—by adjusting lubricating oil temperature.

In practice, temperature control can be challenging. Lubricating oil systems that support large rotating equipment are subjected to variable (and, generally large) heat rate inputs. Sufficient heat must be removed so that oil returned to service is within a desired temperature range. That range is rather narrow. The means for removing heat from the oil is generally limited and the oil has poor heat transfer characteristics. Heat rejection and temperature control, while related, are two distinct topics. Problems arise when they are casually treated as one topic.

Lubricating oil systems supporting large machinery

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incorporate heat exchangers for heat rejection and temperature control. Enthalpy is extracted from the lubricating oil by heat transfer through the exchanger wall. The extraction rate is a function of the resistance to heat transfer, the heat transfer surface area, and the temperature driving force. The generally recognized thermal transport relation is:

$$\Delta Q=\overline{U}*A*(CMTD)$$

where:
ΔQ = energy transfer, Btu/hr
$\overline{U}$ = overall heat transfer coefficient, Btu/h ft² F
A = heat transfer area, ft²
$CMTD$ = corrected mean temperature difference, F

The energy balance equations for the two constituent streams (lubricating oil and coolant) are given as:

$$dQ=m*C_p(T)*dT$$

where:
dQ = energy transfer, Btu/hr
m = (mass) flow rate, lb/hr
$C_p(T)$ = (mass) heat capacity, Btu/lb F, function of temperature
dT = temperature difference, F

The resulting three equations allow the user to quantify the performance of the heat exchanger and predict the lubricant oil temperature returning to the machine. To use the equations, however, the user must have a good value for U, the overall heat transfer coefficient. The coefficient is composed of five components that make a significant contribution to the result:

$$U=\frac{1}{\left(\frac{1}{h_H}+\frac{1}{h_C}+\frac{t}{k}+R_{f,tube}+R_{f,shell}\right)}$$

where:
U = overall heat transfer coefficient, Btu/hr ft² F
h_H = hot side heat transfer coefficient, Btu/hr ft² F
h_C = cold side heat transfer coefficient, Btu/hr ft² F
t = thickness of heat transfer surface, ft
k = thermal conductivity of heat transfer surface, Btu ft/hr ft² ftF
R_f = shell and tube side fouling factor, hr ft² F/Btu

In lubricating oil systems, estimation of one of these components—hH, the oil side heat transfer (film resistance) coefficient—can make the difference between an accurate and inaccurate prediction. The film resistance coefficient represents the resistance to heat transfer from the bulk flowing stream to the wall of the heat exchanger. It reflects the complex interactions of heat, mass and momentum transport.

Considerable study of this physical phenomenon has been made over the last 70 years. To date, it has defied rigorous modeling. Rather, good progress has been made by means of semi-empirical predictions. These predictions utilize well-known Dimensionless Numbers, including:


35,000 hours.
Zero varnish.

Reynolds	$N_{Re} = Dv\rho/\mu$
Prandtl	$N_{Pr} = Cp\mu/k$
Nusselt	$N_{Nu} = UD/k$

And secondary numbers:

Stanton	$N_{St} = N_{Nu}/(N_{Re}*N_{Pr})$
Graetz	$N_{Gr} = N_{Re}*N_{Pr}*D/L$

The suitability of lubricating oil to perform its tasks depends on its thermophysical properties at point-of-use.

Where, in consistent units:

D	= diameter
v	= velocity
ρ	= density
μ	= viscosity
C_p	= heat capacity
k	= thermal conductivity
U	= heat transfer coefficient
L	= length

All of the dimensionless numbers above, with the exception of the Prandtl number, have components that characterize mass transport. Heat transfer is facilitated in turbulent flow, and hindered in laminar flow. Reduced thickness of the boundary layer adjacent to the heat transfer surface wall and greater mixing in the bulk stream are consequences of turbulent mass transport. These result in improved heat transfer.

The semi-empirical predictions in today's models make use of the relationship between mass flow conditions and the film resistance coefficient. It is in the modeled relationship between mass transport and heat transfer that the cautionary issue arises. Lubricating oils are specially formulated for their viscosity properties. As a result, generalized correlations which predict mass, heat and momentum transport phenomena for hydrocarbon streams can be inaccurate when used on lubricating oils. Generalized hydrocarbon correlations are used to calculate the components of dimensionless numbers and, in turn, to predict the film resistance coefficient. The generalized correlations are not sensitive to the specialized nature of lubricating oils.

Users today have a choice among a number of popular, commercially-available computer simulation programs to assist in analysis of lube oil systems. Properties and conditions can be entered into the programs, and heat exchanger sizing and performance predicted. As an additional aid, libraries of pre-determined properties are available as integral parts of the programs.

Prediction of heat removal from

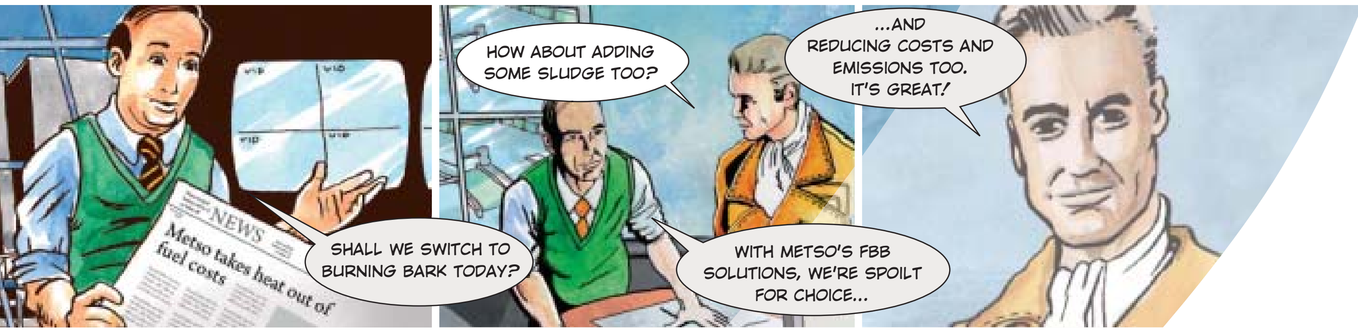

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TABLE 1 COMPARISON OF PREDICTIVE TECHNIQUES

Oil Rate, gpm	543	600				
Oil To HX, ºF	135	140				
Water Rate, gpm	600	600				
Water To HX, ºF	85	90				
Source	**Field Data**	**In-House Model**	**Commercial Pgm "HY"**	**Commercial Pgm "S"**	**Commercial Pgm "T"**	**Commercial Pgm "HT"**
Technique	Actual	1	2	3	4	5
Predicted DQ, BtuH	1,820,000	1,780,000	2,600,000	2,550,000	2,540,000	2,530,000
Oil From HX, ºF	115	118.3	114.4	115.1	115.7	115.2
Water From HX, ºF	91	96.0	98.8	98.6	98.5	98.6
Notes: Heat exchanger characteristics common for all cases						

TABLE 2 ACTUAL FIELD RESULTS

		No. 2 Reservoir Data	
	Design, rv 30 Jul 08	**1 pump op'n**	**2 pump op'n**
Oil Flow, gpm	488	306	545
Oil Reservoir Temp, °F	140	136	135
Oil from HX, F	120	118	115
System DP, psi	39.4	33.5	36
Cooling Water, gpm	593	592	592
CWS, deg F	90	86	85
CWR, deg F	95.5	89.1	91.1
Q Exchanged, BTUH	1,642,000	922,000	1,820,000

lubricating oil can be a challenge to commercially-available models. The thermophysical properties of lubricating oil create a situation where the results of the computer programs can be misleadingly optimistic. Four commercial programs were utilized in the design of the case study. All four gave predictions, with lube oil, of higher heat transfer than was actually observed in the field.

It was also noted that the use of lube oil properties from the libraries associated with the commercial programs introduced further inaccuracies. For sufficient accuracy in designing the projects of the case study, it was necessary to both use a purpose-built program and user-defined properties specific to the lube oil used in the project.

The result of the compounded inaccuracies is a significant difference from what would actually be observed in a real-world project.

This situation represents many facilities installed at this time. Designers, using commercial tools, have sized equipment to meet anticipated needs. If those tools give overly-optimistic predictions, the facilities will be undersized.

The second consideration is the possible impact of the temporary system on the permanent coolers. By lowering the temperature in the reservoir, the mean temperature difference (upon which the permanent, plant coolers operate) is reduced. Actual operating information indicate that, while MTD on the permanent coolers was reduced, the combined effect of the temporary exchanger and the permanent exchangers resulted in net increase in heat removal, and lower temperature lube oil return to the machines.

Case History

Allegheny Energy retained Aggreko to provide temporary, supplemental, lube oil cooling systems for the No. 1 and No. 2 turbines at the Pleasants Power Station. The results of that effort, utilizing the approach described above, are reported in this case study.

Each of the two 700 MW turbines at the Pleasants Power Plant in Willow Island, W.Va. has integrated lube oil reservoirs with coolers. For a number of reasons, the return oil temperature during periods of high ambient conditions approaches the alarm setting. Allegheny desired to eliminate this threat to the turbine bearings and potential reduced output.

The permanent coolers are incorporated into the reservoir, and not easily available for modification. Also, this problem exists only during a short period of the year (mid-summer). Thus, a solution based on temporary equipment had merit. During initial discussions, Allegheny and Aggreko agreed that the solution should be based on cooling a circulating slip-stream on the turbine lube oil reservoirs. Neither party wished to disturb the lube oil flow to and from the machine.

Allegheny desired that suction and return on the reservoir should be established from the top of the reservoir. This would minimize the potential for accidental spillage of lubricating oil. Also, the contents of the reservoir would not be at risk during installation, operation, and decommissioning of the temporary cooling system. This introduced some hydraulics challenges to the design.

It was agreed that Allegheny plant cooling water could be used instead of temporary cooling equipment (portable chiller or cooling tower). This would have some effect on the plant cooling water system hydraulics. However, the decision reduced project complexity and cost. Allegheny had, prior to initiation of discussions, installed stub-outs with valves in their plant cooling water supply and return systems in the area of the lube oil reservoirs. These existing stub-outs facilitated rapid installation of the project and made use of plant cooling water possible.

Performance Prediction

An important step in the design of the temporary project was the prediction of heat transfer performance. Four commercially available design models were set up for the conditions of the project and exchanger performance predictions made. Additionally, an in-house developed model that had shown good performance prediction with heavy oils was used. The results have been summarized in Table 1.

The decision to use Allegheny plant cooling water as the cooling medium was demonstrated to be correct.

As can be seen, reliance upon the popular commercial models would have resulted in the design of a modification that was considerably undersized for the actual needs of the facility. A sketch of the temporary modifications is given in Figure 1.

Each temporary system was designed to reject about 2 MMBtuH from the lube oil reservoirs to the plant cooling water system. This was expected to result in lube oil temperatures to the bearings of less than 110 F during periods of high ambient temperatures. These results were achieved (Table 2).

For each lube oil reservoir, two circulation circuits were installed. The lube oil circuit included hydrocarbon pumps, which took suction from a dipleg extended into the oil from the top of the reservoir, forced it through the shell side of an exchanger and returned it back to the reservoir by means of another dipleg entering from the top of the reservoir.

The cooling water circuit conducted water from the plant CWS, through the tube side of an exchanger, and back to the plant CWR. Plant circulating pumps provided the driving force; no temporary supplement was used.

Installation and Commissioning

Aggreko provided the design, equipment and commodities and site advisory support. Allegheny provided installation labor. The project was needed soon after the decision was made to proceed as hot weather was predicted. The short schedule could only be achieved by use of temporary equipment, pre-work scoping and innovative engineering. In the interest of schedule, Aggreko proposed, and Allegheny agreed, to use braided, stainless steel flexible hose for the lubricating oil circuit. This material could be obtained rapidly and installed more easily than hard pipe.

The possibility of introducing solids contamination coincident with modifications is quite high. Construction activities, particulates in the area of construction and contamination of equipment and commodities are all normal conditions of projects. Regardless, contamination represents a threat to the oil quality, and thus, the bearings.

To avoid contamination from these sources, specific actions were taken. These included using new, braided stainless steel hose instead of pipe. This eliminated contamination associated with pipe fitting and welding, and also scale associated with hard pipe. Also used was specialty equipment cleaning procedures. Even though the major equipment used on the project had been cleaned to industry standards, it was all cleaned to a specification developed for this project. This eliminated any surface contamination, fine rust and so on. As a result, the installation had clean oil-contacting surfaces when commissioned. The project contributed no contamination to the lube oil circuit.

Field Results

Both temporary cooling systems (supporting No. 1 turbine and No. 2 turbine reservoirs) were brought online in two steps. In each case, oil circulation was established with one pump in operation. The system was allowed to stabilize before the second pump was started.

The actual performance of the project is compared with the expected performance, developed during the design phase, in Table 2.

An analysis of operational data indicates that the incremental heat removal during one pump operation was approximately 1 MMBtuH. Incremental heat removal during two-pump operation was observed to be 1.8 MMBtuH. Compared to the design heat removal, as indicated on the turbine manufacturer's exchanger sheets, these represent, respectively, 5 percent and 10 percent of the design duty. However, the reduction of the reservoir temperature over a relatively short period of time (20 F in less than two hours) indicates that the incremental heat removal is a much larger percentage of the total heat load.

For both turbines, the incremental cooling provided by the circulation from only one pump was able to reduce the reservoir temperature significantly. Incremental oil circulation, as established by the second pump, in each case increased heat removal and provided cooler oil to the bearings. For both reservoirs, oil circulation with one pump was sufficient to bring the oil system into the desired operating range.

The decision to use Allegheny plant cooling water as the cooling medium was demonstrated to be correct. Plant cooling water temperature and available flow rate provided a heat sink sufficient to achieve the project objective. In addition, no noticeable adverse effect to downstream equipment that utilizes plant cooling water was observed.

Modifications to lubricating oil systems for the purpose of supplemental cooling can be achieved without increasing risk to the rotating equipment serviced by the oil. Sizing the supplemental project to achieve the desired result requires specialty expertise. Commercially available tools can give misleadingly optimistic estimates of heat transfer performance. Systems designed on the basis of this misleading information can be undersized. Utilizing the practices set forth in this paper, commercial installations can be made that will achieve the process purposes intended. pe

Authors: Larry Denk, P.E. is a principal engineer and Michael Karlin is a process engineer with Aggreko Process Services based in Houston. Daniel Earnest is project manager and Loren Bartlett is plant engineer with Allegheny Energy's Pleasants Power Station.

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Opting for Wireless Technology

Entergy Nuclear finds security and reliability in new system

By Nancy Spring, Senior Editor

When Entergy Nuclear adopted the latest wireless technology at its River Bend Nuclear Station, the company successfully modernized one of its plants and maximized performance—and saved $4 million in the process.

"This project at River Bend is the replacement of a control system that we have for all of our outlying areas," said Fred Wilson, senior project manager. "The traditional system would have been to install fiber optic cables."

Transmission towers with all the necessary documentation and support they require would also have to be figured into the fiber optic cable project.

"It's extremely costly to install fiber optics," Wilson said. "The Innovations Group at Entergy was asked to help us come up with a solution and they came up with an excellent radio solution." Because of the move to wireless, the cost of the project dropped from an initial projection of $7 million to $3 million.

River Bend is one of the first nuclear power plants to implement wireless technology for the continuity of a power project. Entergy Nuclear received an Honorable Mention award for the project from *Power Engineering* magazine for Best Projects of the Year 2009, nuclear power.

Replacing Cable

Entergy's River Bend Nuclear station is located in St. Francisville, La., 30 miles north of Baton Rouge on the Mississippi River. With a maximum net power output of 998 MW, the single-unit facility began commercial operation in June 1986 and serves Entergy's regulated business.

For the water intake process at the River Bend station, the Allen Bradley control equipment is located in three different buildings, the makeup water structure, the circulatory water system and the clarifier building. Traditionally, fiber optics and cable are used to tie all the systems together. Operations staff traveled several miles to the Mississippi to monitor and operate equipment at the makeup water structure. When the river was high, this entailed using a boat to reach installations, a safety hazard.

When the cable and fiber optics that carried information for nearly two miles needed to be replaced, Entergy's Innovations Group and engineers from the River Bend station chose wireless technology instead. The wireless network ties the three locations to the auxiliary control room and the supervisory control and data acquisition (SCADA) system using wireless, radio frequency technology.

Work on the project took about nine months. Digging or trench work that would have been needed to replace the cable and conduit were unnecessary. Trees were cleared to insure consistency of wireless transmission and the timber was sold, with profits returned to the company.

"We've made about $28,000 so far on the sale of the timber so the radio system has just about paid for itself," said Wilson.

Operations personnel are currently using the system to monitor pumps and other equipment at the makeup water structure. "At this point, all we're doing with it is the actual controls to our outlying pumps, valves, switch gears and motors," said Wilson. "In the near future we will add network capabilities."

The system is actually capable of doing all of the plant's remote vibration readings, too, which Wilson said will be added in the future, and plans call for extending the wireless network to the plant's clarifier and the circulatory water system.

"I see what we are putting in now as the beginning of about a 5- or 6-year project to see how much we can do."

Security and Reliability

The closed network that River Bend is using for indication and control is the Motorola canopy advantage wireless data network, said Mike Knop, special projects manager at Jackson Communications Inc., the company that provided the wireless equipment. The system operates at an unlicensed bandwidth and offers a 128-bit encryption algorithm.

"Entergy wanted that extra protection of having the data encrypted when it was sent out wirelessly," said Knop. "It's also password-protected."

Ray Savich, Motorola product marketing manager, point-to-multipoint solutions, said the system provides multiple layers of security and is certified for safe transmittal of financial records, medical information and credit card information. The 128-bit Advanced Encryption Standard (AES) provides the highest grade security.

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"It would take thousands and thousands of years to crack the 128 bit AES encryption code," said Savich.

The project was designed with multiple, redundant secure networks to ensure high reliability. Two series of wireless equipment were installed, the Motorola canopy advantage 5400 series and the 5700 series, which operate at 5.4 GHz and 5.7 GHz respectively. With the dual system, if one series fails it is automatically switched to the other so there is no loss of data.

Interferance avoidance is built into the system. "We don't expect problems like we've seen in the past with some river boat traffic interferences," said Wilson.

From the central tower, the signal can easily travel three miles, said Savich. Point-to-multipoint systems have a range of up to 15 miles (and point-to-point solutions can cover 128 miles). The wireless system units are outdoors in self-contained and weatherproof housings, with cables that run indoors to connect to the SAIC equipment. Because the network operates in a spectrum below 10 GHz, it is resilient to moisture or precipitation. Snow and heavy rains have no affect on signal reliability.

Admittedly, wireless technology is not without concerns, such as cyber security and electromagnetic/radio frequency interference, said Richard Rusaw, EPRI senior project manager. But he said implementation experience and ongoing technical advances in cyber security funded by the Department of Energy demonstrate that these barriers are not limitations to implementation.

Future Plans

Work is currently underway at Entergy's Grand Gulf Nuclear station to eliminate the need for traditional fiber optics and copper cabling required to establish network connectivity to radial wells on the Mississippi River. An instrumentation upgrade project there is slated for completion during the next two years. Installation of wireless equipment for general business network connectivity has begun at Entergy's Vermont Yankee nuclear power station.

"As technology advances, there are many areas we haven't looked at as far as communications and instrumentation and control," said Marshall Rayburn, River Bend senior nuclear equipment operator. "We seem to try to fix the same equipment over and over when we could be using the new technology to do these same jobs cheaper and more efficiently."

Over the years, optical fibers largely replaced copper wire communications in core networks and now fiber optics are being replaced by wireless technology. Motorola alone claims to have 2 million point-to-multipoint systems deployed around the world.

Wireless systems can provide the connectivity that network operators need, securely and cost-effectively. Point-to-multipoint solutions are widely deployed today for data transfer and SCADA, and the system can be installed in a fraction of the time that it takes to install a wireline solution, said Tim Mason, senior director of global solutions marketing for the wireless network solutions portfolio at Motorola.

Based on results so far, Entergy thinks additional efficiencies can be gained by leveraging and integrating this technology across the entire nuclear fleet. pe

For more features on wireless technologies, visit Power Engineering's website at www.power-eng.com.

THE BENEFITS OF WIRELESS

The financial and technical benefits associated with using wireless technology in the nuclear power industry are difficult to ignore, said Richard Rusaw, EPRI senior project manager. "As facilities age, and as operators strive to reduce the total cost of plant operations, wireless technology offers one attractive improvement opportunity."

Rusaw said installed estimates for cabling in a nuclear power plant can be as high as $2,000/foot, so wireless technology could also provide significant cost savings. Initial applications are primarily extensions of the business network, while new applications will target enhanced monitoring and equipment performance. Several utilities have installed wide area networks (WAN) in nuclear power facilities that provide significant productivity improvements.

"A lot of our customers that are looking for secure wireless solutions will typically turn to standards the federal government is defining as their minimum security standards," said Tim Mason, Motorola's senior director of global solutions marketing for the wireless network solutions portfolio. "We follow the highest levels of the government standards for security."

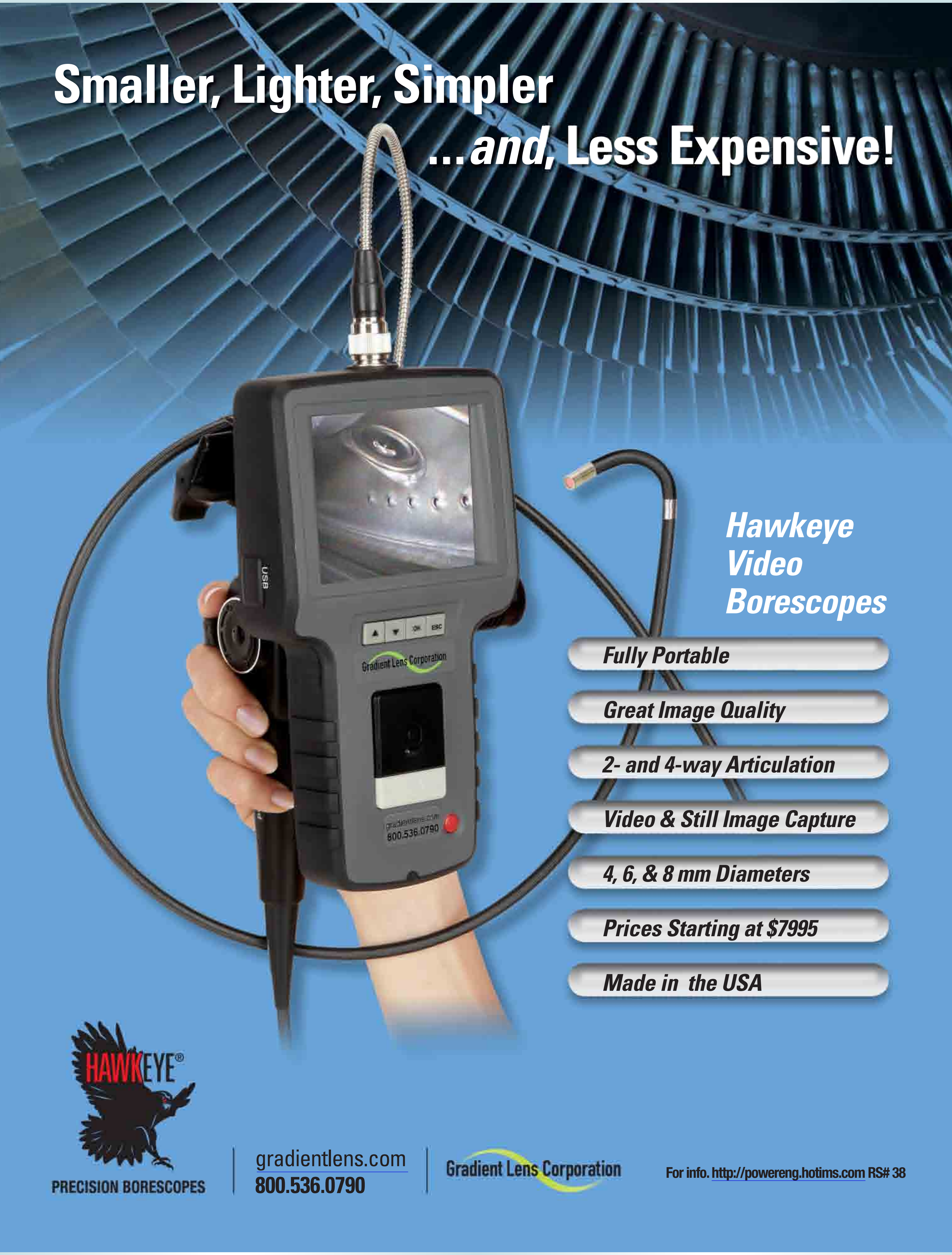
The federal government is interested in wireless, especially as it pertains to energy efficiency. Wayne Manges, program manager for wireless systems at the Energy and Engineering Sciences Directorate, Oak Ridge National Laboratories, tracks wireless sensor technology for the Industrial Technologies Program, part of Energy Efficiency & Renewable Energy at the DOE.

"Wireless is considered a critical enabler for energy efficiency," said Manges, whose work focuses on wireless sensors and controls for manufacturing and industrial applications.

Manges said Luminant's Comanche Peak nuclear plant in Texas has had the world's largest installation of wireless sensor networks for the past five or 10 years. "Wireless control is (already) being used, but River Bend is the first really broad application I've seen."

The Motorola system's modulation is proprietary, but the government is driving toward open standards. "We think that's the future, not proprietary," Manges said.

Is there any difference in the level of security between proprietary and open standards? According to Manges, developers of proprietary systems think no one knows how they did it, but they're wrong, while with an open standards implementation, everyone knows how it was done "and you're still secure. People in this business say that security through obscurity is neither."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Afton Combined Cycle with Hybrid Cooling

A cooling system that may be applicable at any plant site facing water constraints.

By Jack Groves and Todd Krankkala, Power Engineers; and Greg Nugent, Public Service Co. of New Mexico

The Afton Generating Station near Las Cruces, N.M., is a 225 MW-class 1x1 combined cycle project owned and operated by Public Service Co. of New Mexico (PNM). The preliminary design efforts moved through five distinct configurations to reach the final design. The facility represents the state of the art in combined cycles, including unique parallel path water conserving hybrid cooling system. This cooling system is applicable for consideration at all plant sites facing water constraints.

The project was first conceived in 2001 as a 100 percent wet-cooled 550 MW 2x2x1 Frame 7FA unit. This prompted PNM to procure the gas turbines and steam turbine from General Electric and construct one simple cycle turbine as Phase I. In 2005, PNM completed a re-assessment of the optimal resource mix for its customers. As a result, Afton was redefined as a 225 MW-class critically needed 1x1x1 combined cycle asset for Phase II. The reassessment also concluded that the original inventoried steam turbine was not ideally suited for the proposed Phase II configuration. To meet the project schedule, gray market steam cycle equipment was located and purchased in late 2005. Commercial operation was achieved in late 2007.

PNM executive management during the detailed design phase implemented an Environmental Sustainability Policy which included a mandate to substantially reduce cooling water consumptive use at future power generation facilities. The design team elected to reconfigure the cooling system from a 100 percent wet tower to a hybrid parallel cooling system, with a target of consuming a maximum 600 acre-feet (AF) of water as compared to a projected wet system consumptive use of 1,750 AF. This met Environmental Sustainability Policy requirements.

A second goal, beyond water conservation, was to sustain minimal performance impacts during high ambient temperature operation. Such impacts often are a common penalty associated with air cooled-only condensers in the desert Southwest.

The project was confronted with many challenges including:

- Incorporating gray market equipment into an existing plant site
- Compressing and overlapping engineering and construction activities
- Weather-related delays
- Market volatility (pricing and delivery) for labor, materials and equipment
- Final operational shakeout.

This article offers a brief history of the evolution of Afton and a summary of lessons learned. We include emphasis on the hybrid cooling system which conserves 60 percent of the water as compared to a wet tower, with minimal performance impacts during high ambient temperature operation. One hundred percent equivalent availability monthly periods are common as unit operations mature and cooling system operations are being refined and enhanced on a number of fronts.

The Afton Combined Cycle Project fired up in 2007 for commercial operation and represents a high level of power plant development for its market setting. Afton applies industry-standard gas-fired combustion turbine equipment with a water-thrifty hybrid cooling system and delivers 225 MW of baseload and mid-merit power service with NOx emissions at 3.5 parts per million (ppm) or below.

TABLE 1 AFTON AVAILABILITY – 2008 (%)

Month	CTG	STG	Total
January	95.58	97.7	96.64
February	*	*	*
March	86.37	81.79	84.08
April	86.67	80.58	83.62
May	92.99	92.92	92.95
June	99.5	99.45	99.52
July	99.36	91.4	95.38
August	100	93.41	96.71
September	99.56	71.34	85.45
October	*	*	*
November	100	100	100
December	100	100	100
Yearly Total	96.01	90.86	93.44

* Extended outages were carried out in February and October to do carryover work from construction.

The Afton Plant would seem like an obvious match of technology to need. In fact, Afton followed an evolutionary path over two decades of head-scratching and boardroom discussions, from initial development as a peaking unit to its ultimate form and configuration.

In 2001, the project was first conceived as a 550 MW 2x2x1 Frame 7FA unit with wet cooling. PNM moved at that time to procure the gas turbines and steam turbine from GE and decided to install one simple cycle 7FA as Phase I and place the rest of the equipment in inventory. In 2005, PNM redefined Afton Phase II as a 225 MW 1x1x1 combined cycle. As a result, PNM determined that the steam turbine in inventory was not ideally suited for the revised Phase II plant layout. In 2005, PNM located and bought gray market replacement equipment. PNM also took bids for the combined cycle balance of plant

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equipment, including GEA's Parallel Condensing System (PAC). This system was identified by PNM because of its potential to significantly reduce plant water consumption.

Selecting a Site

The Afton site was first identified in 1991 by Energy Southwest Inc. (ESI), a New Mexico developer/consultant. ESI developed the site for peaking and to meet part of the City of Las Cruces' generation portfolio. The proposed power plant use was found to be compatible with the neighborhood; an adjoining El Paso Natural Gas (EPNG) compression station already has three gas-fired GE Frame 5s for mechanical drives. EPNG also had production water wells and industrial-use water rights suitable for a Frame 7.

The site is at 4,220 feet, ideal for emission disbursement characteristics. Beneath the site is a large, proven groundwater resource of suitable quality for power generation use in aquifers of various depths up to 1,500 feet. On a conventional siting scale of 1to 10, the site is ranked a 9. Its sole deficit is a lack of five-mile proximity to a major freeway.

The Afton Generating Station evolved through five different design configurations.

Original Configuration: The project was initially defined by ESI as one natural-gas-fired combustion turbine (CT) linked to a 1x1 GE Frame 7FA/A10 combined cycle plant at a copper mine at Morenci, Ariz. Afton and the Morenci combined cycle were to be operated in conjunction to serve this industrial load. Afton was intended also to provide peaking service for the City of Las Cruces.

Second Configuration: ESI's power sales contract with the mine was placed on a long delay. Meanwhile, the state and federal governments were proposing a deregulated wholesale market for Exempt Wholesale Generators (EWG). The mine's combined cycle project was placed on hold and the focus shifted to Afton, which was re-configured as a gas-fired wet-cooled 1x1 GE 7FA-based 225 MW-class plant. The target sales market shifted to potential service to wholesale loads.

Enter PNM: PNM studied numerous development and siting options and determined that the Afton project conception would serve its needs. PNM bought Afton from ESI and reconfigured it as a full duct-fired, wet-cooled 2X1 GE Frame 7 FA-based 550 MW-class combined cycle. (PNM also studied a 2x2 configuration for Afton, but it proved less efficient and more expensive.) ESI/PNM commissioned design work and bought the key prime movers – two 7 FA gas turbines and one D-11 steam turbine – in a strong seller's market.

Ground Is Broken: The fourth configuration, and the first to achieve a material presence on the site, was a dual-fuel GE 7FA simple cycle fitted with a bypass stack and damper to readily support a future expansion into 1x1 combined cycle. PNM's other inventoried turbines and ancillaries originally destined for Afton were assigned to other projects or sold.

The Arrival of Steam: Configuration five called for a heat recovery steam generator (HRSG) equipped for duct firing and a GE A10 steam turbine. This combination allows the plant to achieve the much lower heat rate of a combined cycle and elevates Afton to a higher-value generator within PNM's system. Configuration five also incorporates an innovative and spectacularly effective water-conserving hybrid heat rejection system.

Design Basis and Timeline

PNM's development of the combined cycle expansion at Afton needed to comply with its Environmental Sustainability Policy, adopted in 2003, which outlines goals to reduce water consumption, air emissions and waste streams. Consequently, PNM decided that configuration five would use a parallel (water/air) cooling system to reduce water consumption over the original full wet cooling design. PNM also added a wastewater treatment plant. The parallel cooling system was critical to making the best use of the plant in a wide range of operating conditions. Specifically, the parallel system was selected to optimize output during summer peak periods. To serve the wet side of the parallel system, PNM had 555 acre-feet per year of water rights.

Because of the goal to serve the 2007 summer peak, PNM decided early in the project to procure key equipment and materials–in particular, alloy piping, structural steel and wiring–well in advance of final design. Schedule also drove some of the major equipment selection and procurement events.

The Afton Combined Cycle conversion was completed amid an array of supply and construction challenges beyond the control of the parties involved. The combined cycle development stage took place neatly within a period when materials costs were rising with eye-popping speed: steel, copper, and concrete generally doubled and in some cases more than tripled. Escalating costs, driven by shortages, were matched by increasing delivery intervals, causing the right side of the project schedule to grow fiendishly complicated.

Parallel Cooling– Selection and Design

The parallel cooling system–which offers a blend of a wet tower and an ACC system for condensing service–was chosen for its ability, via its wet tower, to provide better cooling and higher output in the summer versus a 100 percent air cooled system. The benefit of the dry ACC side of the blend is to reduce overall water consumption when compared to a full-time wet cooling tower.

The system was specified by PNM and its engineering consultants and bid as a complete system. The supplier's scope included the wet surface condenser with air removal skid and the cooling tower, plus the air-cooled condenser and ducting from the steam turbine exhaust flange to the ACC. The Afton plant design is for a thermal duty split between the wet condenser and air-cooled condenser in the range of 40/60 (wet/dry) at an ambient condition of 70 F. This split was selected based on heat balances run by Power Engineers using operating hour assumptions provided by PNM. The Power Engineers design criteria called for a water consumptive use of 600 acre-feet per year (AFY). However, only 555 AFY was available for purchase at the time, so plant operations were adjusted to meet this limit.

At ambient 98 F, the thermal duty split is closer to 45/55 (wet/dry). The design operating point for the parallel cooling system was set at 98 F, 16 percent RH with a steam flow of 594,981 lb/hr and at a maximum steam turbine backpressure of 5" HgA. When conditions are hotter than this, duct firing is reduced to lower steam flow to maintain the STG backpressure at or below this level. (The steam turbine alarms at 5.5" HgA and trips at 7.5" HgA.)

PNM and Power Engineers selected GEA as the supplier for the parallel cooling system, which consists of the following:

- 10-cell air cooled condenser with


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two-speed fans
• Two-cell cooling tower with two-speed fans
• Deaerating surface condenser
• Air removal system.

Noncondensable gases are extracted from the exhaust steam using both liquid ring vacuum pumps and steam jet ejectors. Condensate from the surface condenser and ACC is accumulated in a deaerator/condensate tank.

Makeup water for the wet cooling system comes from raw water wells on the Afton site. The well water is warm (80-90 F) and is cooled prior to treatment. The water treatment system delivers demineralized water for makeup to the condensate tank; reject water from the water treatment skid is dispatched to the wastewater treatment plant.

Treated and reclaimed permeate from the wastewater treatment is sent to the wet tower to serve as makeup water. Reject water from the wastewater treatment system is sent to evaporation ponds on site.

The GEA PAC System functions in several modes, depending on ambient temperature. The system's design basis is for an ambient 98 F and a turbine backpressure of 5" HgA. At 98 F, the system is designed so that all ACC fans run at high speed, both cooling tower fans run at high speed and circulating water passes through the surface condenser at full flow. As ambient drops, the ACC fans operate in varying regimes to maintain design backpressure. Fans can be turned off or run in low-speed or high-speed settings. Control functionality for these functions resides in the Afton plant's distributed control system logic. PNMs operators have discovered that in automatic control mode, the ACC fans tend to cycle between high and low speed too frequently. Because of this, operators are currently controlling ACC fans manually.

In winter the wet tower fans can be turned off, at least from the perspective of backpressure. PNM's current practice is to run one circulating water pump during the winter. The reason for this is that GEA recommends maintaining some water flow through the surface condenser tubing to prevent fouling. It may be feasible to divert auxiliary cooling water for this purpose if the auxiliary pumps can maintain the required minimum flow through the condenser.

In January 2008, one ACC fan saw catastrophic failure of five of its six blades. Inspection of the other nine fans showed that 80 percent of the blades had cracks along the leading edge. GEA and fan supplier Howden replaced the six-bladed fans with seven-blade fans, changed the pitch angle of the blades from 12.8° to 12.3° and also used blades made in a different process. Howden also mounted a strain gauge on the root of one blade and is observing fan stress against fan/motor rpm and ambient wind speeds to determine if wind conditions were involved in the blade failure. The replacement blades have not experienced any noticeable degradation or failures.

The NCG extraction system includes vacuum pumps and steam jet ejectors. In the early period of operation, the ejectors did not perform optimally during start-up conditions when steam pressure is building. So the ejector nozzles were replaced to provide a wider range of effective operation to cover this condition. This has remedied the problem.

Cooling System Performance

Though the Afton DCS allows automatic control of ACC fan speed operation, PNM's

operators prefer to operate the ACC manually during some temperature conditions to keep the fans from cycling excessively between high and low speeds. Table 1 shows actual Afton Combined Cycle plant availability during 2008, its first full year of operation.

Some lessons learned:

The schedule was severely compressed by rightward drift in the start date and some cost and design efficiencies were sacrificed. Mobilization of construction was breathtakingly early: four weeks after the full release for engineering activity. Long lead times and escalating bulk material costs squeezed the engineering effort mightily, and some materials were procured based on preliminary information. In some cases, the plant design was driven by construction requirements; in a more measured schedule setting, additional efficiencies in value-engineered design could be realized.

Although gray market opportunities offered Afton expedited deliveries and potentially lower pricing, there is a cost. The buyer may be forced to a configuration not ideally suited to the site or the performance requirements of the plant. At Afton, the gray market HRSG's piping connections were on the wrong side of the HRSG for the ideal layout; the team elected to use them rather than modify the HRSG. Since the HRSG and turbine were designed for a different site and different conditions, Power Engineers and PNM spent additional time studying the impacts of the differences on Afton. Grey market equipment drawings and specifications (or the lack thereof) need to be carefully reviewed, and this activity should be accounted for in the scope and schedule.

Afton's wastewater treatment plant has seen several process upsets triggered by flows greater than anticipated. These high flows resulted from the cycling operation of the power plant. This problem was solved by providing additional residence time for wastewater streams upstream of the clarifiers.

Afton has proven an excellent site for a power plant. The plant is well matched to its regional grid, is a sound asset for its owner and is a good neighbor. The project went through a dizzying series cycle of embodiments while morphing from an audacious merchant plant concept to a utility jurisdictional asset, and acknowledging both external and internal requirements which shaped the project through its formative stages and determined its final form.

Afton's NOx emissions are notably low, at 3.5 ppm or less. This brings Afton to a tie for lowest power plant emissions in New Mexico. Although Afton is a combined cycle plant in a hot region, it meets PNM's Environmental Sustainability Policy, including the policy's guidelines for water conservation. Afton's hybrid cooling systems has shown itself to be effective and reliable. Canny operational practices, fan blade improvements and water treatment improvements have been incorporated at Afton to make the plant work even better.

Afton, because of its adventurous application of a parallel cooling system to save water and increase output during hot weather, is an excellent model for similar applications elsewhere. It seems inevitable that, with growing pressure for water conservation and increased plant efficiency, similar hybrid cooling systems may find homes elsewhere. pe

Analysis tool

Acumen is launching its trademarked Acumen Fuse, a metric analysis and visualization tool that analyzes schedule, cost, risk, earned value and project performance. Using libraries of metrics, Acumen Fuse provides a means of pinpointing problematic areas and activities within a project and providing solutions for resolution.

The visualization tool takes snapshots of a project throughout time so users can see where the project is changing and what is causing these changes. Fuse allows users to perform path analysis along any point in the project.

Users can also utilize the Comparison Analyzer to compare scenarios, metrics and phases against each other, which allows users to determine issues that have not been previously resolved along with what activities are causing changes and exactly where the problems are.

The program offers native analytical support for the DCMA 14 Point Schedule assessment (including secondary tripwires). It can be imported onto MS Project, Oracle Primavera and Primavera Risk Analysis and MS Excel.

Swagelock
Info http://powereng.hotims.com RS#: 400

Ball valve

The Swagelok FKB series medium-pressure ball valve provides a leak-tight seal for applications up to 15,000 psig (1034 bar). The trunnion-style ball valve features Swagelok's patent-pending direct load design, which delivers a more consistent seal across a full range of pressures.

The valve features low-torque actuation and is available with ISO-5211 compliant actuators. The ball valves also feature a two-way configuration with medium-pressure tube fitting end connections, which provide single-turn makeup, or makeup by torque, for reduced installation time and labor costs.

Swagelok
Info http://powereng.hotims.com RS#: 401

GHG-capable flow meter

Sierra Instruments introduced a line of mass flow meters certified by Sierra for greenhouse gas (GHG) reporting. All Sierra GHG meters are made to conform to the new EPA rule (40 CFR Part 98).

Sierra's GHG certified mass flow meters are designed to provide a way to totalize methane (CH_4) or natural gas burned, enabling the calculation of CO_2 equivalent emissions.

The three GHG Certified thermal mass flow meters on Sierra's GHG webpage are the trademarked Boiler-Trak, and models 640S and 780S, both of which are designed for stationary combustion applications.

Sierra's Model 640S has been optimized for landfill gas, has 100:1 turndown, no moving parts, and generates nominal pressure drop across the immersible sensor probe. The Sierra Model 780S was designed for gas and electricity producers and used to measure methane to compressors, pre-heaters, boilers and other process equipment.

Sierra Instruments
Info http://powereng.hotims.com RS#: 402

Grid security

Schweitzer Engineering Laboratories, Inc. announced that the recently released SEL-3620 Ethernet Security Gateway is now available for $2,800.

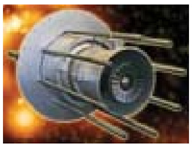
Designed to provide security to critical infrastructure systems such as water treatment facilities, oil and gas facilities, and the electric power transmission infrastructure, the Ethernet Security Gateway protects systems from malicious traffic with VPNs and a configurable ingress and egress stateful firewall. It provides up to 60,000 security event reports and supports Syslog with precise time tagging of events through IRIG. The storage for SEL-3620 offers industry-vetted security and interoperable standards, including IPsec (RFC 4301, 4302, and 4303), X.509 certificates, OCSP certificate revocation, IRIG-B time synchronization, HTTPS web interface, Cisco:OPSAID interoperability, and Syslog.

Tailored specifically to secure smart grid communications, the Ethernet Security Gateway operates with existing IT and control systems, using an intuitive, menu-driven web interface to create an Internet Protocol Security (IPsec) virtual private network (VPN). It secures routable protocols that cross electronic security perimeters, and provides up to 16 VPN connections on three Ethernet ports.

Schweitzer Engineering Laboratories, Inc
Info http://powereng.hotims.com RS#: 403

Ultra low NO_x burner

Hamworthy Peabody Combustion introduces an ulta-low NO_x burner that achieves ignition using a self-cleaning and low maintenance ignitor. A burst mode ignition with flashing indicator lets the operator observe ignitor conditions during use.



The burner can be used at capacities up to 400 MM BTU/hr and in package, industrial and utility boilers ranging from single to multi-burner, wall-fired, Turbo and other boiler types. The burner can be used on a wide range of gaseous fuels like natural gas, propane, and landfill and refinery gases.

Hamworthy Peabody Combustion
Info http://hotims.powereng.com RS#: 404

Low NO_x burner

Hamworthy Peabody Combustion introduces the MSC² burner, which includes multi-stage combustion. It is designed to introduce fuel into primary and secondary airstreams. The burner is also made for low carbon monixide and particulate performance with low NO_x.

For liquids, the low NO_x atomizer is used.

The burners feature a line of gas electric ignitors that can be rated NFPA Class 1, 2 or 3 depending on application requirements. A burst mode ignition with flashing indicator allows the operator to observe ignitor conditions during operation and eliminates the need for an ignitor fuel train.

Hamworthy Peabody Combustion
Info http://hotims.powereng.com RS#: 405

Oil dye

Spectronics Corp has introduced its trademarked Oil Glo 40, an oil-based fluorescent leak detection dye formulated specifically for large industrial systems.

The dye is made to pinpoint leaks in all synthetic- or petroleum-based fluid systems, including light-colored hydraulic fluid, engine oil, dark or blue hydraulic and lubrication

fluids and gearbox oil. Use an ultraviolet lamp to detect the dye in any leaks.

Spectronics Corp.
Info http://powereng.hotims.com RS#: 406

Outage inspection

HRST, Inc. offers an outage inspection program with a Standard and Express Inspection option.

The Standard Inspection covers all high-priority identified findings, corrective action for the findings and a brief explanation of the root cause. The follow-up covers all high- and low-priority findings identified, corrective action including timing, and complete photo documentation of the boiler condition via captioned photos.

The Express Inspection includes everything in the standard inspection. The follow-up covers photo documentation of each location.

HRST Inc
Info http://powereng.hotims.com RS#: 407

Priming pump

Thompson Pumps' trademarked 4JSCG Enviroprime Pump is a high-head 4-inch automatic priming centrifugal pump that provides flows of up to 1,300 gallons per minute and heads up to 330 feet.

The pump handles solids up to 3 inches and is ideal for sewer by-pass pumping and abrasive applications, emergency flood response, and any other applications that require the transfer of liquids that contain solids. The system is designed to prevent product blow-by of pumpage, such as sewage, effluent and waste, from being discharged onto the ground or through hoses that carry the pumpage back to the source, making it environmental friendly.

Thompson Pump & Manufacturing
Info http://powereng.hotims.com RS#: 408

Thread sealant

Henkel Corp.'s new thread sealant, the trademarked Loctite 5452, is designed for use on metal fittings found in high-pressure hydraulic and pneumatic power systems. It is also made to cure four times faster than traditional anaerobic sealants even on stainless steel or inert metals.

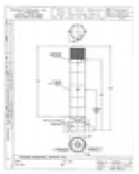
The sealant is made to lock fittings from vibrational loosening. It seals mating surfaces

of flare-style fittings, filling scratches and surface imperfections. It is available in 50 or 250 mL tubes and can withstand operating temperatures from -65 degrees Fahrenheit to 300 degrees Fahrenheit.

Henkel Corp.
http://powereng.hotims.com RS#: 409

Vent silencer

The Stoddard B15N-78 vent silencer is the largest silencer the company has ever built. It measures 53 feet tall, 9 feet in diameter



and features 2, 40-inch inlets through a base mounting skirt.

Steam flow into the silencer is measured in pounds mass and the silencer is designed to accommodate 1,180,000 lbs/hr at an upstream pressure of 1,545 PSIG at temperatures of 600 degrees Fahrenheit.

Stoddard Silencers Inc.
Info http://powereng.hotims.com RS#: 410

Thread sealant

Henkel Corp.'s trademarked Loctite 5802 PST High Purity Thread Sealant is made for use on threaded stainless steel pipes and fittings found in high temperature environments such as nuclear facilities. The sealant is low in impurities such as halogens, sulfur and low-melting-point metals which can be harmful to metal pipes.

The thread sealant is a high viscosity, mediaum-strength sealant that will not decompose at operating temperatures typically found in a nuclear power facility. The single component anaerobic sealant is available in a 50 mL tube.

Henkel Corp.
Info http://powereng.hotims.com RS#: 411

Beam clamps

Harrington Hoists, Inc. has released their new Universal Beam Clamps. The clamps are available in 1 through 10 metric rated tons, meet ASME BTH-1, ASME B30.20, comply with portions of ASME B30.16 and have a design factor minimum of 5:1 per ASME B30.16 requirements.

Harrington Universal Beam Clamps are used when a temporary or semi-permanent

hoist anchor point is required for overhead lifting and vertical rigging applications. Also used as a below-the-hook lifting device, these rugged beam clamps provide solutions for holding and positioning beams for construction. Features include a built in suspension pin for low headroom, lock nut feature to resist loosening and an adjustable jaw opening for a wide range of tapered and flat flanged beams. An optional suspender is available for perpendicular mounting and oversized hooks.

Harrington Hoists, Inc.
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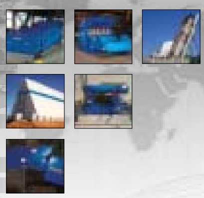

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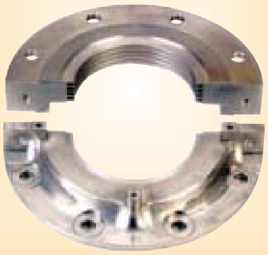

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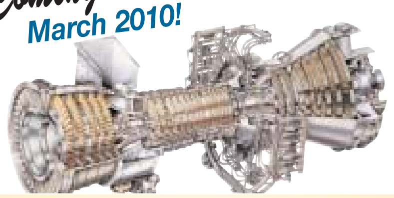

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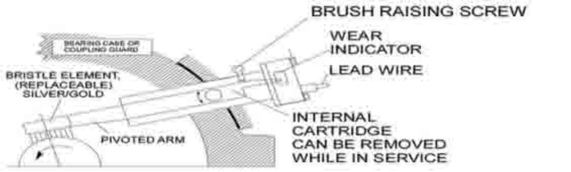

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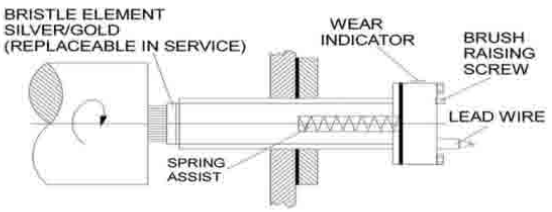

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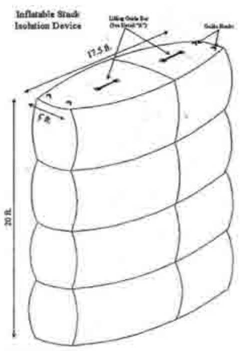

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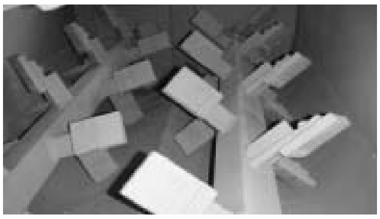

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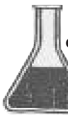

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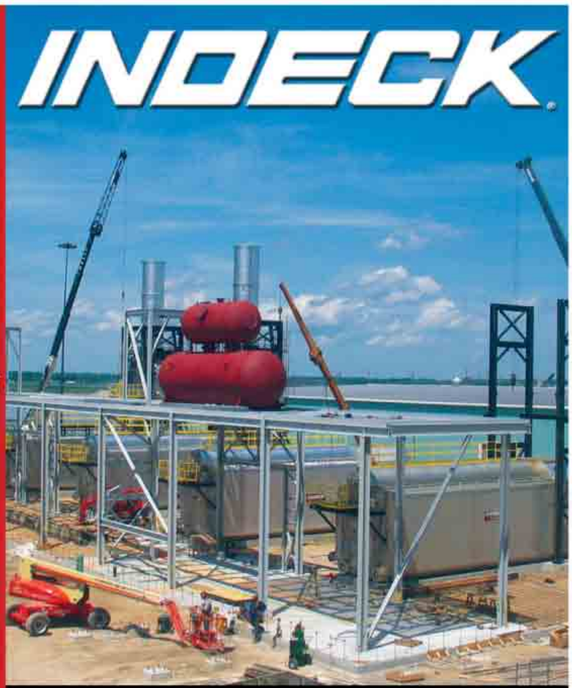

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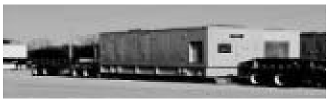

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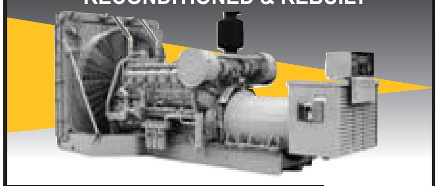

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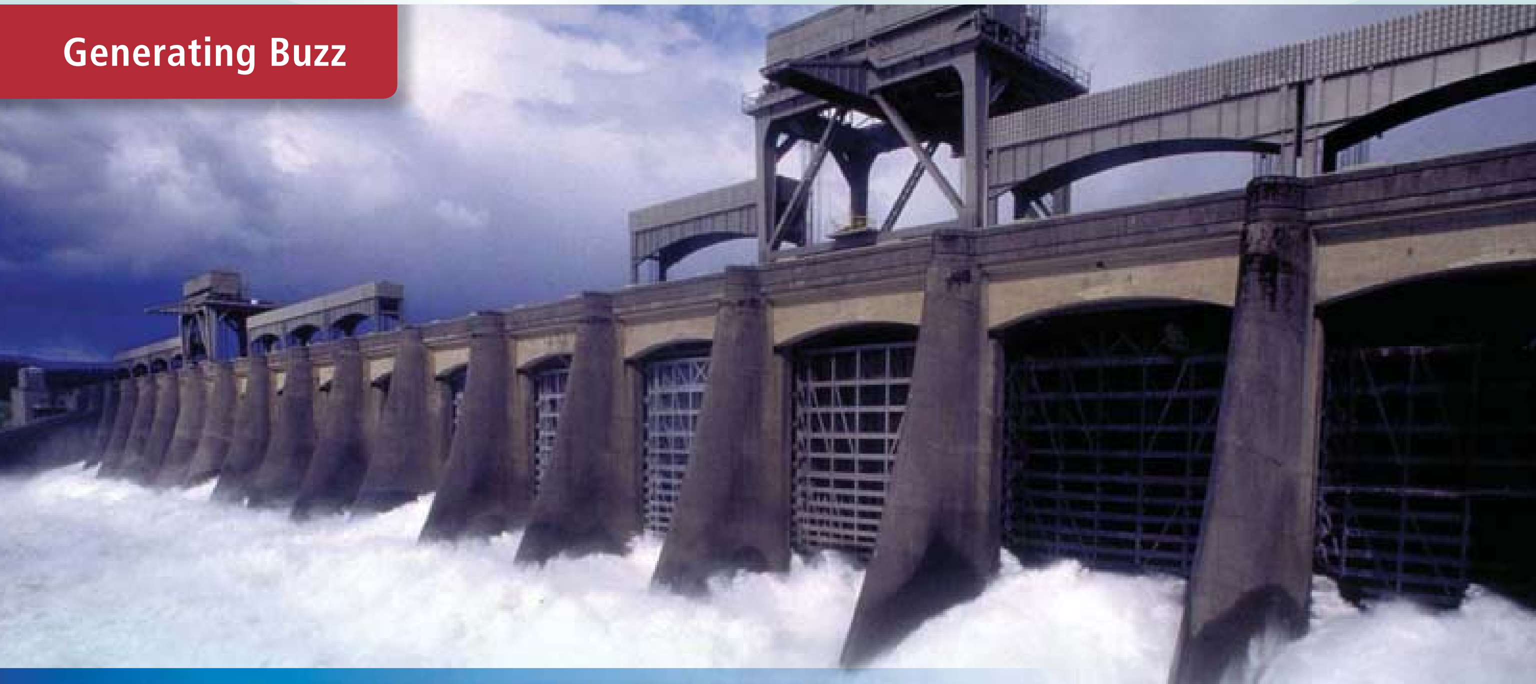

MANAGING DAMS FOR A CHANGING CLIMATE

Civil engineers at the University of Washington and the U.S. Army Corps of Engineers' Seattle office have taken a first look at how dams in the Columbia River basin, the nation's largest hydropower system, could be managed for a different climate.

They developed a new technique to determine when to empty reservoirs in the winter for flood control and when to refill them in the spring to provide storage for the coming year.

Computer simulations showed that switching to the new management system would lessen summer losses in hydropower due to climate change by about one quarter. It would also bolster flows for fish by filling reservoirs more reliably. At the same time the approach reduced the risk of flooding.

Predicted hydrologic changes for the Pacific Northwest and other mountain regions include less springtime snowpack, earlier snow melt, earlier peaks in river flow and lower summer flows. Water managers currently use a system based on historical stream-flow records to gauge when to open and close the floodgates.

The researchers created a computer program that uses long-term forecasts rather than historical records to recalculate when to begin filling and emptying the major storage reservoirs. They compared historical conditions with a scenario where temperatures are 2 degrees Celsius higher on average than today, a change expected in the Pacific Northwest by the second half of this century.

The simulations suggested water managers could successfully deal with warmer conditions by refilling the system's reservoirs as much as one month earlier in the spring.

The project aims to help regional water managers develop methods to deal with changes in the hydrological cycle.

ASIAN OZONE AFFECTS NORTH AMERICA

Springtime ozone levels above western North America are rising primarily due to air flowing eastward from the Pacific Ocean, a trend that is largest when the air originates in Asia.

Such increases in ozone could make it more difficult for the United States to meet Clean Air Act standards for ozone pollution at ground level, according to a new international study. Published online in the journal *Nature*, the study analyzed large sets of ozone data gathered since 1984.

"In springtime, pollution from across the hemisphere, not nearby sources, contributes to the ozone increases above western North America," said lead author Owen R. Cooper, of the NOAA-funded Cooperative Institute for Research in Environmental Sciences at the University of Colorado at Boulder. "When air is transported from a broad region of south and east Asia, the trend is largest."

The study focused on springtime ozone in a slice of the atmosphere from two to five miles above the surface of western North America. That slice is below the protective ozone layer but above ozone-related, ground-level smog that is harmful to human health and crops. Ozone in this middle region constitutes the northern hemisphere's baseline level of ozone in the lower atmosphere. The study was the first to analyze nearly 100,000 ozone observations.

Fossil fuel combustion releases pollutants like nitrogen oxides and volatile organic compounds, or VOCs, which react in the presence of sunlight to form ozone. North American emissions contribute to global ozone levels, but the researchers did not find any evidence that these local emissions are driving the increasing trend in ozone above western North America.

The study used springtime ozone measurements because previous studies have shown that air transport from Asia to North America is strongest in spring. That makes it easier to discern possible effects of distant pollution on the North American ozone trends.

The analysis shows an overall increase in springtime ozone of 14 percent from 1995 to 2008. When the scientists included data from 1984, the year with the lowest average ozone level, they saw a similar rate of increase from that time through 2008 and an overall increase in springtime ozone of 29 percent.

POWER Engineering
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