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Take Advantage of Turbo-Expanders

These devices can play a useful role for recovering energy

By Amin Almasi, mechanical consultant

A turbo-expander, also referred to as an expansion turbine, is a centrifugal or axial flow turbine in which a high pressure gas expands to produce useful work, generally to drive equipment or machinery. The device often provides an attractive option for recovering energy when the pressure of a gas stream needs reducing — and so finds use in a wide variety of plants. Because the work comes from the expanding high pressure gas, the expansion is approximated by an isentropic (nearly constant entropy) process; the reduced pressure exhaust gas from the turbo-expander is at a lower temperature than that of the inlet gas.

Turbo-expanders handle a wide range of services, from those involving cold gases (say, -270°C) to hot gases (above 350°C). Typically, use of a turbo-expander makes sense only for relatively large gas flows. As a very rough indication, units currently in operation range in power ratings from about 25 kW to around 25 MW. However, some special applications have used turbo-expanders with ratings lower than 25 kW.

THE BASICS

A turbo-expander operates according to the thermodynamic and fluid-dynamic laws of physics. Operational flexibility is a key requirement because the device often must handle a wide range of flowrates and pressures. Therefore, it usually has not just one rated operating point but also several alterative ones. When designed and manufactured properly, a turbo-expander can yield very high efficiencies at its rated point and reasonable efficiencies at alternative operating points.

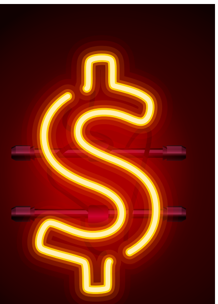
In a simple, single-stage turbo-expander, the high pressure gas flows through variable inlet nozzles (or inlet guide vanes) and then through the wheel, exhausting at a lower pressure and substantially colder temperature. In many applications, the outlet gas goes to a downstream process; therefore, turbo-expander nozzles are used to control the gas flowrate and conditions to maintain the operating conditions (flowrate, pressure, etc.) required downstream. The operation of some turbo-expanders can pose some operational risks. For instance, due to fast temperature reduction of the gas, partial liquefaction or condensation of the expanded gas isn't uncommon.

Manufacturers of turbo-expanders rely heavily on standardization; most components are pre-designed. Parts normally needing to be customized for each specific application are the wheels, shafts, nozzle assembly, gear systems, auxiliaries and controls. Each standard size/model is linked directly to a casing and, therefore, the overall dimension of the machinery. Every standard model or frame can accommodate a specific range of turbo-expander wheel diameters. Model sizes also are directly distinguished by the design pressure and flowrate. The pressure sets the flange ratings. As a very rough indication, wheel diameter can reach up to around 2 m. Fabricated casings are common but ones made by casting or other methods are used sometimes. A fabricated casing provides flexibility to design and manufacture for a broad range of applications, ratings and nozzle loads. The design temperatures typically set the materials of construction for the components. Hot gas turbo-expanders differ completely from cold gas ones.

The inlet nozzle system, often known as adjustable inlet guide vanes (IGVs), is the primary control tool of a turbo-expander; therefore, its mechanism, configuration and details demand great care. The key requirements are precise flow regulation and reliability. These are needed to accurately control the speed of the turbo-expander to avoid speed fluctuations, particularly at part-load and low loads. Some modern multilink mechanisms use sophisticated techniques to adjust the IGVs for precision flow control and minimal actuating forces.

Nozzle segments must contend with severe working conditions due to high gas velocities and other effects. Special anti-friction and anti-wear coatings usually are needed on the nozzle segments to minimize losses during the first isenthalpic expansion. The presence of solid particles and impurities can pose a great risk for

A turbo-expander can generate low temperature gas far more efficiently.



turbo-expanders. For this reason, nozzles typically receive some sort of treatment, such as tungsten-carbide or special coatings, surface induction hardening, etc., to minimize erosion problems and other damaging effects. The appropriate choice depends on the particular application.

HOT GAS APPLICATIONS

Lots of plants have streams of high pressure hot process or waste gases that require cooling before further processing or disposal. Not infrequently, sites opt for turbo-expanders to recover useful work from these streams.

Some turbo-expanders have been designed and built specifically for hot gas services but often steam turbines have been adapted and used. Basically, these latter units feature the same working principle as conventional steam turbines except for the working fluid. However, because the operating, thermodynamic and fluid-dynamic behavior of a hot gas in each service differs from that of steam, successful application requires many checks and verifications to avoid potential problems or issues. Hot gas turbo-expanders can use low alloy carbon steels to some extent. Extreme temperatures and pressures, though, call for suitable alloys, many of which are employed for steam turbines.

COLD GAS SERVICES

Many turbo-expanders find use in low temperature, refrigeration and cryogenic services. Such turbo-expanders primarily serve to efficiently reduce temperature in a high pressure gas stream. Expansion causes the gas to cool dramatically while providing mechanical energy to rotate equipment to do useful work. Some configurations couple the turbo-expander to a compressor, with the generated work used for the compression of the gas in the process. Sometimes, the turbo-expander and compressor are packaged in a single unit on a single shaft.

A turbo-expander can generate low temperature gas far more efficiently than options such as a “Joule-Thomson” (JT) valve or others in many refrigeration, cryogenic and low temperature gas services. Given a certain pressure reduction, the almost isentropic expansion in a

Many turbo-expanders use active magnetic bearings because traditional oil bearings usually won’t suffice.

turbo-expander allows for a lower temperature of the expanded gas than an isenthalpic expansion by means of a throttling valve or other devices. Indeed, the application of a cold gas turbo-expander instead of low efficiency, traditional methods (such as a JT valve) can significantly improve the cooling capacity, performance, efficiency and operational costs of such a processing plant. The lower temperature considerably increases the overall cold gas or refrigeration cycle efficiency. In addition, the turbo-expander generates useful work.

The casing material for turbo-expanders for cold gas and cryogenic applications typically is a stainless steel; special alloys sometimes are chosen. Many such turbo-expanders use active magnetic bearings (AMBs) because traditional oil bearings usually won’t suffice. Modern canned-type magnetic bearings are popular. These high performance bearings suit aggressive, sour or difficult gases typically not tolerated by traditional magnetic bearings and electrical devices. They encapsulate traditional electrical components of the AMB within a metal can made of an advanced material (such as a high nickel alloy) that prevents any contact with the gas.

CHALLENGES FROM NON-IDEALITY

In many applications, turbo-expanders operate, at least partly, in the dense gas thermodynamic region where the ideal gas law poorly approximates true thermodynamic behavior. Therefore, assuming an ideal gas can lead to inaccurate predictions of the flow structure and performance parameters of these turbo-expanders. Unfortunately, for some gases, accurate thermodynamic and fluid-dynamic behaviors may not be readily available for the intended operating range. Yet, improving dense gas turbo-expander performance through fluid dynamics depends upon properly taking into account the non-ideal thermodynamic behaviors of the operating fluid. This demands a good understanding of how the fluid dynamics deviate from ideal gas behavior as well as of the capabilities and limitations of the available thermodynamic models for each specific fluid and application. Expansions in the dense gas region often involve subcritical and supercritical inflow conditions, representing cases of moderate to high thermodynamic non-ideality. Some turbo-expanders require practical simulations of real gas flow through more complex three-dimensional geometries.

A COLD GAS TURBO-EXPANDER

Let's look at a case study for the application of a cold gas turbo-expander in a gas recovery process. The inlet gas is a mixture of different gases destined for a cryogenic separation/recovery process. In that process, the inlet gas first is cooled to about -50°C in a heat exchanger (cold box); this partially condenses the gas. The resultant gas/liquid mixture then is separated into a liquid stream and a gas stream. The liquid stream from the separator flows through a valve and undergoes a throttling expansion from about 63 Barg to around 22 Barg, which is an isenthalpic (constant enthalpy) process that results in lowering the temperature of the stream from about -50°C to about -80°C as it enters the separation/recovery tower. The gas stream from the separator goes into the turbo-expander where it undergoes an isentropic expansion from around 63 Barg to about 22 Barg that lowers its temperature from about -50°C to about -90°C as it enters the recovery tower to serve as distillation reflux.

Liquid (at about -90 °C) from the top tray of the recovery tower goes through the cold box where it is warmed to about 0°C as it cools the inlet gas; it then returns to the lower section of the recovery tower. Another liquid stream (at about 2°C) from the lower section of the recovery tower goes through the cold box and returns to the recovery tower at about 12°C. In effect, the inlet gas provides the heat required to re-boil the bottom of the recovery tower and the turbo-expander cools the gas flow (removes the heat as useful work) to provide reflux in the top of the tower.

The overhead gas (at about -90°C) from the recovery tower is a pure gas suitable for the downstream process. This gas passes through the cold box where it is warmed as it cools the inlet gas. It then is compressed in a gas compressor driven by the turbo-expander and further compressed in a second-stage gas compressor powered by an electric motor. The bottom product from the tower also is warmed in the cold box, as it cools the inlet gas, before leaving the system as a marketable byproduct. ●

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FOLLOW A LEADER

Improve Efficiency with Direct Steam Injection

Technology offers notable cost savings for high-pressure applications

By Tony Pallone, Pick Heaters, Inc.

The most common method of transferring energy with steam is indirect heat exchange, which is used in familiar applications including process, plant sanitation and reactor vessels. Condensing the steam releases latent heat, and a membrane, such as a tube or plate, transfers that heat into a fluid. The process generates a byproduct condensate that is discharged through a trap and returned to its source, typically a boiler, where it continues to produce steam.

This tried-and-true method, however, has a drawback. Because of the pressure drop as the condensate exits the trap, some portion inevitably is lost to flash evaporation. To keep the system functional, cold replacement water must be added. As the condensate is lost, system efficiency is impacted. The level of impact varies in accordance with the steam supply's pressure — the higher the pressure, the less efficient the system (Figure 1).

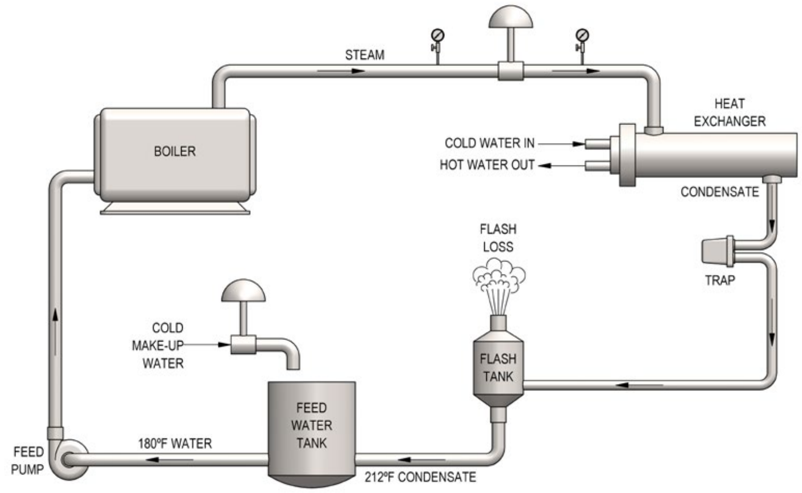
Yet an alternative method exists that is ideal for high-pressure systems: direct steam injection (DSI). Here, the steam is not held within a membrane to keep it separate from the process fluid but rather is blended directly into it. The need to recover condensate is thereby eliminated, and, instead of being lost to flashing, it is used fully. As a result, the system achieves 100% heat transfer efficiency.

DSI'S ADVANTAGES

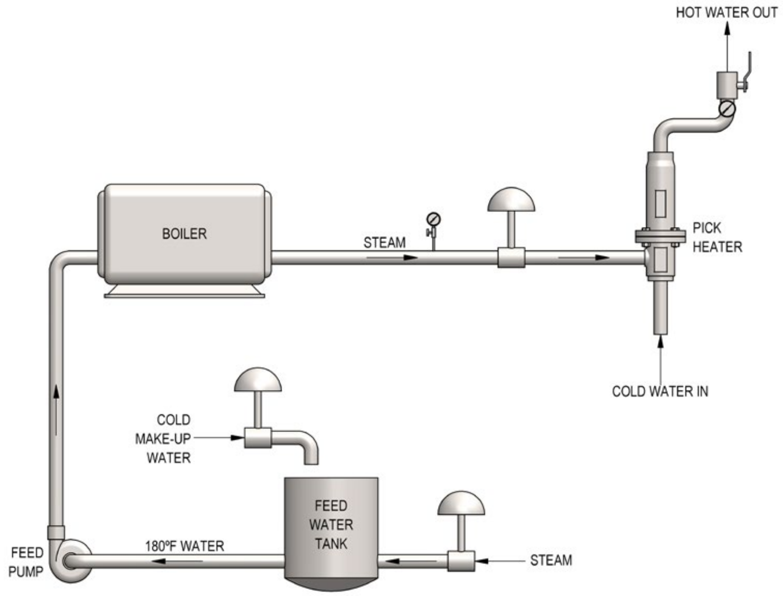
The DSI approach offers several advantages — chief among them is cost savings. The boiler used in a DSI system is fed by the same cold replacement water used in indirect heat exchangers and requires greater heat input to convert this water to steam.

However, this is more than offset by reduced steam demand at the use point, yielding a net reduction in fuel consumption and cost savings for the end user. A DSI system can save up to 28% of the fuel required for indirect heat exchangers.

DSI also offers more precise temperature control because of its rapid-response adaptation to load changes. Condensate is not recovered, eliminating the need for a flash tank or condensate return system (Figure 2). Finally, surface area is not required to effect heat transfer, making for a more compact device that is easier both to house and to maintain.



CONDENSATE LOSS
Figure 1. In indirect heat exchange, a portion of the condensate is lost due to flashing and must be replaced with cold water. Flash losses vary with steam supply pressure. *Source: Pick Heaters Inc.*



DIRECT STEAM INJECTION
Figure 2. With direct steam injection, steam is completely consumed and no condensate is returned. Flash losses are eliminated. *Source: Pick Heaters Inc.*

INDUSTRIAL APPLICATIONS

DSI systems are well-suited to a variety of industrial applications that can benefit from a steady supply of on-demand, precisely controlled hot water. One system option is a constant flow heater, which serves the cross-industry trend of shifting from steam to hot water for jacketed heating, eliminating the potential for hot spots, burn-on and thermal shock. A variable flow heater allows for frequent start-stop applications, making it a natural fit for plant sanitation and clean up.

The food and beverage industry also has employed DSI systems for in-line product cooking, clean-in-place (CIP) heating and nitrogen gas injection. A sanitary jet cooker can heat, cook or sterilize water and slurry-type food products on a continuous, straight-through basis. Some models feature low-velocity mixing and a nonshearing design to handle small food pieces without damage.

In the chemical processing industry, DSI supports automated systems with precise temperature control that ensures optimal effectiveness of jacketed reactors and eliminates the potential for destruction and waste of heat-sensitive products. Other applications include charging reactor vessels, tank cleaning and clean-in-place (CIP) and smooth blending of condensate streams.

Additional industries that have realized efficiency improvements by deploying DSI include pulp and paper, energy and power and pharmaceutical.

THINKING BEYOND THE TRADITIONAL

The biggest obstacle to wider DSI deployment is insufficient understanding of the technology. Process engineers long have been focused on strategies to minimize the condensate lost in indirect heat exchange systems. DSI removes condensate from the equation in a way that may seem too good to be true. To help determine if a DSI system is right for your application, a DSI vendor should provide data and case studies to back up efficiency and cost-savings claims, and conduct a customized energy comparison study.

Although DSI is inappropriate for a few applications — low-pressure systems, for instance, or systems processing liquids that must be kept separate from steam — the technology represents a giant leap forward for a range of industry needs. ●

TONY PALLONE is a writer for Pick Heaters, Inc. For more information visit www.pickheaters.com.

Optimize Steam Generation and Condensate Recovery Process

Proper level control and protective measures can increase your return on investment

By Donald Hite, Magnetrol International, Inc.

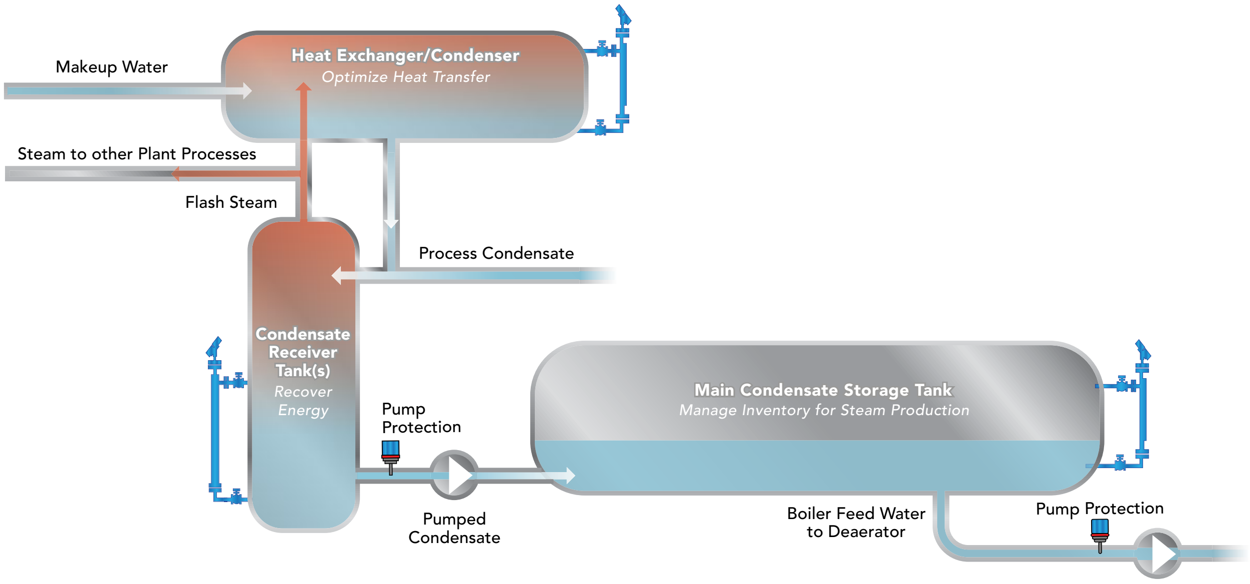
The petroleum refining, chemical process, primary metals and food processing industries allocate significant portions of their total energy consumption, anywhere from 10–60%, to steam production.

As a consequence, any level technology's performance relative to instrument-induced errors, calibration nuances and vulnerabilities to process dynamics can have an immediate and adverse impact on fuel consumption. This also contributes negatively to other aspects of the process, be they makeup water requirements or energy transfer.

In turn, these other aspects contribute indirectly to inefficient fuel use and hinder production throughput and product quality. Adding to this burden is the potential for damage to expensive hardware resulting in forced outages, unscheduled and costly maintenance and production downtime.

It is not an uncommon practice to use waste heat or condensate recovery systems to reduce energy losses and capture valuable condensate. The use of instrumentation technology that cannot adequately or reliably address the control aspects of these processes can inhibit system effectiveness and overall return-on-investment and expose hardware to unnecessary damage.

An overview of the processes involved, along with the unique instrumentation requirements for each component, offers



BASIC STEAM GENERATION CYCLE
Figure 1. This cycle offers plenty of opportunities to improve level control for better efficiency, reliability and maintenance.

insight into the significance of maintaining proper level control and protective measures to realize potential savings in the steam generation, waste heat and condensate recovery systems common in heavy industry.

STEAM GENERATION

Steam generation and condensate recovery systems can vary in complexity depending on the steam end usage and process requirements, e.g., steam to support a paper mill operation versus that for a small to mid-size specialty chemical process operation. Figure 1 is a simplified diagram depicting a basic steam generation cycle, scalable to almost any plant requirement, whether incorporating a fire tube or larger water tube type of boiler. It highlights critical areas in the cycle where addressing level control concerns can have a profound impact on efficiency, reliability and maintenance.

BOILER/STEAM DRUM

At the heart of the system is the boiler and, more specifically, the steam drum. Regardless of its size, its primary and peripheral functions are as follows:

- Provides ample surface area for efficient water and steam separation
- Provides storage capacity to meet immediate boiler feed water requirements
- Facilitates the introduction of chemicals for treatment purposes as well as impurity removal (blowdown)

A boiler — either fire or water tube — presents a dynamic environment with respect to level control regardless of the control strategy — single, two or three element. The common denominator in each of these control strategies is the level measurement itself.

Applying a technology that improves level measurement will help maintain the boiler/steamer drum's normal water level (NWL), so the drum can better serve its primary function of separating water and steam for improved steam quality. This becomes more important when fluctuations in demand have dramatic effects on an instrument's performance during "shrink" and "swell" conditions resulting from pressure changes in the boiler/ steam drum.

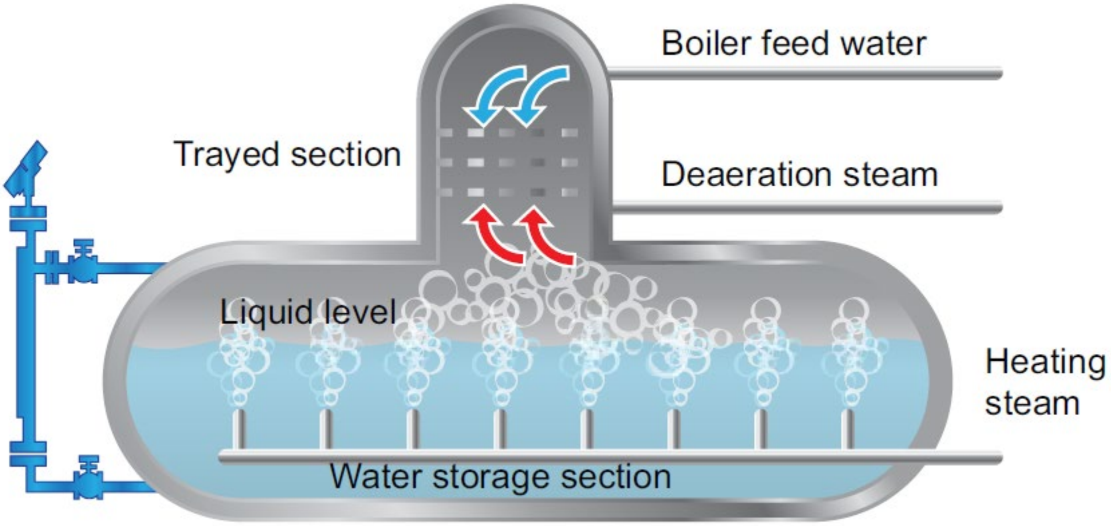
Level technologies historically used on boilers rely on inference or buoyancy to determine the level. This leaves them vulnerable to process dynamics (specific gravity, pressure, temperature, etc.) or limits their ability to manage the level precisely for improved fuel economy.

Although corrections can mitigate the effects, the variables that need to be accounted for increase the level control's installation, hardware and calibration complexity. This has the unintended consequence of introducing new avenues for error. Eliminating potential sources of error (including human) related to an instrument's fundamental technology is the first step in optimizing boiler/steam drum level control.

Key Benefits of Guided Wave Radar for Boiler/Steam Drum Level

- Three-element control strategy: feedwater flow, main steam flow and boilser/steam drum level — actual versus inferred level. Continuous versus discrete indication.
- No calibration or external compensation: data certainty when implementing control strategy during normal operations and "shrink and swell" conditions. Prevents carryover conditions.
- Maintaining NWL in all process conditions improves steam/water separation and overall steam quality.
- Eliminates waste energy due to excessive blowdown to manage level.
- Responsive to changes in demand.
- Steam specific process isolation seal for corrosive high temperature/high pressure applications.
- Probes with condensation control technology (CCT) and automatic steam compensaton (ASC).
- Lower maintenance costs.

In comparison to traditional technologies, guided wave radar (GWR) is a continuous measurement technology that is not vulnerable to changes in process conditions. Because its performance and accuracy are not contingent on the specific gravity or inference, GWR excels in measuring the actual liquid level in all conditions encountered in the boiler/steam drum.



DEAERATOR
Figure 2. This "open" type heat exchanger removes oxygen and other corrosive gases from the boiler feed water to prevent damage to system hardware. Steam supports the deaeration process and preheats the boiler feed water.

Furthermore, GWR does not require external inputs or calibration to achieve specified performance. This effectively eliminates error introduction during the calibration process or from external sources, i.e., pressure and temperature. Reducing the number of variables affecting the measurement provides a high degree of data certainty, allowing operators to maintain the NWL better in the boiler/steam drum for optimal water/steam separation and steam quality throughout a variety of process conditions.

DEAERATORS AND HEAT EXCHANGERS

Another often overlooked level application is the deaerator and its accompanying storage vessel. The deaerator serves as an "open" type heat exchanger whose primary function is to remove oxygen and other corrosive gases from the boiler feed water to prevent damage to system hardware. This is accomplished using steam, which can give up about 970 Btu/lb, to support the deaeration process as well as preheat boiler feed water (Figure 2).

Of course, any appreciable gain in boiler feed water achieved through the process reduces the amount of energy (fuel) required at the boiler — every 10.8°F (6°C) rise in boiler feed water amounts to a 1% savings in fuel cost. Inadequate level controls can inhibit the deaeration process (level too high) or reduce or shut down feed water flow to the boiler (level too low).

A shell and tube heat exchanger's effectiveness in transferring energy is contingent on accurate level control.

The former affects hardware longevity and efficiency while the latter risks production losses and possible pump damage.

In addition to the deaerator, the more common shell and tube heat exchangers/condensers can be found in larger-scale steam generation cycles where their costs are offset by gains in thermal efficiency. A shell and tube heat exchanger's effectiveness in transferring energy is contingent, barring hardware anomalies, on accurate level control.

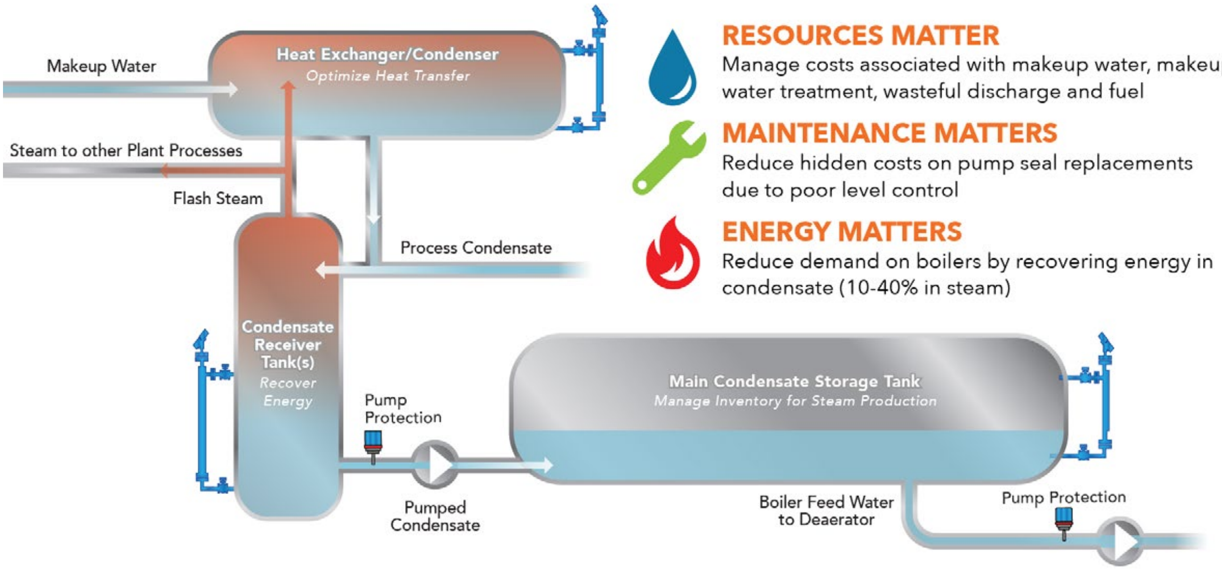
The same attributes making GWR technology uniquely suited for a boiler/steam drum application also can be leveraged on the deaerator to provide improvements in thermal efficiency.

BLOWDOWN FLASH AND BLOWDOWN TANKS

Maintaining water quality in the boiler within design parameters ensures the highest quality steam possible while minimizing blowdown of the boiler, both of which improve energy and resource management. Continuous or manual blowdown of the boiler minimizes scale accumulation and corrosion resulting from impurities in the water. The blowdown and blowdown flash tanks accommodate liquid and impurities from the boiler, with the latter facilitating energy recovery through the flash steam.

It's estimated that up to 49% of the energy can be recovered through the flash steam routed to heat exchangers or the deaerator to preheat boiler makeup water or support the deaeration process, respectively. Additionally, better level control technology at the boiler side eliminates energy losses from unnecessary blowdown to prevent carryover conditions.

Taking advantage of a technology's ability to address the level in either of these vessels, especially the blowdown flash tank, in a plug-and-play type of installation and commissioning format (foregoing calibration, external hardware or inputs) is an easy way to ensure optimal performance.



RESOURCES MATTER
Manage costs associated with makeup water, makeup water treatment, wasteful discharge and fuel

MAINTENANCE MATTERS
Reduce hidden costs on pump seal replacements due to poor level control

ENERGY MATTERS
Reduce demand on boilers by recovering energy in condensate (10-40% in steam)

CONDENSATE RECOVERY SYSTEM

Figure 3. Such systems help control resources and associated costs, protect equipment and minimize maintenance, and reduce energy.

Optimizing boiler, deaerator, heat exchanger/condenser and blowdown usage relative to level control primarily affects fuel economy by better managing the amount of energy required to produce high-quality steam for any given task. Seamless response to changes in demand and reducing maintenance associated with the instrumentation or damage to hardware are residual benefits that have their own financial ramifications; hence, they also should be considered when implementing any technology. The return-on-investment time frame can vary depending on the scale of the operation as well as the time spent maintaining aging instrumentation.

CONDENSATE RECOVERY

The benefits of any condensate recovery system (Figure 3) are well-documented in industries relying on steam generation for their processes. Condensate has real value in that every gallon recovered spares the cost of additional makeup water, makeup water treatment and wasteful discharge to municipal systems. Often it is the instrumentation, or lack thereof, that limits overall system performance, causing the recovery process to fall short of financial expectations.

Three areas of particular interest relative to efficiency when it comes to level controls are the condensate receiver and main condensate tanks, condensate pumps and

ELIMINATING HIDDEN MAINTENANCE COSTS

Condensate Recovery Process Level

- Protect valves & pump seals from exposure to high temperature steam
- Maintain minimum head pressure on condensate pump
- Ensure sufficient headspace for flash steam creation
- Allow capacity to accommodate condensate from various process groups
- Manage boiler feed water supply chain to meet demand

GWR/MLI Technology Benefits

- Redundant and diverse level technologies
- Unaffected by process conditions
- No calibration required
- No moving parts – eliminates instrument induced errors (GWR)
- Setup wizard and full diagnostics – fast startup and fault isolation
- Designed for high temperature steam applications
- Simplifies instrumentation hardware
- Can be pre-configured for the application

Case Study

- Pump Seal - $1,000.00
- Labor - two person for ½ day $35.00/hr equals $280.00
- Discharged condensate $3.65/1000 gallons
- Condensate receiver out-of-service for maintenance $$$
- 1 to 3 pump seal replacements per week reduced to 1 to 3 per year: “Pulp & Paper Plant”
- Maintenance cost of poor level control: $244K+ annually

associated valves, and any shell and tube heat exchangers/condensers.

The condensate receiver tanks accept blow-through steam and condensate from various steam process groups throughout a plant. Condensate later is pumped to the main condensate tank where it is stored, pending reintroduction into the steam generation cycle.

The shell and tube heat exchanger/condenser recovers waste energy from the receiver tank as flash steam, so it can preheat makeup water or other process fluids through the heat of condensation. The resulting condensate drains back to the condensate receiver tank.

The condensate receiver tank’s level transmitter facilitates the automatic management of the condensate level to ensure adequate capacity is available to accommodate (recover) condensate from various plant processes as well as maintaining sufficient headspace in the vessel for flash steam creation.

Aside from being a critical asset for the plant, the condensate in the condensate receiver tank also protects valves and condensate pump seals from direct exposure to high-temperature steam while maintaining a minimum head pressure on the pump. This prevents hardware damage, expensive maintenance and receiver tank downtime and subsequent ripple effects on the steam generation cycle and makeup water requirements.

Last, the level transmitter provides the control signals for the valves and condensate pump necessary to transfer condensate from the receiver to the main condensate tank, ensuring approximately 15% level retention for the aforementioned reasons. At this point, the main condensate tank level transmitters take over to manage boiler feed water supply to service steam generation demand.

SUMMARY

It is rare to identify a single source of inefficiency related to poor level controls that impacts a company's bottom line in the double-digit percentile. Instead, small, incremental opportunities for improvement often are available across various aspects of the steam generation cycle, condensate recovery system and waste heat recovery process that ultimately equate to substantial savings:

- Improved boiler/steam drum control — energy savings and steam quality.
- Reduced fuel consumption — waste heat recovery.
- Hardware protection and maintenance — pumps and pump seals.
- Reduced water consumption, treatment, discharge and inventory management.

The hidden maintenance costs and inefficiencies associated with a technology's vulnerabilities often are overshadowed by the day-to-day operation of these processes. Regardless of an operation's scale, leveraging the inherent attributes of an instrument's fundamental technology in both the short term (engineering, upfront cost, installation and commissioning) and long term (maintenance, day-to-day practicality and energy management) present simple and cost-effective approaches to maximizing the system's return-on-investment. ●

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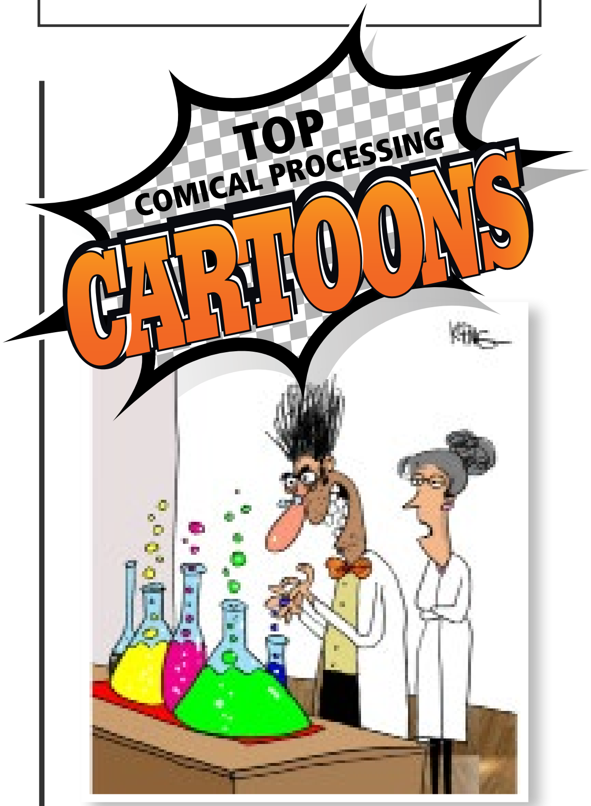

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