# Improve the Performance of Your Boiler System

**Daniel Skiles**
Cleaver Brooks —
Engineered Boiler Systems Group

A condensing economizer, a blowdown heat-recovery unit, or a glycol air heater can increase a boiler system's overall efficiency by recovering heat from the hot fluegas or blowdown water.

Chemical process industries (CPI) plants continually strive to increase efficiency and reduce expenses. Depending on the facility, the boiler system can account for a large portion of the plant's utility costs. Improvement efforts, therefore, often focus on minimizing boiler fuel consumption and electric power usage.

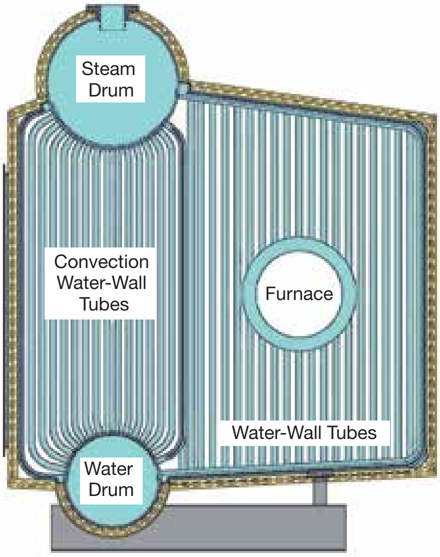
This article examines several options for increasing the efficiency of an industrial boiler system. The boilers discussed are D-type watertube boilers — the most common design for small and medium boilers. A D-type boiler consists of two drums in a vertical configuration with a convection bank of tubes between the drums and a furnace next to the convection section. It gets its name from the shape of the layout — the drum arrangement and the outside furnace tube wall form the letter D, as shown in Figure 1.

A small boiler system (saturated steam capacities up to 90,000 lb/hr and operating pressures to 400–500 psig) normally includes the boiler pressure vessel, an industrial burner with a forced-draft (FD) fan, an economizer, and basic instrumentation and controls. This type of boiler is typical of processes that require low-pressure saturated steam, such as those in most petrochemical and polymer plants.

Several options are available for improving the overall efficiency of a small boiler without adding significant complexity to the system. Here we explore two that improve the overall thermal efficiency by preheating the make-up water upstream of the deaerator — condensing economizers, and blowdown heat-recovery (BDHR) systems.

Manufacturing processes that use high-pressure steam, such as ammonia and methanol plants, and steam turbines that generate power within the plant require larger (and more complex) boiler systems (up to 200,000 lb/hr or more and operating pressures up to 1,500 psig). Due to their high capacities and higher pressures, these boilers often employ two burners, redundant instrumentation for safety, and redundant control systems.

Large packaged boilers generally do not use condensing economizers or BDHR systems because their operating pressures can far exceed the typical BDHR



▲ **Figure 1.** The D-type watertube boiler gets its name from the shape of its layout.

Copyright © 2014 American Institute of Chemical Engineers (AIChE)

design pressure, and the smaller quantities of make-up water used at these high pressures make a condensing economizer impractical. Many larger packaged boilers can use glycol as a heat-transfer fluid to recover heat from the boiler fluegas and transfer it to the fresh combustion air being fed to the burner. This approach provides two benefits — it lowers the stack temperature, and it heats the combustion air, thereby reducing fuel requirements.

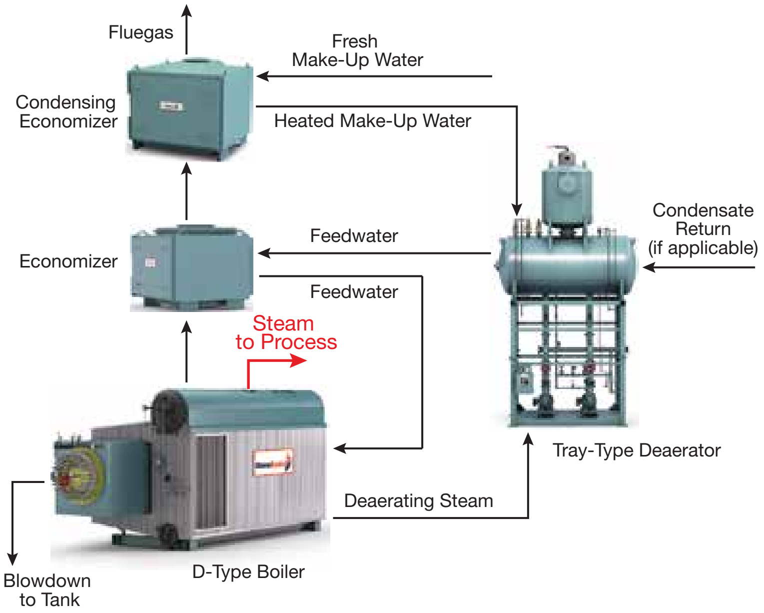
## Condensing economizers

A condensing economizer is a secondary loop, located in the boiler fluegas path immediately downstream of the primary economizer (Figure 2), that exchanges heat between the boiler fluegas and the cold make-up water that is fed to the deaerator upstream of the boiler. Because the deaerator uses less steam to heat the boiler feedwater, the overall system sees a gain in efficiency.

For new equipment installations, this secondary loop can be integrated into the same casing/frame as the primary economizer tube bundle. At facilities where the boiler and economizer have already been installed, this bundle can easily be designed to mate to the existing economizer outlet within its own casing so that modifications to the existing equipment can be minimized.

The design of a condensing economizer is similar to that of the primary boiler feedwater economizer — a rectangular finned-tube layout, main feedwater headers within the casing, and single inlet and outlet connections for simple installation in the field. The tubes typically have welded return bends and header connections to minimize the chance of leaks during operation. The main difference between a standard economizer and a condensing economizer is the tube material. Boiler feedwater economizers can have tubes made of carbon steel (typically electric-resistance welded [ERW] SA-178-A carbon steel or a seamless tubular carbon steel such as SA-192). Condensing economizers require tubes made of stainless steel (Type 316 is commonly used) to prevent cold-end corrosion due to condensation collecting on the tubes.

Let's look at how installing a condensing economizer can increase the overall efficiency of a small packaged boiler. The system is a



▲ **Figure 2.** A condensing economizer recovers heat from the fluegas and uses it to heat the cold make-up water.

**Table 1. A condensing economizer improves the 50,000-lb/hr boiler's efficiency by 4.5 percentage points.**

| Performance Parameter | With Standard Economizer | With Condensing Economizer |
|---|---|---|
| Boiler Load | 100% | 100% |
| Steam Flow, lb/hr | 50,000 | 50,000 |
| Steam Operating Pressure, psig | 150.0 | 150.0 |
| Fuel Input (Higher Heating Value [HHV]), MMBtu/hr | 60.0 | 60.0 |
| Steam Output Duty, MMBtu/hr | 50.2 | 50.2 |
| Make-Up Water, % | 80 | 80 |
| Condensing Economizer Feedwater Inlet Temperature, °F | – | 65 |
| Condensing Economizer Feedwater Exit Temperature (to Deaerator), °F ±10°F | – | 133 |
| Economizer Feedwater Inlet Temperature, °F | 228 | 228 |
| Economizer Feedwater Exit Temperature, °F ±10°F | 308 | 308 |
| Economizer Fluegas Exit Temperature, °F ±10°F | 304 | 300 |
| Condensing Economizer Fluegas Exit Temperature, °F ±10°F | – | 131 |
| Fluegas to Condensing Economizer, lb/hr | 53,191 | 53,191 |
| Heat Regained by Condensing Economizer, MMBtu/hr | – | 2.6 |
| Efficiency (Based on HHV) | 83.5% | 88.0% |

Copyright © 2014 American Institute of Chemical Engineers (AIChE)

50,000-lb/hr boiler firing natural gas, operating at 150 psig, with a feedwater temperature of 228°F at the outlet of the deaerator, and a target fluegas temperature (at the economizer exit) of 300–305°F at 100% load. A condensing economizer can lower the fluegas temperature down to the dewpoint of water, which for a typical application with a moisture content of 17–18% is in the range of 130–140°F.

Table 1 summarizes the performance of the system. The condensing economizer reduces the fluegas temperature from 300°F to 131°F, in turn increasing the temperature of the make-up water going to the deaerator from 65°F to 133°F. The 2.6 MMBtu/hr of heat recovered from the fluegas reduces the amount of steam required by the deaerator. The bottom line: Adding a condensing economizer increases the overall efficiency of the system from 83.5% to 88.0%.

The major design parameters for this equipment, which determine the efficiency gain that can be achieved, are the amount of make-up water required by the system and the amount of heat available in the boiler fluegas.

Where steam is used for heating or power generation, most of the steam generated by the boiler is recycled back to the deaerator in the form of returned condensate. A closed system such as this requires a very small amount of make-up water, so a condensing economizer would not provide much benefit. Rather, this type of heat recovery is more appropriate for applications where the steam from the boiler is either absorbed by the process or removed from the system as wastewater. Typically, a make-up water flow of 50–100% of the total feedwater flow to the boiler is needed for a condensing economizer to be economical.

The other important variable is the amount of heat available in the fluegas. The temperature of the fluegas exiting the feedwater economizer is typically around 300°F, and the condensing economizer reduces this to approximately 130°F. The quantity of fluegas depends on project-specific conditions such as steam capacity, operating pressure, and emissions limits, which dictate the excess air and fluegas recirculation rates.

These two variables must be evaluated for each application to determine whether a condensing economizer will provide a beneficial increase in efficiency.

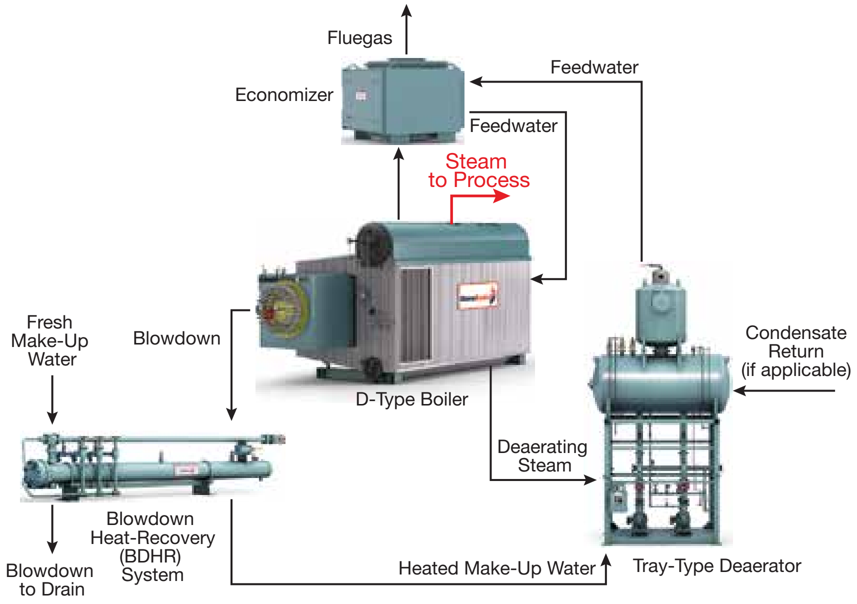
## Blowdown heat-recovery systems

A BDHR unit is similar to a condensing economizer in that it also preheats the make-up water being delivered to the deaerator, which increases the overall efficiency of the boiler system by reducing the amount of steam required by the deaerator to heat the boiler feedwater. The difference between these two pieces of equipment is the heating medium: The condensing economizer uses the boiler fluegas to heat the water, whereas a BDHR system uses the boiler's continuous blowdown water.

The continuous blowdown is a fixed amount of water that is removed from the boiler's steam drum to prevent the buildup of particulates, which can accumulate due to the continuous conversion of water to steam within the vessel. The flowrate of continuous blowdown is typically about 2–3% of the boiler steam capacity. This water is taken directly from the steam drum and has already been heated from the inlet feedwater temperature to the saturation temperature of the boiler. The BDHR system provides a way to recover this heat from the blowdown stream. The alternative — a blowdown tank with an aftercooler to lower the water temperature — would send most of this energy, literally, down the drain with the discharged water.

The BDHR system is usually located immediately downstream of the boiler. Installing it just upstream of the blowdown drain, as shown in Figure 3, minimizes the extent of piping modifications required.

A BDHR system is a basic shell-and-tube heat exchanger. The shell-and-tube design is ideal for this type of duty, as it allows for many tubeside passes, which ensures maximum heat transfer. It also maintains high fluid velocities, which reduces scaling and fouling by the particulates



▲ **Figure 3.** A BDHR system captures the energy in the blowdown stream and uses it to heat the fresh make-up water.

Copyright © 2014 American Institute of Chemical Engineers (AIChE)

**Table 2. A blowdown heat-recovery system reduces the small boiler's fuel consumption by 500,000 Btu/hr.**

| Performance Parameter | Without BDHR | With BDHR |
|---|---|---|
| Boiler Load | 100% | 100% |
| Steam Flow, lb/hr | 50,000 | 50,000 |
| Steam Operating Pressure, psig | 150.0 | 150.0 |
| Fuel Input (Higher Heating Value [HHV]), MMBtu/hr | 70.2 | 69.5 |
| Steam Output Duty, MMBtu/hr | 58.7 | 58.1 |
| Deaerator Pegging Steam Used, lb/hr | 8,469 | 7,897 |
| Make-Up Water, % | 80 | 80 |
| Make-Up Water Inlet Temperature, °F | 65 | 65 |
| BDHR Feedwater Exit Temperature (to Deaerator), °F ±10°F | — | 76 |
| BDHR Blowdown Water Inlet Temperature, °F | — | 373 |
| BDHR Blowdown Water Exit Temperature, °F | — | 90 |
| Economizer Feedwater Inlet Temperature, °F | 228 | 228 |
| Economizer Feedwater Exit Temperature, °F ±10°F | 307 | 307 |
| Economizer Fluegas Exit Temperature, °F ±10°F | 303 | 304 |
| Fluegas to Stack, lb/hr | 62,249 | 61,628 |
| Heat Regained by BDHR, MMBtu/hr | — | 0.50 |

in the blowdown water. Due to the abrasive nature of the blowdown, the tubes are typically fabricated from stainless steel and include excess thickness as a corrosion allowance. An important point to note is that these systems are typically designed for operating pressures up to only 300 psig.

Consider again the 50,000-lb/hr boiler discussed earlier, operating under the same conditions. Like the condensing economizer, the BDHR unit preheats the fresh make-up water sent to the deaerator. The blowdown water being used as the heating medium has an operating temperature of 373°F and a flowrate of 1,500 lb/hr (which is 3% of the boiler steam capacity).

Table 2 compares the performance of the boiler system with and without the BDHR. The BDHR increases the overall efficiency by increasing the temperature of the make-up water from 65°F to 76°F. Like the condensing economizer, it allows the deaerator to use less steam (in this case, 572 lb/hr less), which lowers the energy requirement and reduces fuel consumption from 70.2 MMBtu/hr to 69.5 MM Btu/hr.

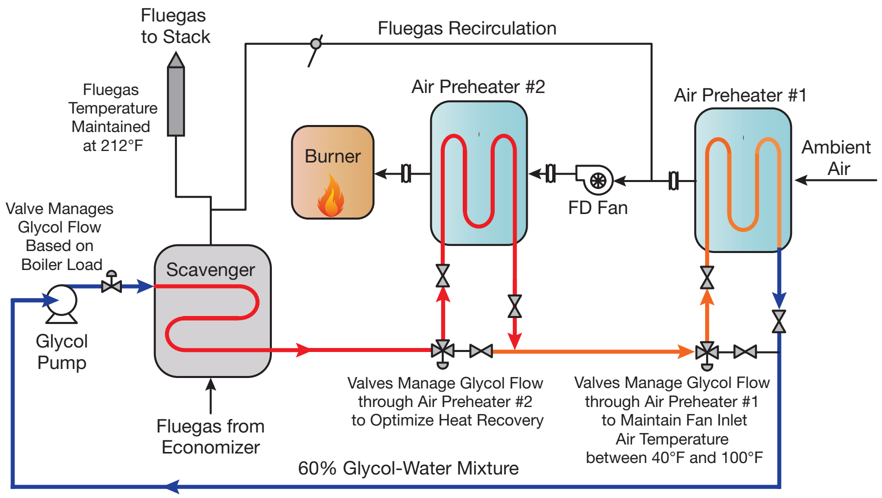
The main constraints on the design of a BDHR system are also the amount of make-up water required by the system and the amount of blowdown water available, which are directly related to the steam capacity of the boiler. The amount of make-up water required determines how much heat can be recaptured from the blowdown. A BDHR is best suited for boiler systems that require a large amount of make-up water and have high blowdown rates. It is less effective for systems that have small make-up water requirements and those with large make-up water requirements and low blowdown rates.

## Glycol scavenging systems

A glycol scavenging system (so named because the glycol "scavenges" for waste heat) is a combustion-air preheater that uses glycol as a heat-transfer fluid to exchange heat between the fluegas and the incoming combustion air. Such a system can be designed in one of two ways.

Some facilities employ a plant-wide glycol system for heat transfer throughout the site. At these plants, air preheaters can be added as an additional heat sink for the glycol system while they heat the combustion air. This is the simplest design.

If the facility does not have an existing glycol system for heat transfer, one must be provided as a closed-loop unit local to the boiler. Such a system (Figure 4) consists of a glycol scavenger to transfer the heat from the fluegas to the glycol, a glycol pump skid to provide circulation, and an inlet air preheater to transfer the heat



▶ **Figure 4.** In a glycol scavenging system, the fluegas heats the glycol heat-transfer fluid, which in turn heats the incoming combustion air.

Copyright © 2014 American Institute of Chemical Engineers (AIChE)

from the glycol to the combustion air.

The economizer fluegas exit temperature for a larger packaged boiler (like that for the smaller packaged boiler) is in the range of 300–305°F. The glycol heat-transfer fluid can absorb enough heat to lower the fluegas temperature to 215°F (which is even lower than the feedwater inlet temperature to the boiler system). The hot glycol is sent to a dual-inlet air preheater system. The first preheater heats the cold ambient air and maintains it at a minimum temperature of 50°F. This is done so that during the cold winter months, condensation does not form inside the forced-draft fan when the cold ambient air (<50°F) is mixed with the recirculating fluegas (≈300°F). The second air preheater is located downstream of the fan; otherwise, the heated, expanded air would require a larger, higher-horsepower fan. This second air preheater can heat the combustion air to above 140°F, which reduces the fuel consumption of the burner.

Table 3. A glycol scavenging system improves the large boiler's efficiency by about 2 percentage points.

| Performance Parameters | Without Glycol Heaters | With Glycol Heaters |
|---|---|---|
| Boiler Load | 100% | 100% |
| Steam Flow, lb/hr | 355,000 | 355,000 |
| Steam Operating Pressure, psig | 550 | 550 |
| Fuel Input (HHV), MMBtu/hr | 430.5 | 420.4 |
| Steam Output Duty, °F ±10°F | 360 | 360 |
| Economizer Feedwater Inlet Temperature, °F ±10°F | 228 | 228 |
| Economizer Feedwater Exit Temperature, °F ±10°F | 384 | 386 |
| Boiler Gas Exit Temperature, °F ±10°F | 781 | 781 |
| Economizer Gas Exit Temperature, °F ±10°F | 303 | 304 |
| Glycol Scavenger | | |
| Fluegas Exit Temperature, °F ±10°F | — | 212 |
| Glycol Flow, lb/hr | — | 150,000 |
| Glycol Inlet Temperature, °F ±10°F | — | 165 |
| Glycol Outlet Temperature, °F ±10°F | — | 240 |
| Air Preheater #1 at Fan Inlet | | |
| Inlet Air temperature, °F ±10°F | — | 50 |
| Outlet Air Temperature, °F ±10°F | — | 105 |
| Glycol Flow, lb/hr | — | 38,850 |
| Air Preheater #2 at Fan Outlet | | |
| Inlet Air temperature, °F ±10°F | — | 105 |
| Outlet Air Temperature, °F ±10°F | — | 156 |
| Glycol Flow, lb/hr | — | 150,000 |
| Fluegas to Stack, lb/hr | 380,885 | 379,254 |
| Fuel Flow, lb/hr | 18,954 | 18,504 |
| Efficiency (Based on HHV) | 83.5% | 85.6% |

Table 3 summarizes the performance data for a large packaged boiler with and without a glycol scavenger. The glycol scavenging system provides an efficiency gain of 2.1% (from 83.5% to 85.6%) and reduces the boiler's fuel consumption by 450 lb/hr. Because a boiler such as this can operate full time for most of the year, this reduction in fuel consumption can provide a significant savings over the full life of the boiler.

Several limitations to this type of system should be considered before a glycol scavenger and air preheaters are added to a packaged boiler. A glycol air-heating unit can be used with any boiler system that includes a floor- or grade-mounted forced-draft fan (typically larger than 200 hp). Because smaller packaged boilers use smaller (usually <200 hp) windbox-mounted fans, adding a glycol system would require significant modification to the fan design and inlet ducting to the burner.

Another limitation is that during the cold winter months in some areas, the glycol circulation flowrate must be reduced through the pumps in order to maintain an outlet fluegas temperature above the water dewpoint. This is done to avoid cold-end corrosion in the outlet ducting and stack due to condensation.

## In closing

Multiple solutions are available to increase the efficiency and reduce the operating costs of an industrial boiler. The best solution for any packaged boiler depends on the size of the boiler and the scope of the process it is part of. Selecting the right option for any given application involves evaluating the current (or future) system to determine what resources have been incorporated into the facility and are available, and evaluating how those can be utilized to increase the efficiency of your application. Although every application is unique and the details vary depending on the specific project conditions, the estimates provided here give a reasonable indication of the potential savings that can be achieved.

**DANIEL SKILES** is an application engineer at Cleaver Brooks — Engineered Boiler Systems Group (Lincoln, NE; Phone: (402) 323-6350; Email: dskiles@cleaverbrooks.com). He currently works in the Sales Dept., where new project requests for quotations are reviewed and the boiler systems are initially designed. He received his BS in chemical engineering from the Univ. of Nebraska in 2007 and has worked with Cleaver Brooks since that time. He plans to take the chemical engineering P.E. exam in the spring as a part of his continuing education. He is a member of AIChE.

Copyright © 2014 American Institute of Chemical Engineers (AIChE)