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The V-Temp™ Economizer System and Method for SCR Temperature Control

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Abstract

Emission requirements for fossil-fired boilers mandate that the boiler's air quality control system (AQCS) be capable of meeting emission standards from minimum load through full load. This flexibility is more critical than ever so that coal-fired power plants remain competitive with other sources of renewable fuels and power generation methods.

One major component in the boiler's AQCS is the selective catalytic reduction (SCR) system for nitrogen oxides (NO_X) control. For optimum NO_X reduction, the gas temperature entering the SCR must be maintained above the temperature at which ammonium bisulfate forms. The formation of ammonium bisulfate will degrade the SCR's NO_X removal efficiency resulting in shorter catalyst life. At loads that cannot maintain at least this temperature, typically 70 to 80% load, the SCR will require a means to increase the boiler's economizer exit gas temperature (EEGT). The solutions currently available to resolve the EEGT issue do not provide the turndown required by most power plants for loads of 40% and below.

Babcock & Wilcox Power Generation Group, Inc. (B&W PGG) has patented the V-Temp™ system to control the flue gas temperature leaving the boiler and entering the SCR, within the SCR's desired operating load range. This system controls the distribution and flow of the economizer fluid so that the EEGT can be increased at reduced loads. The V-Temp system maintains an application-specific minimum EEGT at reduced loads, permitting the SCR to remain in service and to control NO_X emissions, while minimizing the risk of ammonium bisulfate formation in the downstream flue, at the SCR inlet, or in the SCR catalyst.

This paper will include results from successful installations of the V-Temp system on both supercritical and subcritical boilers. Optimization of this system is currently being developed to allow for operation of the boiler down to 25% load with the SCR in service while maintaining unit efficiency at full load.

Background

Three factors have contributed to coal-fired, base-load boilers being converted to permit operation as load-following, cycling units.[1] First, electricity demand in the United States (U.S.) has decreased in the past few years because of the economic recession. Second, reduced natural gas prices have allowed gas-fired generation to be a lower-cost option for economical dispatch than coal-fired plants. Finally, deployment of intermittent renewable generation, including wind, has increased. The overall impact of these trends for coal-fired plants has been to increase the need for various modes of flexible operation, such as increased load-following operation, higher unit turndown during low demand, lower minimum load operation, two-shifting, frequent unit starts (hot, warm and cold), increased load and thermal ramp rates, frequent reserve shutdown, and long-term plant layup.

One major operational factor that may result from boiler cycling is the potential for catalyst fouling in NO_X control equipment. This fouling is usually caused by lower than desired flue gas temperature at the SCR inlet and the resulting formation of ammonium bisulfate on the catalyst. Catalyst suppliers specify the minimum gas temperature for ammonia injection to attain the necessary SCR operation and NO_X reduction based on specific unit characteristics.

Available Options to Raise EEGT

Boiler operators have previously used a number of options to raise the flue gas temperature entering the SCR. However, each option has shown disadvantages while in service.

- Economizer surface removal – The simplest option to increase the gas temperature entering the SCR is through heat transfer surface removal from the economizer. The amount of economizer surface that is removed is set by the lowest load condition that requires the SCR to be in service. However, this also affects the full load gas temperature leaving the economizer, thereby decreasing the efficiency of the boiler at normal high load operating conditions.
- Flue gas bypass – Another common option that has been used to raise the flue gas temperature entering the SCR is to employ a flue gas bypass system. Hot flue gas upstream of the economizer is bypassed around the economizer and mixed in the flue gas stream after the economizer outlet. However, the flue gas bypass system does not provide the required turndown necessary to meet the flexible operating conditions of current coal-fired generating facilities. Flue gas bypass systems also require special design considerations because of the hot design conditions of the flues, the flyash in the flue gas, and the mixing of the two gas streams. Also, it is often difficult to retrofit a boiler with a flue gas bypass system because of the lack of space required to install the bypass flues.
- Split economizer – A split economizer adds economizer surface after the SCR. While this system effectively raises the flue gas temperature entering the SCR, it adds significant cost because a new economizer enclosure is required downstream of the SCR.
- Waterside bypass – This system bypasses a portion of the feedwater around the economizer to increase the EEGT. The water is fed back to a mix header at the economizer water outlet. There are two main concerns with this system. First, the feedwater may not be evenly distributed to the stringer tubes. Because the stringer tubes are typically the main support system for the economizer, it is important that the integrity of the tubes is maintained. Second, the mix point at the economizer outlet tends to be in the gas stream. Adequately cooling the feedwater pipe at the mix can also cause an efficiency reduction at full load.

Because of the limitations of these previous approaches, B&W PGG developed the V-Temp economizer system while working directly with a utility customer to achieve SCR turndown on a unit that historically had operated as a base-load boiler.

The V-Temp System and Process

The V-Temp economizer system reduces heat absorption in the economizer by reducing the water flow in selected tubes within the economizer. The heat absorption is reduced by making the temperature difference between the fluid inside the tubes and the flue gas over the tubes very small or the same at various points within the economizer bank. The heat transfer of the economizer surface downstream of these points (where the temperature of the gas and the fluid temperature are similar) will become ineffective and will result in a higher gas temperature leaving the economizer.

The economizer feedwater system is split into underflow and overflow sections.This is accomplished by adding a second inlet header at the economizer inlet. (See Figure 1.)

A major design consideration for the V-Temp system is the split between the number of economizer tubes being fed by the overflow and underflow headers. The split varies based on the desired operational load range or turndown of the system and the required SCR minimum inlet temperature. Once the number of tubes is determined for the overflow and underflow headers, the sectional arrangement of each tube type (i.e., underflow or overflow) is equally grouped into sections across the width of the unit. Each design is specifically tailored to the required operating conditions of the unit.

A mix header is located at the end of the underflow and overflow sections. The mix header can be located between two economizer banks or between the economizer banks and the stringer tubes. The purpose of the mix header is to mix the hot (~700F) feedwater from the underflow sections and the cold (~550F) feedwater from the overflow sections.

The underflow/overflow sections are evenly spaced across the width of the economizer. This allows the mix headers to effectively mix the flow from both the underflow

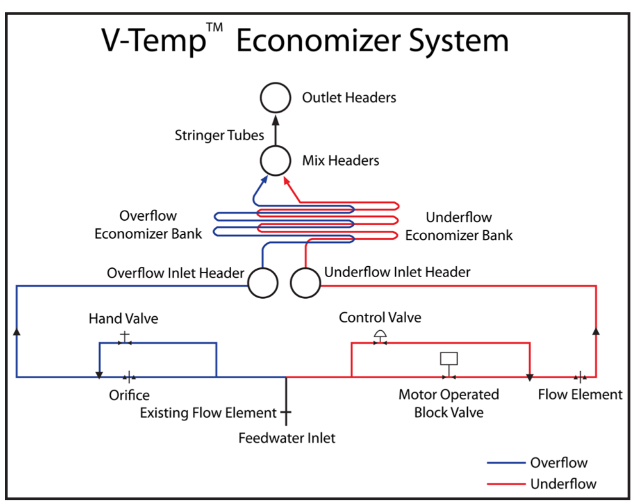

Fig. 1 V-Temp economizer system schematic.

and overflow sections across the entire width of the unit. The feedwater that leaves the mix headers flows directly to the economizer stringers. Because the stringer tubes are generally a support structure for the components in the backpass of the boiler, it is important that proper mixing occurs in the mix headers feeding the stringer tubes. Figures 2a and 2b illustrate an economizer design before and after the addition of the V-Temp system.

B&W PGG designs the economizer to operate as a normal economizer at full load.

The majority of the physical changes that make the V-Temp system unique are in the feedwater piping. Typically, economizers are fed by a single header with a single feedwater pipe line feeding that header. Because the V-Temp system uses two inlet headers within the economizer, modification of the existing feedwater piping is required to feed the overflow header.

The major pieces of equipment required in the feedwater system (see Figure 3) are:

- Main feedwater flow element – FE-1 is the existing feedwater flow measurement device. It is used to determine boiler load on the control curve. FE-1 is located upstream of the new V-Temp equipment.

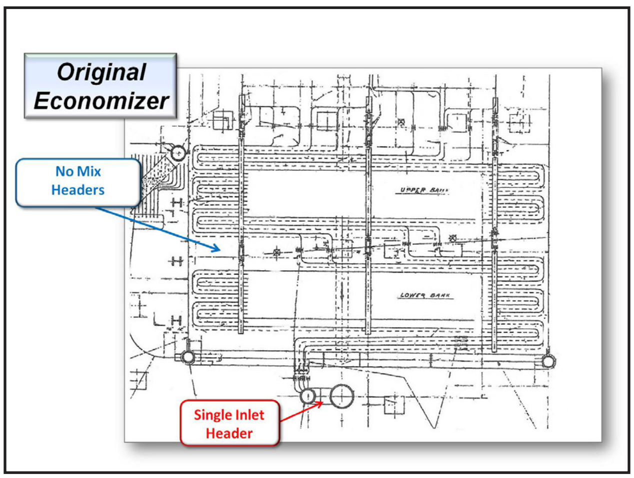

Fig. 2a Original economizer design.

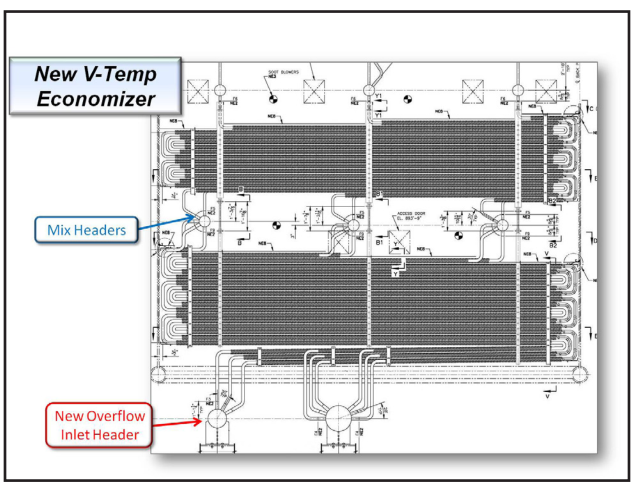

Fig. 2b V-Temp economizer design.

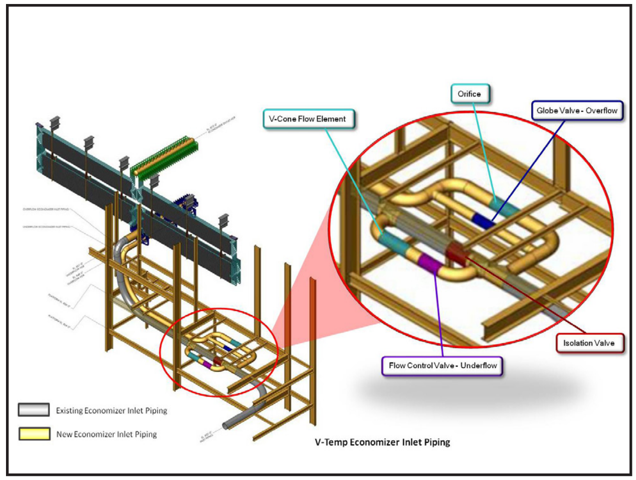

Fig. 3 Expanded view of V-Temp system.

- Motor operated block valve – MOV-1 is located in the underflow feedwater line and is used to limit the flow area to the underflow sections. This valve is either fully closed or fully opened.
- Control valve – CV-1 is located in the underflow feedwater line, in a bypass line around MOV-1. CV-1 modulates to control the flow to the underflow sections based on the control curve input.
- Underflow flow element – FE-2 is located in the underflow feedwater line and is used to measure the underflow flow rate.
- Orifice – OP-1 is located in the overflow line and is used in conjunction with HV-1 to balance the feedwater flow pressure drop between the underflow and overflow systems. OP-1 is not always required.
- Hand valve – HV-1 is located in the overflow line and is used in conjunction with OP-1 to balance the feedwater flow pressure drop between the underflow and overflow systems. HV-1 is not always required.

A design evaluation is completed on each project to determine whether HV-1 and OP-1 are required. If the pressure drop across the valves of the underflow system is too great in relation to the overall economizer pressure drop, then OP-1 and HV-1 are included in the system. At initial startup, HV-1 is manually adjusted to ensure equal distribution of flow between the overflow and underflow sections. HV-1 is then locked in place and not adjusted during normal operation.

The V-Temp system can be retrofit into an existing economizer as well. While some of the design flexibility is not available with this option, certain situations may allow the existing economizer to remain with only jumper tubes required to mate with the new overflow inlet header (see Figures 4 and 5). The feedwater piping system would remain as described in Figure 3.

Economizer Water Bias Flow Control

The V-Temp system biases feedwater to the overflow economizer sections at loads at which the EEGT would typically drop below the minimum ammonia injection tem-

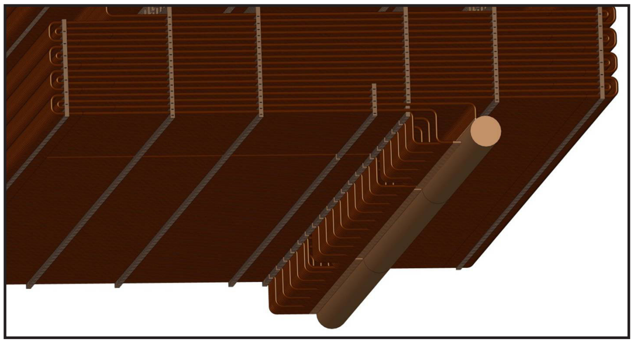

Fig. 4 Before V-Temp economizer system.

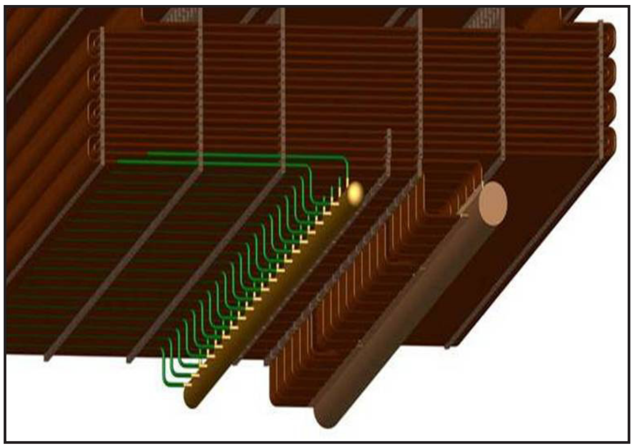

Fig. 5 After installation of V-Temp economizer system.

perature (MAIT) of the SCR catalyst. EEGT is the control variable; however, it is not used as feedback to control bias flow because during system operation, EEGT responds very slowly to the control valve position changes. Feedwater residence time in the underflow economizer sections can be over 30 minutes at low loads.

From full boiler load down to loads at which the EEGT is above the MAIT under normal operation, the control valve and block valve are 100% open and feedwater flow is unbiased (see Figure 6). Feedwater is distributed as evenly to each economizer section as the piping arrangement permits.

At loads at which the EEGT would drop below the MAIT, the V-Temp system is put into service (see Figure 7). Water is biased to the overflow sections by fully closing the block valve. The control valve is initially 100% opened, but modulates as needed to achieve the desired EEGT.

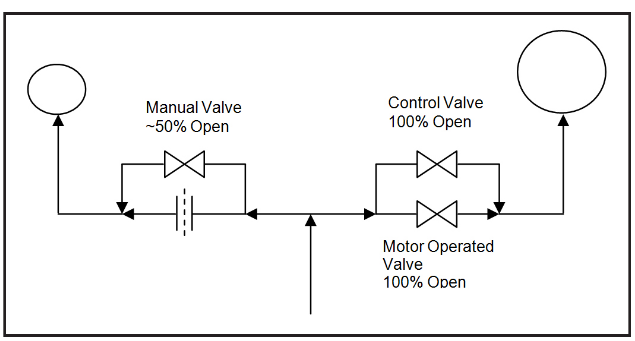

Fig. 6 Valve positions – all loads above the SCR MAIT (including full load).

When the boiler load drops below the desired turndown load for the SCR, the V-Temp system is taken out of service (see Figure 8). MOV-1 is opened 100%, CV-1 is opened 100%, and the economizer operates as it does at maximum continuous rating (MCR). The V-Temp system does not operate during boiler startup and shutdown.

Figure 9 shows the valve positions of the MOV-1 and CV-1 across the entire boiler load range. In the example in Figure 9, the V-Temp system is designed to operate from 43% load to 79% load. This typical control curve would be developed for each V-Temp application, based upon the performance required of the system to obtain the necessary EEGT at all loads at which it is in service.

The controls for this system are based on a control curve similar to the one shown in Figure 10. Ideally, the control valve position would be set based on the measured flue gas temperature leaving the economizer (or entering the SCR). However, the mass flow through the underflow sections is significantly reduced to the point that it could take a long period of time for the water flow to move completely through the underflow economizer sections. Depending on the size of the economizer, this can vary from 1 or 2 minutes to over 30 minutes. Therefore, the EEGT may not fully adjust to changes to CV-1 for an equal amount of time.

The control valve position is controlled by receiving the signal from the flow measuring device and comparing the desired underflow flow rate [determined from the control system curve of total feedwater flow rate vs. underflow flow rate (see Figure 10)] to the actual measured underflow feedwater flow rate. The control valve modulates until the

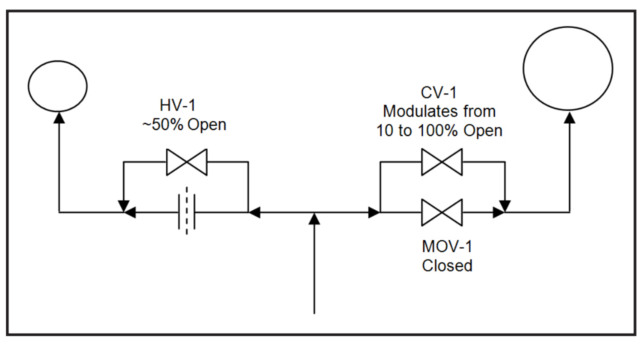

Fig. 7 Valve positions – loads below the SCR MAIT to minimum load required for SCR operation.

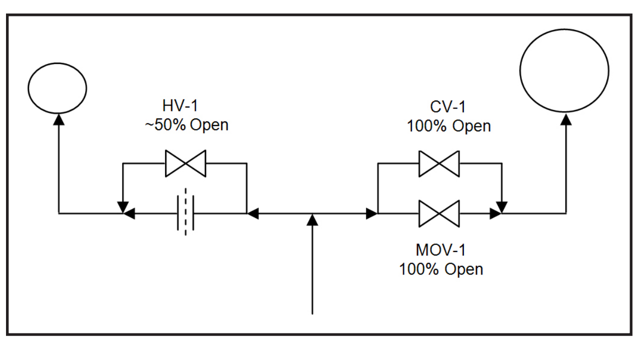

Fig. 8 Valve positions – start-up to minimum load required for SCR operation.

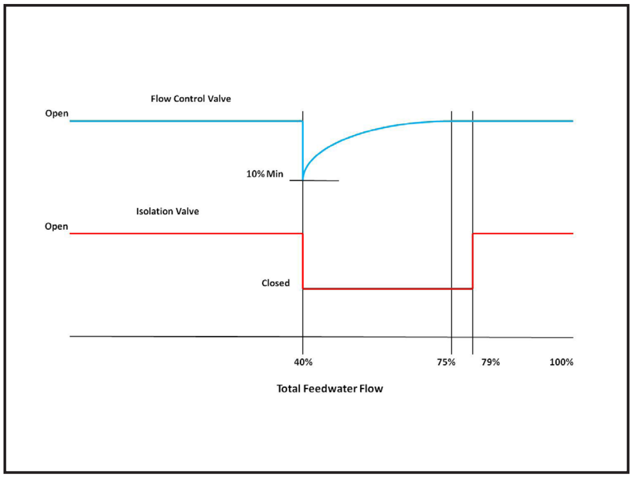

Fig. 9 Valve positions across the load range.

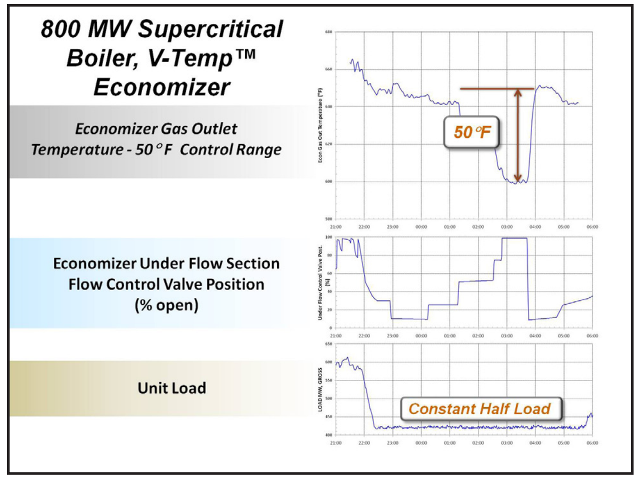

Fig. 11 V-Temp economizer test control range.

measured flow matches the desired underflow flow rate from the control curve.

The initial control curve is set based on B&W PGG's predicted performance models. The control curve can be easily adjusted after startup based on actual performance.

Testing Results

B&W PGG has installed and tested the V-Temp system on four boilers, three supercritical once-through boilers and one subcritical drum boiler. In all installations, the V-Temp system has performed as designed. One of these installations was an 800 MW supercritical boiler. Testing results on this unit are presented to show the capability of the V-Temp economizer system. For one test, B&W PGG considered the sensitivity of changes in the position of CV-1 and its effect on the EEGT of the unit. The boiler was held at 50% MCR load, MOV-1 was fully closed, and the control valve was opened in steps. After each step, the EEGT was allowed to level out and then measured. As shown in Figures 11 and 12, the system was capable of a 50F control range with the V-Temp system in service at a constant load.

It is clear that changing the CV-1 position has the predicted effect on the EEGT of the unit.

Furnace/Downcomer Recirculation

Utilizing the V-Temp system on drum boilers can limit the turndown because of the potential of a steaming economizer. B&W PGG developed a second patented system which can be used to improve the turndown of the boiler while controlling the flue gas temperature entering the SCR. The furnace/downcomer recirculation system (Figure 13) combines the downcomer water from the drum with the feedwater to the economizer.

If the V-Temp is limited to a 45 to 50% load turndown before a steaming economizer occurs, then the furnace/downcomer recirculation system can be added to assist with turndown to loads near 25%. The V-Temp and the furnace/downcomer recirculation systems can provide a complete package for achieving SCR turndown to the boiler's minimum stable load (see Figure 14).

This system can also be used on once-through boilers that need a higher economizer feed temperature to maintain SCR operation at lower loads. For a once-through boiler, the recirculation system draws the fluid from a location within the furnace circuitry, instead of the downcomers as on a subcritical drum boiler.

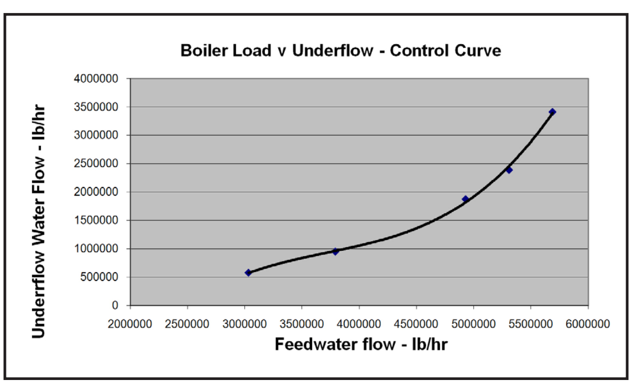

Fig. 10 Control curve – boiler load vs underflow rate.

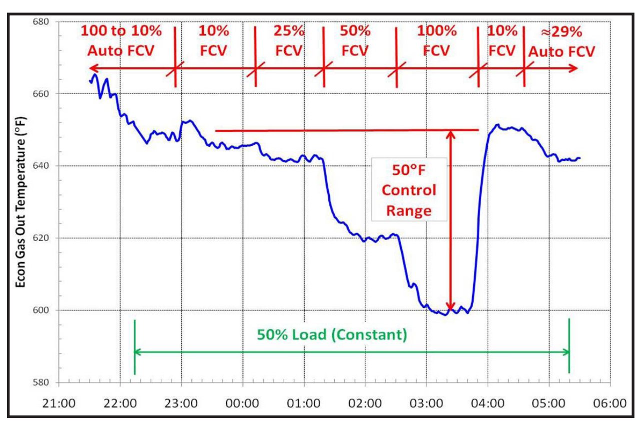

Fig. 12 CV-1 position vs EEGT.

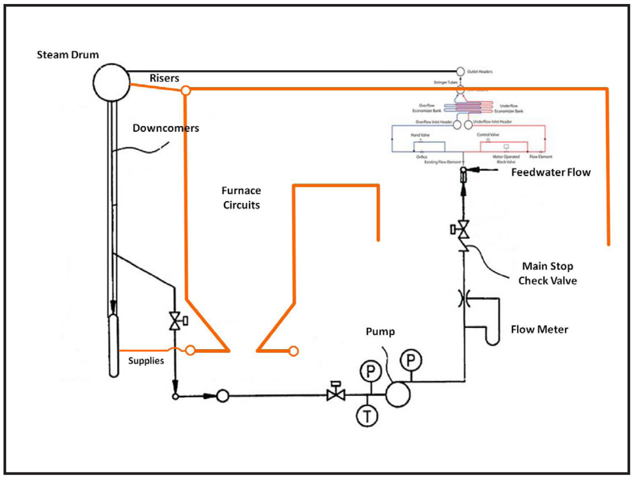

Fig. 13 Furnace/downcomer recirculation system.

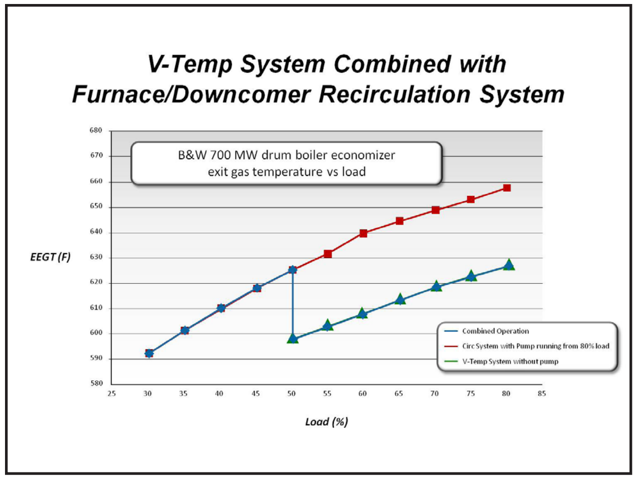

Fig. 14 Furnace/downcomer recirculation system performance curve with V-Temp system.

Conclusions

B&W PGG has installed the V-Temp economizer system on four boilers, three supercritical pressure once-through boilers and one subcritical pressure radiant drum boiler. Based upon the results from these installed applications, the V-Temp economizer system has provided a cost-effective, technically superior design for SCR inlet gas temperature control. The benefits of the V-Temp economizer system are: 1) lower maintenance costs, 2) an extended turndown range, 3) lower gas side pressure drop, and 4) a total installed cost that is equal to or less than other gas-side temperature control alternatives. An additional future benefit of the V-Temp economizer system is its capability to be used with a furnace/downcomer recirculation system that will allow the SCR to be operational at even lower loads. The combination of these systems will allow for very low load boiler turndown.

References

1. Hesler, Steve, Electric Power Research Institute, "Mitigating the Effects of Flexible Operation on Coal-Fired Power Plants," Power, Vol. 155, No. 8, August 2011, pp. 50-56.

V-Temp is a trademark of Babcock & Wilcox Power Generation Group, Inc.