WOODWARD

Application Note 83400
(Revision A)
Original Instructions

Boiler Feedwater Control

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Introduction

In today's world of unstable oil markets and rapidly changing environmental constraints, there is a growing awareness of the need for precise plant control. Standards placed on control-system designers and manufacturers become more exacting every year. To meet these requirements, controls engineers are constantly developing new approaches to their work.

One area that has received much attention is the area of boiler control. While feedwater control is just one element of this complex process, a good deal of time has been devoted to its study. In order to build on this work, it is important to understand the basics of the feedwater process as they pertain to the entire boiler system. It is to this end that this paper is devoted.

Introduction to Boiler Systems

Boilers are used in a variety of applications. The range of use extends from a simple hot-water heater in a residential home to the production of steam for a thousand-megawatt turbine at an electric utility plant. As the size of the boiler increases, so does the complexity of the control system.

A general diagram of a boiler system is shown below in Figure 1.

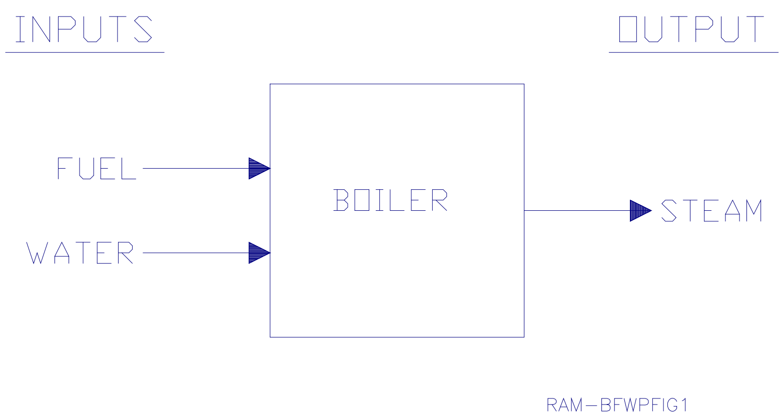

Figure 1 – Simple Boiler Schematic

It can be seen that a boiler has one basic objective—the delivery of steam at a desired pressure and temperature to a process (in some applications, the required output may be hot water). To achieve this, two basic inputs are required: fuel and water. Boiler fuel may consist of coal, natural gas, fuel oil or solid waste.

Complex boiler systems contain three elements of control, as shown in Figure 2.

These control functions are firing demand (combustion control), steam temperature and feedwater. In general, the firing demand control adjusts the amount of fuel being fired in the boiler. Steam-temperature controllers manipulate the temperature of the steam output through the use of de-superheaters or attemperators. Feedwater controllers modulate the amount of water in the boiler system (called the boiler water inventory).

It is important to note that while there are three distinct control systems mentioned here, in actual practice they are very interrelated. Improper adjustment of the feedwater entering the system can significantly affect the combustion control and the steam temperature control, which will in turn affect overall boiler efficiency. For this reason, it is desirable to tune these loops so they have minimal interaction with each other.

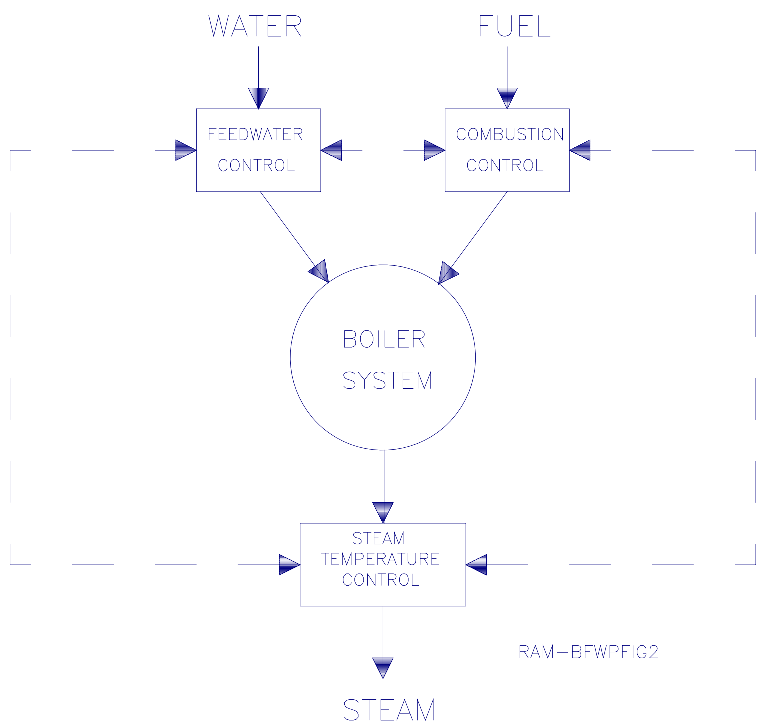

Figure 2 – Control Elements In A Typical Boiler System

A Typical Feedwater Supply System

Figure 3 details the typical elements found in a feedwater supply system:

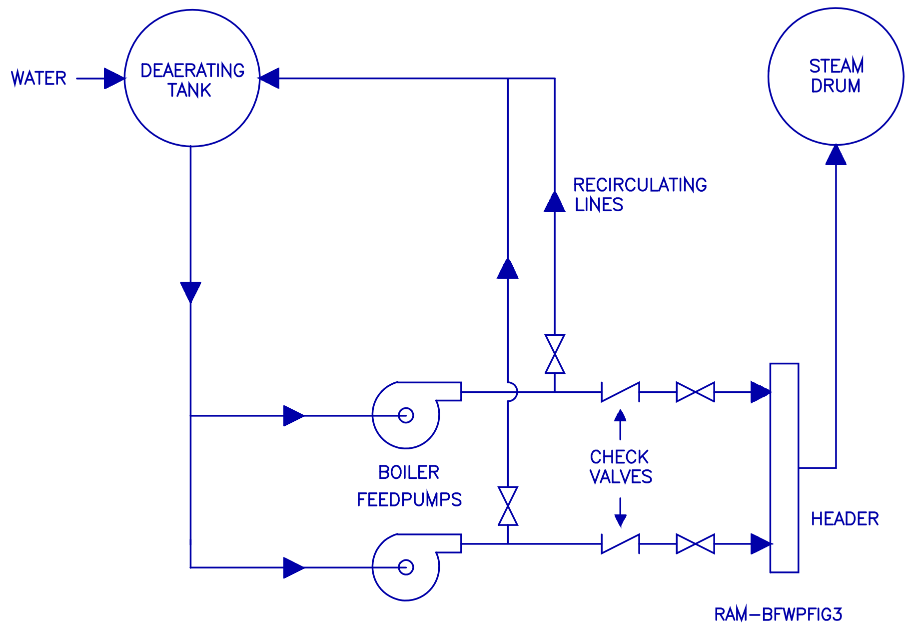

FIGURE 3 – TYPICAL ELEMENTS OF A BOILER FEEDWATER SYSTEM

Most boiler systems contain a de-aerating tank which removes dissolved gases from the feedwater (these gases can be corrosive to the rest of the boiler system). The de-aerating tank is the source of feedwater to the pumps. Because feedwater de-aeration is achieved through boiling, the water leaving the tank may be very close to the boiling point. It would be undesirable for the water at the pump suction to flash to steam, so the de-aerating tank is located at an elevation above the feedwater pumps. This elevation should be chosen in order to guarantee enough pressure at the pump suction to prevent flashing. The water pressure at the pump suction is called net positive suction head (NPSH).

Recirculating lines are installed in the system for pump protection. Because a significant amount of heat is generated by the pump, it is desirable to maintain at least 15–20% flow through the pump at all times. This flow serves to carry the heat away from the pump and prevent overheating. The buildup of heat in a feedpump can be significant because many pumps operate at 60–70% of full-load power at zero-flow conditions. Thus, recirculating lines serve to protect feedwater pumps from overheating during zero or low net flow conditions. Many feedwater pumps also have internal cooling loops to carry away the heat.

Check valves are installed in systems requiring more than one feedpump to prevent backfeeding pumps not in use.

The outlet of the feedwater pump leads to the steam drum, which will be discussed in the next section.

Steam Drum Fundamentals and Construction

The central element in the standard boiler system is the steam drum. Refer to Figure 4 for a cross-sectional diagram of a typical steam drum (sometimes called the boiler drum). One of the major goals of a feedwater control is to maintain the level of the water in this drum.

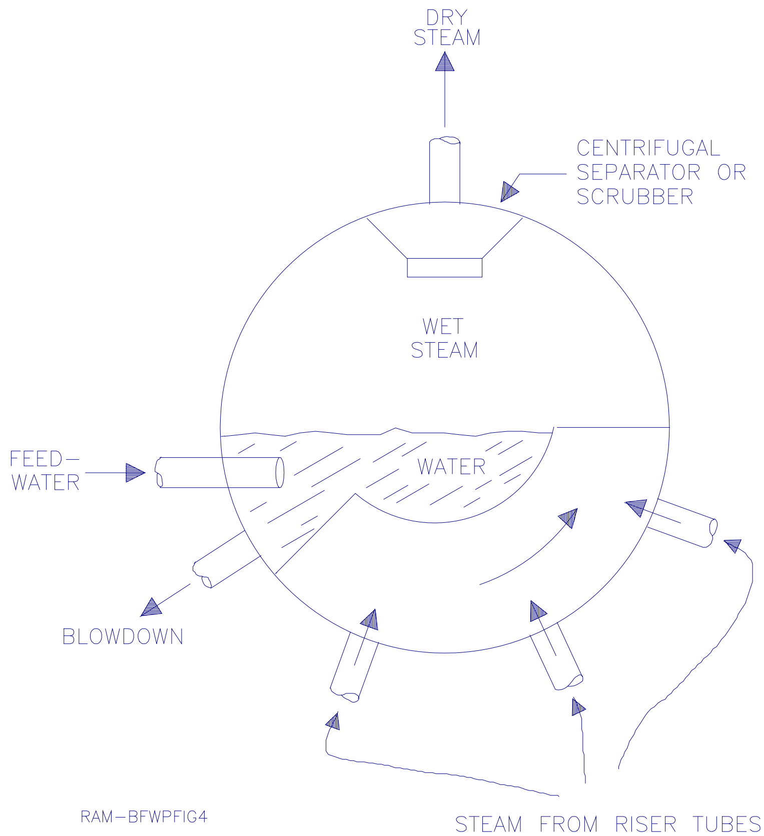

FIGURE 4 – STEAM DRUM CROSS–SECTION

In general, the steam drum is maintained at half water and half steam. The inlet from the feedwater system is below the level of the water to prevent disturbance in the water surface. As shown in Figure 5, this water leaves the drum to enter the downcomer tubes on its way to the mud drum. The mud drum collects sludge, formed in the boiler system, which tends to gravitate toward the mud drum because it has the lowest elevation in the system. Water then enters the riser tubes where heat is applied to turn the water into steam. Note that this system is a natural circulation system and is not driven by a pump, but relies on the rising action of the heated water and steam in the riser tubes for circulation. Forced-circulation systems also exist.

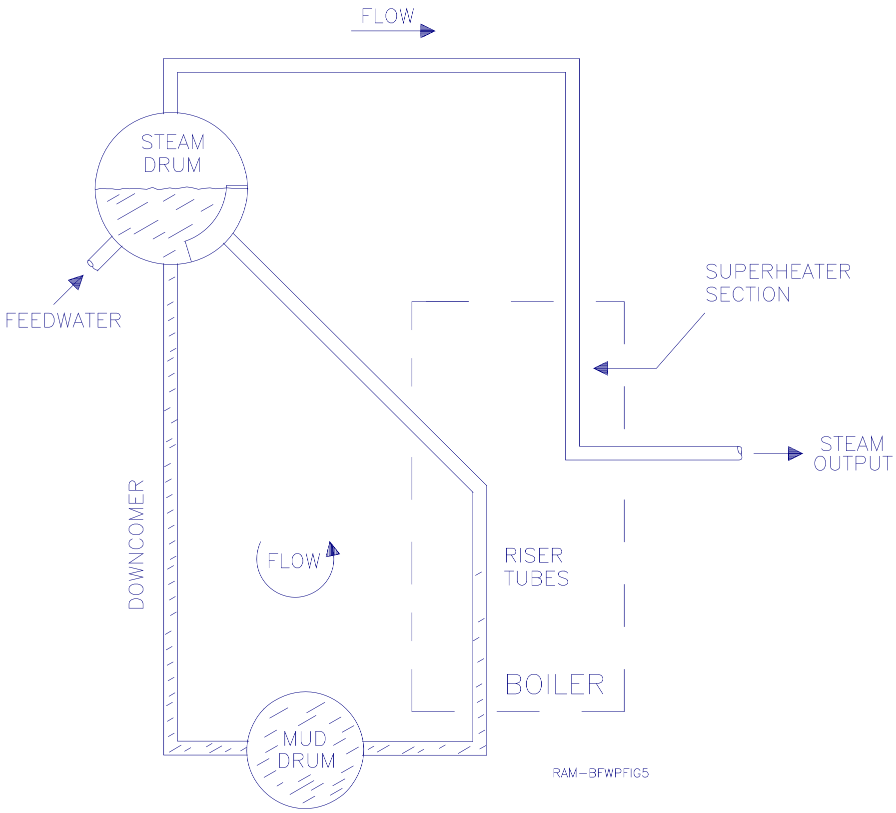

Figure 5 – Standard Boiler Arrangement

Primary blowdown is taken from the mud drum. This blowdown consists of the sludge collected here. Water as secondary blowdown is also removed from the steam drum to take away any dissolved solids that may prove corrosive to the boiler system.

The steam entering the steam drum from the riser tubes is "wet steam" which indicates that it still has water droplets present. The steam inlet is separated from the water in the drum by baffles. Because it is desirable for dry steam to enter the superheater, centrifugal separators or steam scrubbers may be used to return the water droplets to the water in the drum. Saturated steam enters the superheater where it passes again through tubes to be heated while maintaining pressure.

Due to the tremendous amount of energy imparted to the water and steam in the first pass through the riser tubes, the pressure in the steam drum will be exceptionally high, often exceeding 1000 psig (6895 kPa). The resultant pressure in this drum must be accounted for when sizing the feedwater pumps. The output pressure of the pump is typically sized at about 50 psig (345 kPa) over the expected steam drum pressure. This guarantees positive flow from the pump.

As was mentioned above, drum level is critical and is one of the major elements of controlling feedwater pumps (although, at times, drum level is not maintained for the sake of smoother control, as we will see). To better understand the reason behind keeping the level constant, we refer back to Figure 1.

The boiler system, including the drum and all of the piping from feedwater pump to steam output, can be regarded as a fixed-volume system. Keeping this in mind and knowing that steam is at a higher energy level than water (when both are at the same pressure), we can say that the total amount of energy contained in the system is proportional to the ratio of water to steam in the entire system. If the total content of water rises, the system contains less stored energy; if the ratio contains more steam, more energy is said to be contained in the system. Aside from the riser tubes, which hold a very small percentage of the total volume, the only area in the system that can support a varying ratio of steam to water is the steam drum. Thus, the level of water in the steam drum is roughly a proportional indicator of the total energy stored in the boiler system.

Now, assume that the final output of the system (steam at a given pressure and temperature) does not change over a period of time. This is tantamount to saying that the energy extracted from the system is constant. If the drum level is allowed to fluctuate through large swings (causing the energy stored in the system to fluctuate accordingly), and if a steady system output is required, the only way to compensate is to vary the firing rate of the boiler (see Figure 1). Thus, by allowing the drum level to wander, there is interference with the combustion control of the boiler and a reduction in overall efficiency. It is for this reason that maintaining drum level is a critical process in feedwater control.

Feedwater Control

Feedwater systems are available in many forms. Very small boilers may contain a constant-speed pump with on-off control. While this is an inexpensive solution, it does not provide the best efficiency because it tends to interfere with the combustion control system. However, on small systems, this solution may be the most economical.

On more complex systems, some sort of variable feedwater flow needs to be realized. This can be achieved through a variable speed pump or by utilizing a constant-speed pump with a proportional valve at its output. As the boiler system gets larger, there is more of a need for complex feedwater control. Digital control systems are now widely used in this application because of the precise control and greater flexibility that they provide. Many utility users are also purchasing fault-tolerant feedwater controls in order to minimize the possibility of a mainline unit shutdown due to feedwater control problems.

The most obvious control scheme for feedwater applications is simple level control. This is also known as single-element control because drum level is the only indicator used to control feedwater flow. See Figure 6.

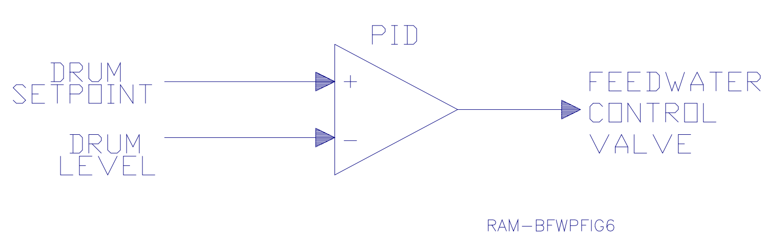

FIGURE 6 – SINGLE-ELEMENT SIMPLE LEVEL CONTROL

Drum level is sensed by a transducer and fed back to the control system, which in turn proportionally moves the valve to compensate. If the drum level is increasing above its nominal point, the modulating valve is cut back; if drum level decreases below the nominal point, the valve is opened to increase feedwater flow. This controller may be strictly proportional or it may include integral gain. The simple goal of this scheme is to maintain a strict level of water in the steam drum.

To understand why this is not sufficient for most feedwater control applications, refer to Figure 7.

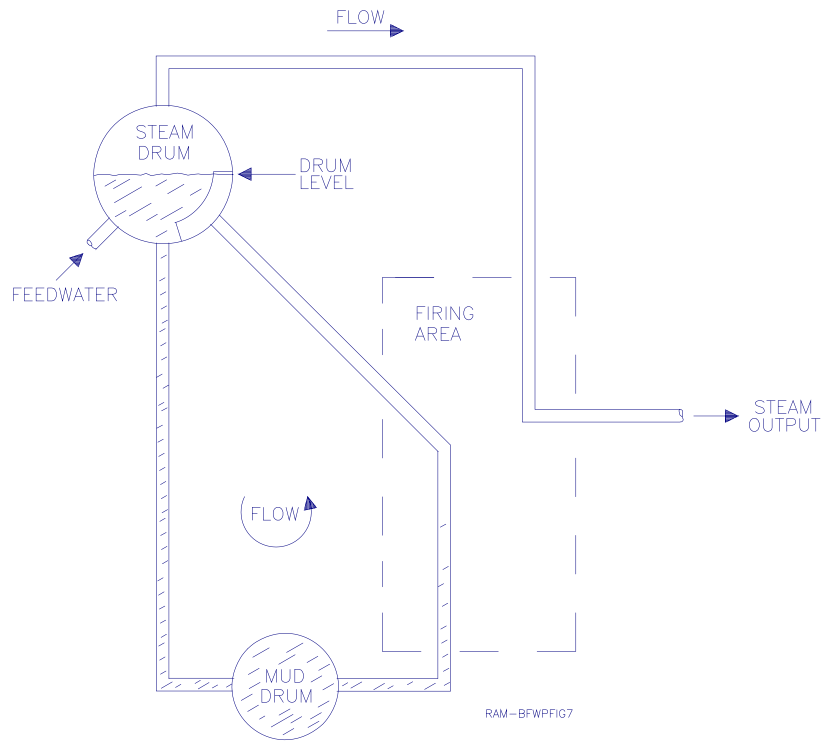

FIGURE 7 – UNDERSTANDING SHRINK AND SWELL IN A BOILER SYSTEM

Under steady-state conditions, the demand from the boiler system (steam flow) will be constant. Ideally, this would indicate that feedwater entering the system will flow at a constant rate and the firing rate from the combustion control is uniform. Now, assume that the steam demanded from the system undergoes a step increase. To make up this increase in energy output, it is obvious that the firing rate must also experience an instantaneous boost. And, to compensate for the increase in mass flow at the output of the system, it is logical to assume that an increase in feedwater flow will be needed.

In this situation, it is important to understand the internal dynamics of the boiler system. When the steam demand is instantly increased, the proportion of steam to water in the riser tubes will also increase. When the proportion of steam is increased, the volume of the entire system will also rise. Because of the boiler construction, the only place that this volume will be taken up is in the steam drum. This phenomenon is known as swell and is indicated by an instant increase in drum level when the firing rate undergoes a step increase. The opposite event, known as shrink, occurs upon a decreased firing rate, causing a corresponding drop in drum level.

If an instant increase in steam output is required (causing an accelerated firing rate and swell in the steam drum), a simple level control would react to this swell by decreasing the feedwater flow to the drum. However, it can be seen that the increased mass flow at the system output requires an increased feedwater flow at the input and, thus, the level control has reacted in the wrong direction to the firing-rate change. As the increase in steam flow translates to a greater quantity of water leaving the steam drum to enter the downcomer, the level control will eventually have to play "catch-up" to establish proper feedwater flow. Such a scheme will provide unstable feedwater control in large boiler systems.

With this in mind, it is worthwhile to define some goals to feedwater control.

First, the control should monitor drum level. This is not to say that the drum level should be maintained at a strict level, since this is impossible when shrink and swell are present in the system. However, to an extent, the control should not allow the drum level to deviate beyond specific boundaries, which vary depending on drum size.

Second, the control should be able to balance the input of the system (feedwater) with the output of the system (steam). We saw above that the single-element level control does not properly react at first to this requirement.

Going along with this, the third objective to feedwater control is to avoid any sudden changes in boiler water inventory. Ideally, the control should smoothly adjust this inventory whenever there are any sudden changes in load. Incidentally, it is interesting to note that when a boiler is at 100% output (steady state), the boiler water inventory is less than at an output level below 100%. The reason for this is that at high output the ratio of steam to water in the system is greater and, consequently, the total mass of water contained in the system is less.

Fourth, it is imperative that the interaction of the feedwater control and the combustion control be minimized. As has been discussed, poor feedwater control will interfere significantly with the firing rate, causing a decrease in overall efficiency. Recall that under steady steam-demand conditions, the best fuel economy is obtained when the firing rate is held constant.

Fifth, a good feedwater control should be able to compensate for any fluctuations in feedwater supply pressure. These fluctuations will change the flow characteristics of the control valve and, thus, the overall dynamics of the feedwater system. Variation in feedwater pressure, along with shrink and swell provide the two greatest challenges for a feedwater supply control.

As discussed earlier, single-element level control provides an inadequate response for sudden load changes in the boiler system. To combat the problems encountered with shrink and swell, we introduce a second element of control - steam flow (Figure 8).

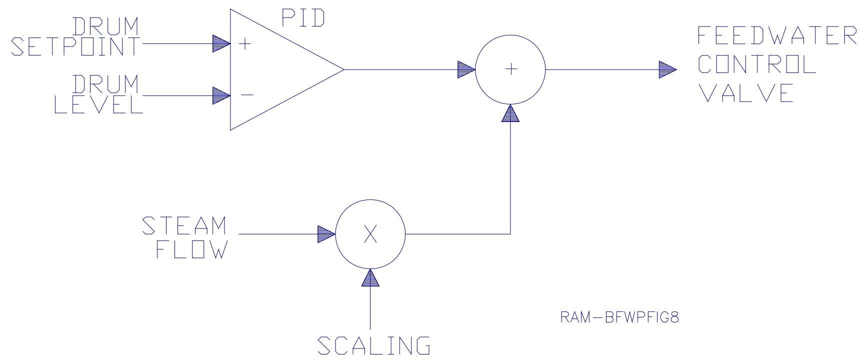

Figure 8 – Two–Element Feedwater Control

A flow transducer is located at the output of the boiler system. The purpose of this scheme is to sense a change in steam demand and use this signal to compensate for the wrong-way reaction of the drum-level controller. This is demonstrated in Figure 9.

Ideally, a feedwater control should avoid sudden changes to feedwater output when the system load demand changes (objective 3 above). To this end, when steam demand is suddenly increased, the feedwater flow rate should instantaneously remain unchanged. Swell will occur in the steam drum and as the level then begins to drop back to the nominal point, the feedwater flow is gradually increased to match the additional mass flow at the steam output.

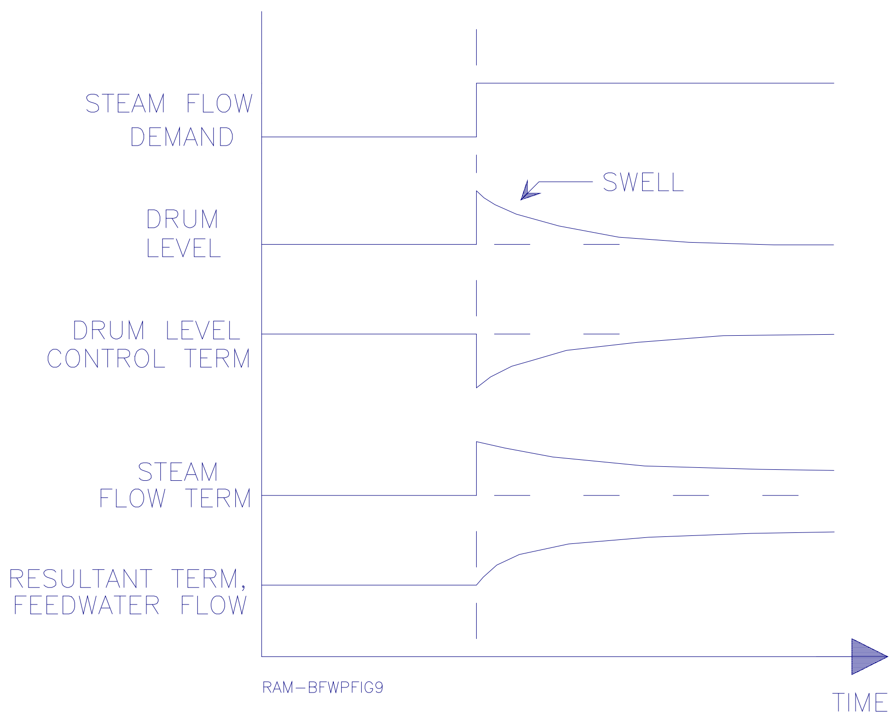

FIGURE 9 – DEPICTION OF TWO–ELEMENT CONTROL SYSTEM RESPONSES

To achieve this, the reaction of the steam flow term should be equal and opposite in direction to the change in the drum-level term. Figure 9 demonstrates these reactions separately, and also shows their resultant when combined in a two-element feedwater controller. Over time, the steam-flow term will adjust the feedwater flow rate to its new level.

These two control loops will require field tuning to achieve the proper dynamics. When ideally tuned, a step change in steam demand should produce no instantaneous fluctuation in feedwater flow rate. However, immediately following the step change in demand, the feedwater rate should begin to adapt to the new flow demand (as the resultant feedwater curve in Figure 9 illustrates).

As boiler systems get more complex, more elements of control may be added. To compensate for fluctuations in feedwater pressure, a feedwater flow controller may be added. This three-element scheme is shown in Figure 10.

As mentioned earlier, varying feedwater pressure can pose a problem for feedwater controllers. Fluctuations in pressure will be reflected by changes in the rate of flow through the control valve. By monitoring this flow and employing a cascade controller (as in Figure 10), compensation can be made for these variations. The feedwater flow is no longer running open-loop. The decision to use a three-element controller will be based on whether the additional control system and instrumentation cost will be offset by the overall increase in boiler efficiency.

Systems with inherently large swings in feedwater pressure will most likely employ a controller of this type.

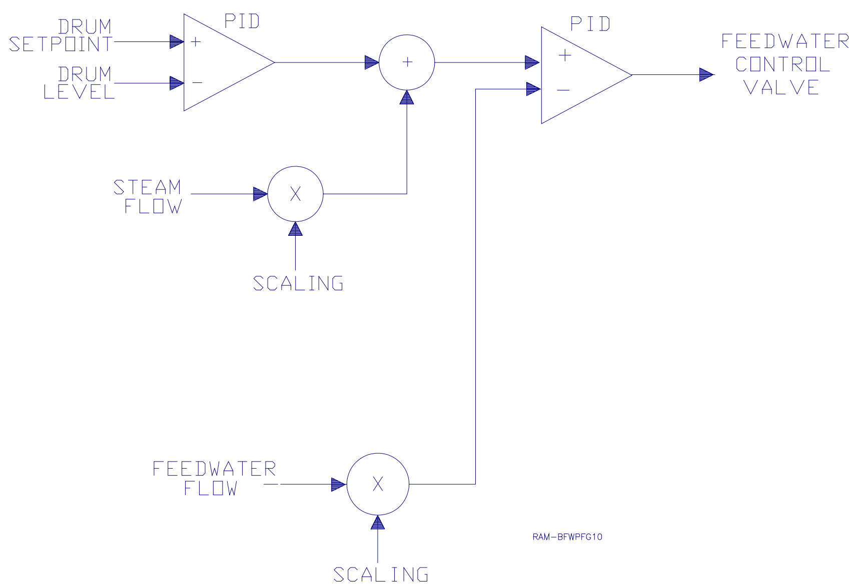

FIGURE 10 – THREE-ELEMENT CASCADE FEEDWATER CONTROL

Summary

As was mentioned in the introduction, boilers are comprised of a complex combination of interrelated control systems. Most notable are the combustion control, steam temperature control, and feedwater control systems. This paper has attempted to present the reader with the basic knowledge behind feedwater systems and their control.

Overall system efficiency is critical in boiler control. By recognizing and minimizing the possible areas of interaction between the multiple control areas present in boiler systems, great steps can be made toward achieving maximum efficiency. Having isolated these systems, efforts may then be made to optimize the individual elements.

[Written by Alan Metzger, 1992. The author acknowledges Sam G. Dukelow’s text, “The Control of Boilers”, copyright 1986, for much insight while preparing this text.]

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