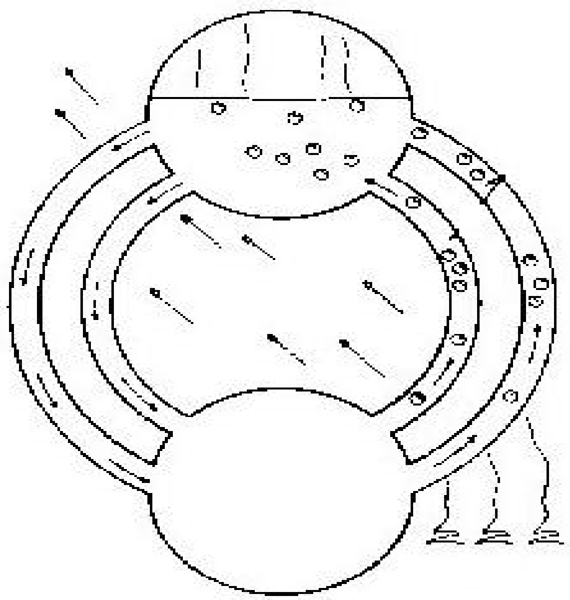
Improving Boiler Room Efficiencies

A Seminar on the ways and means of increasing boiler room efficiencies.

Boiler Drum Level
Measurement and Control



Presented by
David C. Farthing
Federal Corporation

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A Message from the speaker

Energy costs today are at there highest in recent history. Gaining whatever efficiencies may be found in thermal processes can help to stabilize the effects of rising energy cost.

Also today's economic and environmental demands dictate that we get the greatest practical efficiencies from our plants. To do this we must have a basic understanding of what those efficiencies are and how we may implement them.

My hope for you today is, that you will leave this seminar with a clearer understanding of some of the economically and technically feasible opportunities you have to improve your steam plant.

Regards,
David C. Farthing
Industrial Sales Manager
Federal Corporation

Introduction

Improved efficiency can have many connotations everything from fuel savings, improved equipment operation and useful life span, to labor and manpower savings. This paper will focus on the effects of boiler drum level and feedwater control as a means of energy savings by thermal/mass balancing the boiler. This paper will also discuss the effects of steam drum pressure and feedwater temperature on the overall efficiency of the boiler.

Steam Plant Optimization & Automation

Steam plant optimization is the overall improvement of the plant's operation. The most common strategies used to accomplish this task includes, and generally focuses on, the improvement of primary equipment operating efficiency, i.e. fuel and energy savings. In heavy commercial and industrial boiler applications these efficiencies are normally found in the application of waste heat recovery equipment, systems and process automation, and improved operating practices.

Boiler Drum Level Control has historically benefited from improvements in systems and process automation techniques. As such three separate control strategies, single element, two element and three-element control will be analyzed in this paper.

Liquid Level Measurement

The measurement of liquid level enables us to locate the surface of a liquid with respect to some referenced level. Level measurement is necessary in Boiler Drum Level Measurement for the safe and efficient operation of the boiler.

Inferential Level Measurement

One of the most flexible and convenient means of measuring liquid level is the *static pressure* or *inferential method.* This method is based on the fact that the static pressure exerted by any fluid is directly proportional to the height of the liquid above the point of measurement, irrespective of volume. Thus any instrument which is affected by pressure can be calibrated in terms of the height of a given liquid. The liquid sightglass is based on this method of measurement as the weight of water will find its own level in any open or closed loop.

Inferential Measurement is heavily influenced by sudden changes in liquid density, pressure or level disturbances and thus requires a stilling well to help dampen these disturbences. The use of a *water column* on the boiler drum acts as a stilling well for the level control devices and the sightglass.

In steam boiler applications the communication lines to the measurement instrument must remain unobstructed. Interruption of the vapor side communication line will result in an artificially low reading due to the effects of the drum pressure acting on the water column to compress the reading. While interruption of the liquid communication line will result in an artificially high reading, as condensate from the vapor line will tend to condense in the chamber and fill it up.

Volumetric Level Measurement

Volumetric Level Measurement is found in the form of float (displacement) type devices, which transmit the level in a vessel by simply floating on the surface of the liquid. Float operated liquid level measurement is a direct measurement in which the float rises and falls with the surface of the liquid level. In this method, the float, through a transmitter arm, can actuate a pointer, recording pen or electronic/pneumatic transmitter.

One of the most important aspects of float measurement is the effect of density on the level reading. As density falls the liquid loses its ability to support the float and the float rides deeper in the fluid suppressing the level reading accordingly. Thus it is important to know the density range that the float is to operate in and design accordingly. As an example, a float designed for 60 degree ‘F’ water, with a density of 1.0, would sink and fail to register any level in a tank filled with say gasoline having a density of 0.60.

Most single element drum level sensing devices and mechanical level switches use volumetric level measurement.

Differential Pressure Level Measurement

One of the simplest methods of measuring liquid level in a closed tank is to use a differential pressure device having a range equal to the liquid head being measured. Again, product density is important as the head pressure exerted on the differential element is in direct relationship to the density of the liquid being measured.

Liquid levels in closed tanks under pressure may be measured by this method. In these applications, the reference leg of the differential meter body must be connected to the pressure in the tank being measured so that the differential being measured will be independent of any pressure changes other than those due to changes in level.

In closed tank applications with condensing liquids, the reference line should be filled with the liquid being measured during installation. As noted the density of liquids change with temperature and the reference leg, which is at condensing temperature, will always read heavy in relation to the level measurement leg resulting in a zero shift. Therefore the meter body must be calibrated with a full liquid reference leg in order to correct for the zero shift.

The Boiler Water/Steam Drum

The boiler water/steam drum, or steam drum, is an integral part of the boiler's design. This vessel has three specific purposes; 1] provide a volume space to hold the boiling water in the boiler, 2] provide enough water volume to allow for good thermal mixing of the cooler bottom drum water with the hotter surface interface water, and 3] provide surface area and volume for the efficient release of the entrained steam bubbles from the boiler water.

The surface area and volume of the vapor space in the water/steam drum is critical to the efficient separation of the steam bubbles from the water. Too small an area can result in an excessive surface tension and high velocities, which result in wasted heat and drum water carry-over. Too large an area is simply a waste of materials and labor to construct the vessel.

The boiler water/steam drum also provides a logical location for 1] addition of feedwater, 2] addition of chemical water treatment and 3] surface blowdown, which helps reduce the surface tension of the water/steam interface to allow better steam release.

Because all of these task involve the removal and addition of some mass (water or steam) the water/steam interface is always in a state of flux. Maintaining a stable interface level is critical to the safe and efficient operation of the boiler.

Low water levels affect the internal thermal recirculation of the boiler water resulting in cold spots in the boiler water and steam collapse. This lack of circulation also reduces the effectiveness of the chemical water treatment and can cause precipitation of the chemicals as chemical salts or foams.

High water levels raise steam exit velocities and result in priming or boiler water carry-over in to the distribution system. Priming results in wet dirty steam while carry-over can result in dangerous water hammer and pipe or equipment damage.

Boiler Drum Level Control - ON/OFF vs. Modulating

The objective of the boiler drum level control strategy is to maintain the water/steam interface at its optimum level to provide a continuous mass/heat balance by replacing every pound of steam leaving the boiler with a pound of feedwater to replace it.

The interface level is subjected to several disturbances in the water/steam drum; not the least of which, are drum pressure and feedwater temperature. As steam pressure rises or falls due to load demand there is a transient change in drum level due to the expansion or contraction of the steam bubbles in the drum water. When the steam pressure is lowered the water level rises as the steam bubbles expand (swell). Conversely as the steam pressure rises the water level lowers as the steam bubbles compress (shrink).

Also as sub-cooled feedwater enters the water/steam drum it will cool the drum water at the entry point to below the operating pressure boiling point. This acts to condense the steam bubbles in the boiler drum water and collapse the steam blanket. Thus it is important that the water/steam drum is large enough to absorb this sub-cooled water without being overly effected by its influence.

The Effect of Feedwater Temperature on Boiler Performance

It is the influence of feedwater temperature on packaged boilers, which is most commonly overlooked when selecting a feedwater strategy. If we acknowledge that boilers are rated from and at feedwater temperatures of 212 degrees ‘F’ and zero PSIG, then the choice between ON/OFF feedwater control or Modulating feedwater control becomes of great importance as boiler horsepower, volumes and load swings increase.

To gain operating pressure in the boiler drum additional Btu input is required to raise the water temperature from the threshold of 212 degrees ‘F’ steaming temperature to that of operating pressure. The steam tables and the chart below help to expand on this.

Btu Required to Raise Boiler Water to Steaming Temperature at Pressure

Additional BTU Required to Develop 1 Boiler Horsepower vs. Feedwater Temperature

Feedwater	Boiler Operating Pressure										
Temperature	0	25	50	75	100	125	150	175	200	225	250
50	5,766	7,664	8,733	9,492	10,113	10,631	11,079	11,459	11,838	12,149	12,459
100	4,041	5,939	7,008	7,767	8,388	8,906	9,354	9,734	10,113	10,424	10,734
125	3,179	5,076	6,146	6,905	7,526	8,043	8,492	8,871	9,251	9,561	9,872
150	2,316	4,214	5,283	6,042	6,663	7,181	7,629	8,009	8,388	8,699	9,009
175	1,454	3,351	4,421	5,180	5,801	6,318	6,767	7,146	7,526	7,836	8,147
200	591	2,489	3,558	4,317	4,938	5,456	5,904	6,284	6,663	6,974	7,284
212	177	2,075	3,144	3,903	4,524	5,042	5,490	5,870	6,249	6,560	6,870
225		1,626	2,696	3,455	4,076	4,593	5,042	5,421	5,801	6,111	6,422
230		1,454	2,523	3,282	3,903	4,421	4,869	5,249	5,628	5,939	6,249
240		1,109	2,178	2,937	3,558	4,076	4,524	4,904	5,283	5,594	5,904
250		764	1,833	2,592	3,213	3,731	4,179	4,559	4,938	5,249	5,559
260		419	1,488	2,247	2,868	3,386	3,834	4,214	4,593	4,904	5,214
270		74	1,143	1,902	2,523	3,041	3,489	3,869	4,248	4,559	4,869
275			971	1,730	2,351	2,868	3,317	3,696	4,076	4,386	4,697
280			798	1,557	2,178	2,696	3,144	3,524	3,903	4,214	4,524

ON/OFF feedwater control introduces sudden volumes of sub-cooled water at twice the boilers steaming capacity, which results in large excursions in the boiler water temperature, drum level and drum pressure. These excursions reduce boiler performance and fuel to steam efficiency by sub-cooling the boiler feedwater and requiring the burner to over-fire to compensate for the sudden mass/heat upset. While this may be acceptable in small boiler applications, it can become both inconvenient and dangerous in larger boilers.

As an example a 500 Bhp (17,250 PPH) (287 PPM) boiler is operating at 225 PSIG with a boiler water temperature of 397 degrees ‘F’. The boiler is operating at 75% firing rate and 80 percent efficiency producing 12,900 PPH (215 PPM) steam flow (15,686,720 Btu Input). The feedwater system is ON/OFF and has a recovery volume of 3% low water capacity (517.5 Lbs.) at the call for water switch point and a 2% over capacity (345 Lbs.) at a stop water switch point for a total of 5% water recovery capacity. This is 862.5 pounds of water. At the current steaming rate the feedwater cycle is 4.01 minutes (862.5/215).

The feedwater pump in this application would be capable of delivering 575 pounds of water per minute, i.e. twice the maximum steaming rate. Feedwater temperature is 180 degrees ‘F’ as it is assumed no deaerator or economizer is being used since neither of these components can function in an ON/OFF feedwater system.

Thermal Dynamics #1: It takes 1 Btu to raise 1Lb. of water 1 deg. ‘F’ in 1 hour.

Resultant impact on our boiler example:

- 862.5 Lbs. water fed at 575 pounds/minute = 1.5 minutes total delivery time at a 217 degree rise.
- First effect = Boiler water sub-cooled from original 397 degrees ‘F’ to 386.15 deg ‘F’.
  - ✓ 95% of Water @ 397 + 5% Water @ 180 = 377.15 + 9 = 386.15 ‘F’ boiler water.
- Second effect = Steaming pressure falls from 225 to 195 PSIG due to sub-cooling.
  - ✓ Steam Pressure @ 397 ‘F’ = 225 PSIG, Steam Pressure @ 386 ‘F’ = 195 PSIG.
  - ✓ This is a 13% drop in steaming pressure.
- Third effect = Steam nozzle discharge velocity goes form 4,049 to 4,618 Ft./Min. due to specific volume difference between 225 PSI steam and 195 PSI steam. 400 Ft./Min under critical velocity for carry over. Priming most like to occur.
- Fourth effect = The boiler must increase its firing rate by 5,598,600 Btu or 26.76% of total firing rate in 1.5 minutes if it is to recover steaming pressure and temperature before the next feedwater cycle. However since the boiler is already operating at 75% of firing capacity the addition of another 26.76% would mean that the boiler would have to fire at 101.76% to recover. It becomes obvious the boiler will not recover full horspower.
- Fifth effect = Drum level will artificially rise about ½ to 1.0 inch due to the lowered steaming pressure resulting in a short cycling of the drum level control signal and shut the feed supply off ½ inch early.
- Sixth effect = Once boiler drum pressure reaches operating pressure the water level will shrink by ½ to 1.0” due to the higher steaming pressure.

It is obvious the mass/heat balance in the boiler has been upset and a great deal of energy must be expended to recover the upset and bring the process back into balance.

What Really Happens

In actual operation the boiler simply fires at a higher firing rate trying to maintain boiler horsepower, wasting energy, until some semblance of mass/heat balance is made. And if the load is somewhat steady state the occurrences of priming, carryover or high/low water trips are generally tolerated as just a matter of how the system operates.

Conversely if the boiler where to be mass/heat balanced matching pounds of water in with pounds of steam (water vapor) out, the result would be as follows:

12,900 PPH X 217 deg 'F' rise X 1 Hour =2,799,300 Btu/Hr or a 17.84 % steady state increase in firing rate to make up for the sub-cooled feed water. An energy savings of over 17% can readily be realized by moving from an ON/OFF feedwater system to a modulating feedwater system in this example. Plus the additional benefits of reducing priming, carryover, nuisance level trips and improved steam delivery.

Of course once you have committed to a modulating feedwater system you can gain the benefits of pressurized and per-heated feedwater systems and economizers both of which, serve to reduce the amount of additional heat input required for sub-cooled feedwater. (See *Improving Boiler Room Efficiencies, Economizers; D.Farthing)*

Example of the Effect of Feedwater Temperature on Boiler Performance

	Factory Design	As Observed	Deaerator First Recovery	Typical Economizer
Boiler Type Watertube/Firetube	**W**			
Name Plate Rated Boiler BHP	**500**			
Normal Operating Pressure	**225**			
Calculated BTU Input for boiler type	**22,485,674.16**			
Observed Feedwater Temp	**212**	**180**	**225**	**262**
Hours Day Operated	**16**	**16**	**16**	**16**
Days per Month	**22**	**22**	**22**	**22**
Calculated Bhp BTU Output Bhp	**16,732,500.00**			
Calculated Efficiency (Input/Output)	**74.41**			
Calculated Bhp	**500.00**			
Rated Steam PPH at 100% Firing	**17250**			
BTU addition for Operating Pressure	**3,279,750**	**3,918,000**	**3,055,500**	**2,451,750**
BTU Lost/Gained Per Hour	**0.00**	**-552,000.00**	**224,250.00**	**862,500.00**
Boiler HP Lost or Gained/ Hr.	**0.00**	**(16.49)**	**6.70**	**25.77**
Net Boiler Horsepower	**500**	**484**	**507**	**526**
Net Steam Output	**17250.0**	**16680.9**	**17481.2**	**18139.2**
Net Efficiency	**74.41**	**71.96**	**75.41**	**78.25**
Percent Increase/Decrease BHP	**0.000%**	**-3.299%**	**1.340%**	**5.155%**

Boiler Level Control Strategies

Modulating control of the water/steam interface level is normally addressed in one of three principal strategies, single-element, two-element or three-element control. The application of any one of these strategies depends on the specific boiler size (economics) and load variations (dynamics).

Single-Element Control

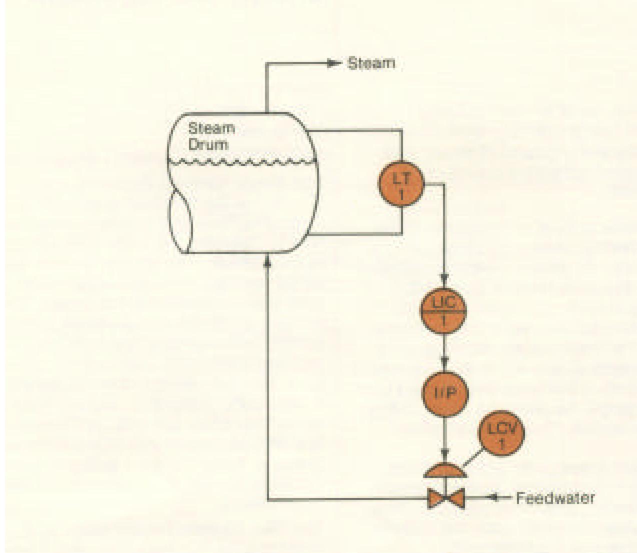
Single-Element control is perhaps the simplest strategy. In this system drum level is measured using a single measurement device and provides a control signal to the feedwater regulator in direct relation to the ***current*** operating drum level. This system is used in both ON/OFF and modulating feedwater control strategies.

The single-element drum level strategy is only effective for smaller boilers with relatively steady demands and slow to very moderate load changes. This is because the shrink and swell effect causes an incorrect initial control reaction, which can lead to over/under filling of the drum. (*See ON/OFF control example above.)*

As steam demand increases, there is an initial lowering of the drum pressure resulting in an artificial rise in drum level as the steam bubbles expand and swell the drum water level. This phenomenon sends a false control signal to reduce feedwater flow, when in fact the feedwater flow should be increasing to maintain mass balance.

Conversely, on a loss of steam demand, there is an initial rising of steam drum pressure which acts to lower the drum level by compressing the steam bubbles and shrinking the drum water level. This sends a false signal to increase feedwater flow when in fact it should be decreasing to maintain mass balance.

FIGURE 2 – Single Element System



Drawing courtiousy of Honeywell

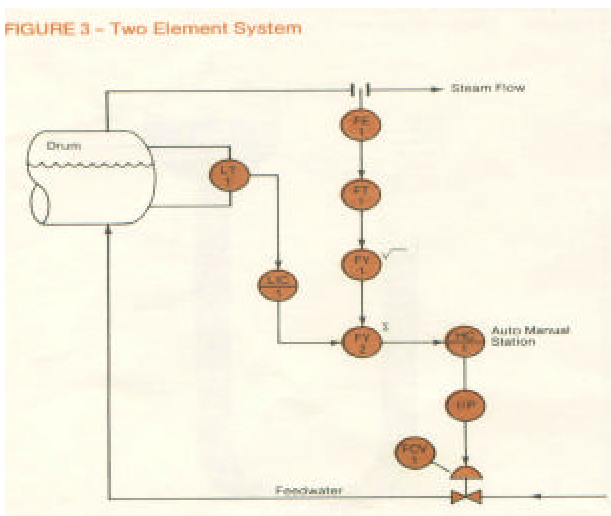
Processes experienceing sudden or large load changes, can result in ‘phasing’ of the shrink and swell effect causing the water level controller to lose control of the drum level and result in nuisance low water trips or high water priming and carry-over.

Two-Element Control

The two-element drum level strategy is suitable for processes with moderate load swings and speeds, and it can be used on any size of boiler. This system uses the two variables, drum level and steam flow to mass balance the feedwater demand.

Drum level is measured and the error between the desired setpoint and the actual control point is sent to a math summer as one of two process variables. Steam flow is measured and added (summed) to the math summer as the second process variable. The result of the math summer is the control output to the feedwater control valve.

Since steam flow is very dynamic, the result of this strategy is that it will sense the rise or fall in load demand before the drum level begins to change. The startegy then adds or subtracts control output to stabilize the reaction of the drum level controller on the feedwater control valve. And since steam flow is normally the larger variable it can easily over ride the trim effect of the drum level measurement on moderate load changes, insuring a correct response to the demand change. During steady load the drum level controller influences the feedwater control valve and acts to trim the level to the desired setpoint.



Two-Element Control, drawing courtiousy of Honeywell

This strategy has two drawbacks, which should be considered. First like the single element strategy the two-element control can not adjust for pressure or load disturbances in the feedwater supply, as this is not a measured variable in this strategy. And second the two-element control cannot eliminate phasing interaction between feedwater flow and drum level because only the relatively slow process of the drum level is controlled. This second issue can lead to sub-cooled drum water on a large increase in demand by allowing excessive feedwater to enter the drum without consideration to the boilers thermal dynamic capabilities.

Three-Element Drum Level Control

To address the issues of phasing still present in the two-element control strategy, a third element, feedwater flow is added to the drum level control strategy. In this system the math summer output of the two-element controller is *cascaded* down to a second *Feedwater Flow Controller* to act as a Remote Setpoint.

The feedwater controller is a fast acting flow controller, which uses feedwater flow as its process variable and steam flow as its setpoint. Thus for every pound of steam flow leaving the boiler a pound of feedwater is added. This loop has final control on the feedwater valve. As the remote setpoint from the two element level control changes with steam flow and drum level variations due to blowdown or other minor losses, the feedwater controller modulates its output to regulate the necessary feedwater flow to keep the drum level in a mass/heat balanced and level state.

Independent tuning of each controller allows for very precise control of the drum level regardless of steam demand and feedwater influences. However it is very important to take the thermal dynamics of the boiler's recovery rate into account when tuning the feedwater controller. If you fail to do this and set the *controller reset* too fast on the feedwater controller you may inadvertently sub-cool the drum and start a cyclic phasing action much like that found in a two-element system. Do the math it will save you a lot of heartache.

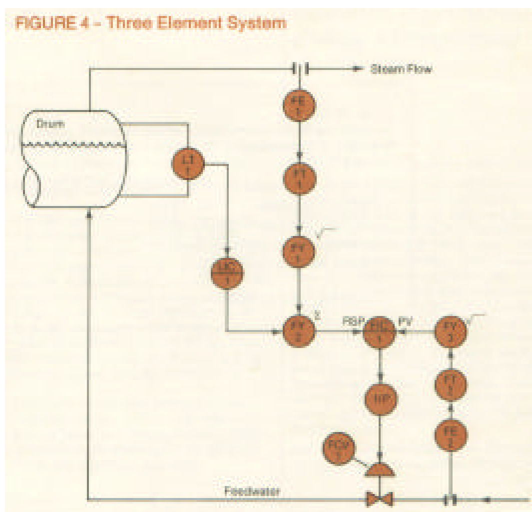


FIGURE 4 - Three Element System

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The three-element control strategy can easily handle large and rapid load changes because it is matching the mass balance between the steam flow from the boiler and the feedwater flow to it. This strategy is a must on multiple boilers sharing the same feedwater header and supply system, due to the variations in the available feedwater flow to any one boiler, while two or more boilers are on line. This is irrespective to boiler size.

Additionally if the boilers are subjected to sudden or unpredictable demand changes such as in a batching process, this strategy is capable of matching these demands without operator trim corrections or supervision.

Conclusion

As you can see from the examples we have evaluated, managing feedwater efficiently does have its practical benefits.

About the Author

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Mr. Farthing combines his twenty-eight years of experience in thermal processes with a degree in General Engineering Technology from Oklahoma State University as well as a degree in Business from the University of Central Oklahoma. He is both a practitioner and academic in the field of boilers and thermal process control systems, as Sales Manager for Federal Corporation and adjunct instructor of *‘Boiler Construction, Operations, and Maintenance’* for Oklahoma State University, Oklahoma City campus.

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