Energy conservation in process heat boilers and heaters – An instrumentation approach

Efficiency improvement is the key word we hear all across in current market condition due to raising fuel cost and global warming issues. Though the manufacturers take lot of care in design of the products for better fuel efficiency, seldom the equipment are delivering the designed efficiency in operating conditions. This could be due to various changes in operating parameters such as fuel quality, operating people skill and knowledge, load pattern of the utilities, etc.

Selection of boiler/heater: Selecting the suitable boiler/heater capacity is crucial for energy saving. Higher capacity equipment operating at part load consumes more energy. A careful study of heat load, minimum, maximum and peak load with duration need to be analyzed while sizing the equipment. Depending upon the equipment selected and operating condition, heat recovery system such as air preheater, water preheater or economizers, condensate heat recovery system should be designed. Adding this at later stage involves shutdown/alteration of ducting and piping/space constraints, etc.

For steam application, we should explore the possibility of cogeneration to maximum extent possible. Replacing the pressure regulating valves with saturated steam turbine also improves plant efficiency in existing installations.

However, more practical approach in evaluation is required before investing in this technology.

Depending upon the fuel used and capacity of the boilers, the energy saving methodology also varies. We will discuss the modalities of saving energy by adopting instrumentation and control for medium size boilers and heaters, as these are used widely in process industries.

Oil fired burners: Burners used are generally pressure jet, modulating type. These burners are economical and good at full load conditions. If the load pattern falls less than 60 per cent always, one may consider derating of the burner. These burners are operated...
with air damper control. For 11 KW and above blowers, providing variable frequency drive helps in good electrical energy saving. Also, it helps in better control of excess air in combustion. Straight replacement of the damper with VFD is not advisable since in lower frequency the pressure of air discharged may not be adequate for combustion. It may also lead to back firing, which is not safe.

Combustion control and O₂ trimming: The combustion controller receives the steam pressure signal from the pressure transmitter and compares it with the fuel demand from the lookup tables. The output of the steam pressure control loop represents fuel demand and is connected to the oil control valve actuator to control fuel flow. The same signal is sent to lookup tables within the controller, which contain the air settings for a certain fuel flow as determined during the combustion test. The signal from the oxygen analyzer is the process input for the excess air (O₂) control loop, which compares it with the fuel demand from the lookup tables. The result becomes the set point for that loop. The output of the O₂ controller is used to trim the output of the pressure control loop. This adjusted signal is connected either to the VFD on the FD fan motor. In this way the boiler is always operating with the correct fuel-air ratio, eliminating the need for seasonal adjustments and compensating for changes in temperature and mechanical wear.

If the boiler isn’t operating at design efficiency due to mechanical wear, old controls or conservative fuel/air settings, upgrading the combustion control system can improve boiler efficiency 5 per cent or more, with a resulting reduction in fuel consumption, or more available steam for the same amount of fuel. It also provides the additional benefits of reducing the need to replace refractory or tubing, and a reduction in the total amount of NOX and CO₂ emissions and significant savings in electricity.

For 6TPH and above capacity the payback is very attractive.

Solid fuel fired boilers and heaters (grate/FBC): In solid fuel firing, sizing the correct capacity is critical as no modulation similar to oil firing is available. Hence, operating under low load condition leads to higher energy loss. Due to the cost advantage of solid fuel in comparison with FO, users are not looking into the wastage seriously and compromising on the efficiency. Boilers are provided with induced draft fan (ID), forced draft fan (FD), secondary air fan and fuel feeders. Fans are invariably 11 KW and above capacity leaving ample scope for
energy saving. VFD’s shall be installed to all the fans and fuel feeders. It is practically not possible to adjust the VFD in manual mode. It throws a good challenge for automation since the fan curves are not linear. Also, for different fuel feed rate the fans are not adjusted in same proportion.

**Automatic Combustion Control:**
Pressure incase of boiler or temperature in case of heater, furnace pressure and O\(_2\) in the stack are to be measured. These signals should be given to a programmable controller. O\(_2\) trimming with online oxygen monitoring is attractive for 8 TPH and above capacity boilers.

The boiler master control loop receives the drum pressure signal from the drum pressure transmitter and compares it with the operator-entered set point. The controller modulates its output in order to eliminate any difference between the signal and the set point. The output of the controller represents the boiler demand for steam and is sent to the variable speed drives on the feeders or distributors if automatic feed control is used and is also sent to the fuel/air ratio station.

**Fuel/Air Ratio Adjustment**
The lookup table entered into the controller during commissioning once the combustion test has been performed. The means of trimming or fine-tuning the fuel-air ratio are provided by online O\(_2\) monitoring.

**Furnace Pressure**
The furnace pressure control loop receives the signal from the furnace pressure transmitter, compares it with the operator-entered set point and generates a correction signal. The total air flow demand output from the fuel/air ratio is characterized in order to linearise the FD to ID speed or position, and is then added as a feed forward signal to the furnace pressure control output. The result is sent to the VFD on the ID fan.

A word of caution in this automation is that combustion control system should be designed involving a combustion specialist and not by mere instrumentation engineering knowledge and skill to ensure safe operation of the boiler under various conditions.

**Boiler water level management**
The surface area and volume of the steam space in the water/steam drum is critical to the efficient separation of the steam bubbles from the water. 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. High water levels increase steam exit velocities and result in priming or boiler water carryover into the distribution system.

**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 kg of steam leaving the boiler with a kg of feed water to replace it. The interface level is subjected to several disturbances due to drum pressure and feed water 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 raises the water level lowers as the steam bubbles compress (shrink).

Feed water, which is lower than steam temperature enters the water/steam drum and will cool the drum water at the entry point to below the operating pressure boiling point. This condenses 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 influence of feed water temperature on packaged boilers is overlooked when selecting a feed...
water strategy. ON/OFF feed water control introduces sudden volumes of sub-cooled water at twice the boiler's steaming capacity, which results in large change in the boiler water temperature, drum level and drum pressure. This reduce boiler performance and fuel to steam efficiency by sub-cooling the boiler feed water and requiring the burner to fire more to compensate for the sudden mass/heat upset.

For example, an 8 TPH boiler is operating at 15-kg/cm\(^2\) pressures with a boiler water temperature of 200 degrees 'C'. The boiler is operating at 75 per cent load and 84 per cent efficiency producing 6,000-kg/hr steam flow. Heat input is 38; 57,143 kcal/hr the feed water system is ON/OFF. The switch set point to normal water level is 3 per cent low for pump ON and water capacity is 240 kg at the ON water switch point and a 2 per cent over capacity 160 kg at pump OFF water switch point. For a total of 5 per cent water filling capacity it is 400 kg of water. At the existing load, the feed water cycle is 400/100 = 4 minutes.

The feed water pump capacity would be 10 m\(^3\)/hr. (166 kg/minute). Consider feed water temperature is 80°C, we shall calculate the heat and mass.

400 kg water fed at 166 kg/min = 2.4 minutes to fill.

- Boiler water sub-cooled from original 200°C to 194°C. 95 per cent of Water @ 200 + 5 per cent Water @ 80 = 190 + 4 = 194 C boiler water.
- Steaming pressure falls from 15 to 13 kg/cm\(^2\) due to sub-cooling. Steam pressure @ 200°C = 15 kg/cm\(^2\), Steam pressure @ 194°C = 13 kg/cm\(^2\) This is a 13 per cent drop in steaming pressure.
- The boiler firing rate increase shall be 9, 00,000 kcal/hr in 2.4 minutes if it is to recover steaming pressure and temperature before the next feed water cycle.
- 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.

- Once boiler drum pressure reaches operating pressure the water level will shrink by ½ to 1.0” due to the higher steaming pressure.

From the above it is clear that the mass/heat balance in the boiler has been upset and additional energy must be spent to recover the upset and bring the process back into balance.

Alternatively, if the boiler where to be mass/heat balanced matching feed water input to the steam output, the result would be as follows:

6,000 kg/hr water to be raised from 80 to 200°C, which amounts to 7,20,000 kcal/hr. This gives a 20 per cent energy saving compared to the ON/OFF water control apart from additional benefits of reduced priming, carryover, nuisance level trips and improved steam delivery.

**Single-element control**

In this system drum level is measured using a level transmitter and a controller provides signal to the feed water control valve. The single-element drum level strategy is only effective for
smaller boilers with relatively steady demands and less load changes. When 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 sends a false control signal to reduce feed water flow, when in fact the feed water 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 feed water flow when in fact it should be decreasing to maintain mass balance.

Processes having 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
This system uses the two variables, drum level and steam flow to mass balance the feed water demand.

Drum level is measured and the error between the desired set point 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 feed water control valve.

Since steam flow is dynamic, it will sense the rise or fall in load demand before the drum level begins to change. The strategy then adds or subtracts control output to stabilize the reaction of the drum level controller on the feed water control valve. And since steam flow is normally the larger variables it can easily over ride the trim effect of the drum level measurement on moderate load changes, ensuring a correct response to the demand change. During steady load the drum level controller influences the feed water control valve and acts to trim the level to the desired set point.

The drawbacks are, like the single element strategy, the two-element control cannot adjust for pressure or load a disturbance in the feed water supply, as this is not a measured variable in this strategy. And the two-element control cannot eliminate phasing interaction between feed water flows and drum level because only the relatively slow process of the drum level is controlled. This can lead to sub-cooled drum water on a large increase in demand by allowing excessive feed water to enter the drum without consideration to the boilers thermal dynamic capabilities.

Three-element drum level control
To avoid phasing which is present in the two-element control, a third element, feed water 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 feed water flow controller to act as a remote set point. The feed water controller is a fast acting flow controller, which uses feed water flow as its process variable and steam flow as its set point. This loop has final control on the feed water valve.

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. In water tube boilers and bi-drum boilers you will observe the shrink and swell effect related problems more, which can be solved by using three-element controls.

Plant master controller
When multiple boilers are connected to a plant this strategy shall be adopted.

A lead/lag option allows boilers to be turned On or Off as the plant demand requires. As the demand increases and the first boiler is at full load, the second boiler is automatically brought on line by the controller. When the second boiler reaches full capacity, the controller brings the third boiler online. When plant demand decreases, the controller automatically shuts down the boilers running at minimum load. The user sets a configurable dead band on the load points and the lead/lag sequence from the front panel of the controller. A digital output from the controller to the Burner Management System (BMS) is provided for each boiler. A digital input for feedback from the BMS indicates that the boiler is online. If the feedback signal is not received, the controller instructs the BMS to light the next boiler in the sequence.

Data Acquisition
"You can not manage what you do not measure” - Peter Drucker

For a steam boiler or heater the following parameters should be measured to know the efficiency.

Steam pressure (boiler), feed water flow, temperature, inlet and outlet oil temperature (heater), fuel flow, flue gas outlet temperature, air inlet temperature, $O_2\%$, $CO\%$ in the exhaust gas.

Data logging system using data logger, paperless recorder or advanced SCADA system with control loop may be incorporated depending upon the complexity of data management. Nevertheless a system is mandatory to improve and monitor the efficiency of the boiler.