Improve boiler efficiency and recover water from flue gas

Syamal Kumar De

Rising energy costs have made it imperative of companies within the process industry to periodically review their energy consumption and diverse methods to improve energy efficiency to improve operating margins. This case study highlights the advantages of a condensing boiler in reducing energy cost.
Energy conservation initiative

Natural Gas (NG) is a very common and clean fuel which is widely used by various industries for steam generation. Natural gas is also well known for its combustible behavior and the most non-polluting and easy-to-combust fuel due to its low C/H ratio. Therefore, it has always been in great demand not only for various industrial uses but also for many domestic applications including usage in car, bus etc to meet stringent norms of the environment. Moreover, it is easy to handle.

In a usual operation of any medium pressure boiler designed for 15 bar saturated steam generation, there are mainly three types of heat losses; conductive and convective heat loss through insulation and radiation, heat loss through blow down and heat loss through exit flue gas. Though, energy loss through insulation, radiation and blow down is minimal, large and sizeable amount of heat energy is lost with the flue gas exited in the atmosphere at high temperature. Recovering this heat energy from this flue gas from various types of boilers is a real challenge (Table 1).

Normally, net calorific value (NCV) of natural gas varies is in the range of 8500-8600 Kcal/sm^3. Having flue gas temperature in the range of 110-115°C in a natural gas fired boiler, boiler efficiency varies in the range of 91-92%. Flue gas temp of different conventional steam boilers using different fuel is given in Table 1 based on our operational experience.

Due to change in Govt policy and huge demand supply gap, natural gas price had radically increased from beginning 2009. Price increase was further coupled by the volatile price of liquefied natural gas (LNG) which was being imported to meet the excess demand. Atul Ltd (Aromatics Division) being an export oriented unit, was badly affected and started losing business mainly on aromatic applications including usage in car, bus etc to meet stringent norms of the environment. Moreover, it is easy to handle.

To achieve the stated objective, M/s Transparent Energy System Pvt Ltd (TESPL), a Transparent Group Company & known for innovative solutions in various fields, was invited to explore and provide a techno-commercially feasible solution for having improved boiler efficiency. After rigorous discussion and technical appraisal, installation of a condensing boiler (the patented technology of TESPL) was proposed by TESPL. Atul was convinced with the techno-commercially feasible solution suggested by TESPL and decided to go for installation of a 24 TPH (tonnes per hour) boiler designed at 14 bar with 3 stages economizers system. This entire condensing boiler was successfully designed, manufactured and commissioned by TESPL in mid 2014 and helped us to achieve the energy conservation objectives.

Boiler efficiency

Any petroleum fuel contains constituents like Carbon (C), Hydrogen (H), Oxygen (O), Sulphur (S), Nitrogen (N) and water or moisture (H_{2}O) etc. in different proportions. Combustion of C,H,S in presence of air releases energy due to exothermic nature of the reaction. Gross Calorific Value (GCV) is defined as the energy released due to combustion of per unit mass of fuel. It is generally expressed in Kcal/Kg or Kcal/sm^3.

Combustion of Hydrogen (H) present in fuel forms water which remains in vapor form in flue gas; let’s call this mass as x_1. Moisture/water present in the fuel also evaporates and remains in water vapor form in flue gas; let’s call this mass as x_2. x_3 is normally very less in natural gas. Combustion also carries atmospheric moisture along with air which also remains in flue gas in vapor form. Let’s assume this mass as x_4. Therefore, total water vapour present in the flue gas is x_1+x_2+x_4.

For evaporation of this total water and reach to flue gas temperature requires energy, known as enthalpy, which is taken away from the gross energy released during combustion process. As a result, heat carried away by the water vapour in the flue gas is not available for steam generation. It is directly lost in the atmosphere. The air and the combustion products other than water (CO_{2}, CO, NO_{x}) and nitrogen also take away a significant amount

<table>
<thead>
<tr>
<th>Steam Boiler using different fuel</th>
<th>Flue Gas Temp</th>
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<tr>
<td>1. Coal Fired Boiler</td>
<td>160-170°C</td>
</tr>
<tr>
<td>2. Furnace Oil Fired Boiler</td>
<td>170-180°C</td>
</tr>
<tr>
<td>3. Conventional Natural Gas fired Boiler</td>
<td>110-115°C</td>
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<tr>
<td>4. Condensing Boiler, Natural Gas fired</td>
<td>53-56°C</td>
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Table 1. Heat recovery from flue gas from different types of boilers
of heat.

Hence, GCV minus heat lost in the water vapour, inerts and combustion products per unit mass of the fuel is called Net calorific Value (NCV). Boiler efficiency is calculated based on NCV of the fuel as heat carried or lost with water vapour is any way not available for heat transfer. It is NCV which is available for heat transfer in the boiler for steam generation.

Condensing boilers use heat from exhaust gases that would normally be released into the atmosphere as flue gas. To use this latent heat, the water vapour from the exhaust gas is turned into liquid condensate through heat exchange of cold demineralized feed water which is preheated in a specially designed condensing economizer. Due to this process, a condensing boiler is able to extract more heat from the fuel it uses than a standard boiler. It also means that less heat is lost through the flue gases.

Flue gas temp coming out from the boiler at 330-340°C is passed through the 1st stage non-condensing economizer and decreased to 170-175°C. Then it is again passed through a 2nd stage non-condensing water pre-heater where temp is reduced to 80-85°C. Finally it is passed through a 3rd stage condensing economizer where final temp of the flue gas is further reduced down to 53-55°C by preheating the boiler feed make up water fed at 31°C. Reducing the flue gas temp from 33°C to 55°C is very unique in industrial boiler operation. This serves two purposes at a time.

1. It helps in improving thermal efficiency by lowering NG consumption for unit production of steam. A schematic diagram of condensing boiler showing reduction in flue gas temp in stages is given below.

   Efficiency of the natural gas fired boiler at different flue gas temperature is shown in the Fig 1. At 55°C flue gas temp, boiler efficiency is ~ 100% compared to 91-92% in a conventional boiler having flue gas temp of 110-115°C. At 45°C flue gas temp, boiler efficiency can be as high as 103% setting a new benchmark.

2) Recovering water from the flue gas. Due to low C/H ratio, burning of 1 mole methane (Molecular weight of methane is 16) generates 2 moles of water (Molecular weight of water is 18). Therefore, combustion of 16 kg methane generates 36 kg water on complete combustion with sufficient air which is carried away with the flue gas in the form of vapour. This water is generally lost in the atmosphere. Cooling down the flue gas temp below dew point and recovering the water from the flue gas directly leads to conservation of natural resource. Latent heat of condensation of water from flue gas is indirectly used for preheating the boiler feed water entering @ 31°C.

   Estimated natural gas saving per year at different capacity condensing steam boiler is given Fig 3 based on actual operational experience of condensing boiler of Atul Ltd. Min 3 Sm³ natural gas can be saved per MT of steam generation Vs conventional boiler. NG saving can be increased upto 4 to 5 Sm³ per MT of steam generation depending of the lower flue gas temp and efficient design.

   Installation of 24 TPH condensing boiler had led to saving of 550000 Sm³ natural gas per year @ 80% load and value addition of more than ₹1.7 Cr on account of only energy conservation.

   About 60,00,000 litres water is recovered per year by condensation from flue gas at flue gas exit temp of 55°C. This is almost 40% water recovery from the flue gas. Condensed water is little acidic and pH varies in the range of 3-4. This water is used and recycled in the process for suitable use.

   Acidity is mainly due to presence of mainly weak carbonic acid formed by scrubbing of carbon di-oxide gas with condensed water at lower temp. This CO₂
able use in the process with the by-pass arrangement of the condensing section to have flexibility in flue gas shift.

4) Pressurized de-aeration tank to remove dissolved oxygen from feed water by steam sparging.

Benefits of installation of condensing boiler:
1. Boiler efficiency can be increased > 100% depending on the temperature of condensate return.
2. Minimum 3 Sm³ natural gas can be saved per MT of steam generation Vs conventional boiler. NG saving can be increased up to 4 or 5 Sm³ per MT of steam generation depending on the lower flue gas temp and efficient design.
4. De mineralized water recovery from flue gas leading to conservation of natural resource.
5. Reduction in CO₂ emission in the atmosphere.
6. Low ambient temperature due to lower flue gas temp in chimney (50-55°C).

Installation of condensing boiler has gained the momentum in all developed countries to reduce energy cost. Population of such boiler installation has been limited in India. However, it is always better late than never and therefore, Atul did it for a larger goal.

Editor’s Note: Atul Ltd (Aromatics Division) has successfully installed 24 TPH condensing boiler designed at 14 bar steam pressure for conservation of energy and natural resource which is in operation for more than a year. M/s Transparent Energy System Pvt Ltd (TESPL), Pune, has engineered and successfully installed the entire system for Atul Ltd. This has resulted in savings of 5,50,000 Sm³ natural gas and conservation of 60,00,000 liters of water per year.