Boiler Efficiency calculations

Efficiency is a very important criterion in Boiler selection and Design. Efficiency figure depends upon the type of boiler as well as on the type of fuel and it's constituents. For example, efficiency of a Bagasse fired boiler is about 70% where as that of oil fired boilers is about 85 %. Higher moisture content in Bagasse reduces it's efficiency. So better criterion is efficiency based on LCV or NCV. This is widely used in Europe and efficiency based on HHV or GCV is used in other parts of the world.

There are basically two methods to calculate efficiency of the boilers : Input-Output method and Heat Loss method. In Input-output method, boiler must be in steady running condition and the data of heat input in the form of fuel and air and heat output in the form of steam and other losses is taken.

Here we are going to discuss the second and more popular method. In this method, first we calculate the heat input. Then all heat losses are calculated. Effective heat output is heat input less the heat losses. Output to Input ratio gives the efficiency.

Heat losses in fired boiler are :

a) Dry gas losses
b) Loss due to moisture in fuel
c) Loss due to moisture formed during combustion
d) Loss due to moisture in combustion air
e) Unburnt fuel loss
f) Loss due to radiation from Boiler to surroundings
g) Manufacturers Margin OR unaccounted losses

Sample Case :

Let us calculate Boiler efficiency of coal fired boiler. Ambient temp is 80 F and Back End Temperature (Exh gas temp) is 302 F. The percent composition of Coal is as under:

Carbon , C - 76.0 ; Hydrogen, H_2 - 4.1 ; Nitrogen , N_2 - 1.0 ; Oxygen, O_2 - 7.6 ; Suphur, S - 1.3 ; Moisture, H_2O - 3.0 ; Ash - 7.0 ;

The Combustion calculations of the above fuel is already explained in detail in the other article.

From the above calculations, Unit Wet Gas, Kg / Kg of fuel = Unit Wet Air + (1-Ash)

= 13.12 + (1-0.007)

= 14.05

Unit Dry Gas, Kg / Kg of fuel = Unit Wet Gas – (Moisture in Air + Water produced during combustion)

= 13.484

Higher Heating Value, HHV or Gross Calorific Value, GCV in BTU/Lb

$= 14600.C + 62000 (H_2 - O_2/8) + 4050.S$

Lower Heating Value, LHV or Lower Calorific Value, LCV or Net Calorific Value, NCV, BTU/lb

$= HHV - 1030(9.H_2 + Moisture)$

Let us use HHV and LHV notation.

$HHV = (14600 \times 76 + 62000 (4.1 - 7.6/8) + 4050 \times 1.3)/100$
$= 13101.65$ BTU/lb (7278.7 Kcal/kg)
$LHV = 13101.65 - 1030(9*4.1+3)/100$
$= 12690.6$ BTU/lb (7050 Kcal/kg)

Calculations of the Losses based on Higher Heating Value:

a) Dry gas losses:

Exhaust gases always leave the boiler at a higher temp than ambient. Heat thus carried away by hot exhaust gases is called Dry gas losses

Heat Losses, $La = UnitDryGas \times Cp \times (Tg-Ta) \times 100/HHV$
$= 13.478 \times 0.24 \times (302 - 80) \times 100 / 13101.65$
$= 5.48$ %

b) Loss due to Moisture in fuel :

The moisture present in the fuel absorbs heat to evaporate and get superheated to exit gas temperature.

$Lb = MoistureInFuel \times (1089 - Ta + 0.46 \times Tg) \times 100/HHV$
$= 0.03 \times (1089 - 80 + 0.46 \times 302) \times 100 / 13101.6$
$= 0.263$ %

c) Loss due to Moisture Produced during combustion :

$Lc = MoistureProduced \times (1089 - Ta + 0.46 \times Tg) \times 100/HHV$
$= 0.369 \times (1089 - 80 + 0.46 \times 302) \times 100 / 13101.6$
$= 3.23$ %

d) Loss due to Moisture in air :

$Ld = MoistureInAir \times Cp\ of\ Steam \times (Tg-Ta) \times 100/HHV$
$= 0.0132 \times 12.95 \times 0.46 \times (302 - 80) \times 100 / 13101.6$
$= 0.133$ %

Here, Moisture in Air = 0.0132 lb/ lb of dry air at 60% Relative Humidity

Cp of steam = 0.46

e) Unburnt fuel loss :

This is purely based on experience. Unburnt fuel loss depends up on type of Boiler , grate, grate loading and type of fuel. For Bio-Mass fuels, it ranges from 1.5 to 3 %, for oils from 0-0.5 and almost nil for gaseous fuels.

Let us consider Unburnt fuel loss, Le = 2.5 % for Coal.

f) Radiation Loss:

Radiation Loss is because of hot boiler casing loosing heat to atmosphere. ABMA chart gives approximate radiation losses for fired boilers.

Let us take a radiation Loss , Lf = 0.4 % in this case.

g) Manufacturer's margin :

This is for all unaccounted losses and for margin. Unaccounted losses are because of incomplete combustion carbon to CO, heat loss in ash ..etc. This can be 0.5 to 1.5 % depending up on fuel and type of boiler.

In this case, let us take, Manufacturer's margin Lg = 1.5%.

Total Losses = La + Lb + Lc + Ld + Le + Lf + Lg

= 5.48 + 0.263 + 3.23 + 0.4 +0.133 +2.5 + 1.5

= 13.506 %

Therefore, Efficiency of the boiler on HHV basis = 100 – Total Losses

= 100 – 13.506

= 86.494 %

<u>Efficiency based on LHV:</u>

Efficiency based on LHV = EfficiencyOnHHV x HHV/LHV

= 86.494 x 13101.6/12690.6

= 89.29 %