Fundamentals of Combustion and Heat Losses

The principles of combustion are common to heaters, boilers and other forms of industrial combustion, e.g. in furnaces and kilns. Conventional fuels consist mainly of two elements – carbon and hydrogen. During combustion, they combine with oxygen to produce heat. The fuel value lies in the carbon and hydrogen content.

Ideally, combustion breaks down the molecular structure of the fuel; the carbon oxidizes to carbon dioxide (CO_2) and the hydrogen to water vapour (H_2O). But an incomplete process creates undesirable and dangerous products. To ensure complete combustion, even modern equipment with many features must operate with excess air. That is, more air is passed through the burner than is chemically required for complete combustion. This excess air speeds up the mixing of fuel and air.

On one hand, this process ensures that nearly all the fuel receives the oxygen it needs for combustion before it is chilled below combustion temperatures by contact with heat exchange surfaces. It also prevents fuel that is not burned completely from exploding within the boiler.

On the other hand, excess air wastes energy by carrying heat up the stack. A fine line exists between combustion efficiency and safety in ensuring that as little excess air as possible is supplied to the burner.

Dry flue gas loss (LDG)

Heat is lost in the "dry" products of combustion, which carry only sensible heat since no change of state was involved. These products are carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), nitrogen (N_2) and sulphur dioxide (SO_2). Concentrations of SO_2 and CO are normally in the parts-per-million (ppm) range so, from the viewpoint of heat loss, they can be ignored.

Calculate the dry flue gas loss (LDG) using the following formula:
LDG = **[24** + **DG** + **(FGT** x **CAT)]** / **HHV,**
where
DG (lb./lb. fuel) = $(11CO_2 + 8O_2 + 7N_2) \times (C + 0.375S) / 3CO_2$
FGT = flue gas temperature, °F
CAT = combustion air temperature, °F
HHV = higher heating value of fuel, Btu/lb.
CO_2 and O_2 = percent by volume in the flue gas
$N_2 = 100 - CO_2 - O_2$
C and S = weight fraction in fuel analysis

Tip: Minimizing excess air reduces dry flue gas losses.

Loss due to moisture from the combustion of hydrogen (LH)

The hydrogen component of fuel leaves the boiler as water vapour, taking with it the enthalpy – or heat content – corresponding to its conditions of temperature and pressure. The vapour is a steam at very low pressure, but with a high stack temperature. Most of its enthalpy is in the heat of vaporization. The significant loss is about 11 percent for natural gas and 7 percent for fuel oil. This loss (LH) can be calculated as follows:

LH (%) = **[900** + **H_2** + **(hg** x **hf)]** / **HHV, where**
H_2 = hydrogen weight fraction in fuel analysis
hg = 1055 + (0.467 - FGT), Btu/lb.
hf = CAT - 32, Btu/lb.
Where hg is hydrogen (gas) and hf is hydrogen (fuel).
Tip: Only a condensing heat exchanger will reduce this loss appreciably.

Loss due to radiation and convection (LR)

This loss occurs from the external surfaces of an operating boiler. For any boiler at operating temperature, the loss is constant. Expressed as a percentage of the boiler's heat output, the loss increases as boiler output is reduced. Hence, operating the boiler at full load lowers the percentage of loss. Since the boiler's surface area relates to its bulk, the relative loss is lower for a larger boiler and higher for a smaller boiler.

Losses that are unaccounted for (LUA)

For reasons mentioned earlier, use an assumed loss value of 0.1 percent for natural-gas-fired boiler systems and 0.2 percent for oil-fired systems.

Then, calculate efficiency as follows:
Efficiency (E) % = **100** x **LDG**x **LH**x **LR**x **LUA,**
where
LDG= Dry flue gas loss
LH = Moisture from hydrogen loss
LR = Radiation and convection loss
LUA= Unaccounted for losses

The simplest way to calculate fuel-to-steam efficiency is the direct method of calculation

Direct Method for Calculating Boiler Efficiency

1. Measure steam flow via kg (or lb.) over a set period. Use steam integrator readings, if available, and correct for orifice calibration pressure. Alternatively, use the feedwater integrator, if available, which will in most cases not require a correction for pressure.

2. Measure the flow of fuel over the same period. Use the gas or oilintegrator, or determine the mass of solid fuel used.

3. Convert steam flow, feedwater flow and fuel flow to identical energy units, e.g. Btu/lb. or kJ/kg.

4. Calculate the efficiency using the following equation:
   Efficiency = 100 X (steam energy - feedwater energy) ÷ fuel energy

Reference:
http://oee.nrcan.gc.ca/publications/infosource/pub/cipec/2000-869_Boilers_and_Heat_E.pdf