Student Study Section

Understanding High Efficiency Boilers

produced by the TSB Domestic Heating Group

As part of the Institute's Code of Professional Standards, members are asked to follow the discipline of PD to help assist them in keeping up-to-date with current and new developments.

The following article and question paper can contribute to a maximum two hours study time, as part of your formal PD as a member of the IoP. PD is an important aspect of the Institute's ethos, bringing credit to all those who enter into such a commitment in order to remain competent.

At the end of the article, there are 10 questions to complete to enable you to assess your understanding of the subject.

High Efficiency Boilers

The secret of high efficiency boilers lies in the products of combustion, to understand this we must first look at the requirements for combustion. Natural Gas consists of a combination of gasses.

Nitrogen (N_2) 3%
Carbon Dioxide (CO_2) 0.3%
Propane (C_3H_8) 2%
Ethane (C_2H_6) 4.3%
Methane (CH_4) 90%
Butane (C_4H_{10}) 0.4%

As you can see the main gas is Methane. For ease of calculation we will call Natural Gas – Methane. To allow Methane to burn correctly we must introduce two other components, Oxygen and some form of ignition. For correct combustion Methane requires two volumes of Oxygen for every volume of gas. To allow us to introduce the Oxygen we must add almost ten volumes of air (9.54 to be exact), as Oxygen is approximately one fifth the content of air. Nitrogen is the remaining four fifths.

The formula is:

$1\ CH_4 + 2\ O_2 + 7.54\ N_2$

We must now introduce some form of ignition. This mixture of Methane and Oxygen will ignite at 704°C. When ignited the burning gasses produce Carbon Dioxide and water vapour, the Nitrogen does not burn.

The completed formula is:-

$\therefore\ 1\ CH_4 + 2\ O_2 + 7.54\ N_2$

ignition temperature 704°C

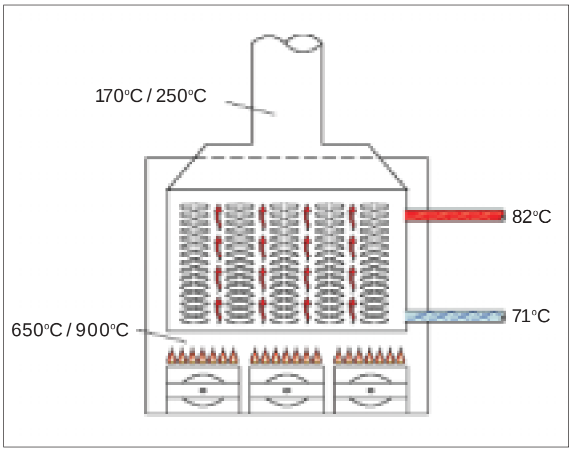
$= 1\ CO_2 + 2\ H_2O + 7.54\ N_2$

The interesting flue gas in relationship to high efficiency boilers is the H_2O. This is water vapour but due to the high temperature of the flue gasses, approximately 170/250°C when measured in the flue, the vapour is steam. This steam contains energy, which is discharged through the flue into the atmosphere. A high efficiency boiler uses this normally wasted heat and converts it to useful energy.

You can see from figure 1 that the approximate temperature in the combustion chamber is in the region of 650 – 900°C (dependant on design). The flue gasses – not the flames – pass through the heat exchanger where it loses most of its heat to the water contained in it.

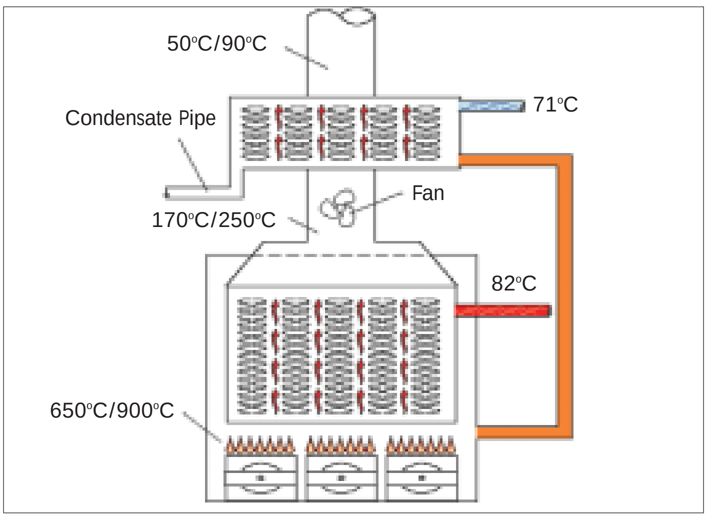
The flow pipe will reach its working temperature of 82°C and a correctly sized pump will return the water 11°C cooler. The flue gasses are collected in the collector hood, which is attached to the flue pipe. You can see that the temperature in the flue pipe is in the region of 170/250°C.

Figure 1



It doesn't take a genius to realise that we are throwing away, via the flue pipe, some useful heat. To utilise this heat – known as sensible heat – we could fit an extra heat exchanger in the flue.

Figure 2



As the flue gasses are relatively cool in comparison to the gas flame and in order to gather as much heat as possible, it would be reasonable to pass the coolest water in the heating system through this new heat exchanger. The coolest water in a heating system is the return water. The heat in the flue gasses will increase the temperature of this returning water, before it enters the boiler via the return connection (modern high efficiency boilers incorporate two heat exchangers in one unit).

It may be possible to increase the return temperature by as much as 5°C, this means that the gas will only have to raise the temperature a further 6°C, therefore using less gas to achieve the same output.

As a result of this heat exchange, the flue gas temperature will decrease, the kinetic energy of the flue gasses will reduce, therefore they will have less buoyancy and a fan is required to assist the exit of the gasses.

As the flue gasses cool, the water vapour that was originally steam condenses into a liquid. This happens when the flue gas temperature reduces to 55°C and below (dew point of flue gasses). The boiler requires a sump to collect this liquid and a discharge pipe to remove it. The PH of the condense is approximately 4.5, which is mildly acidic, therefore heat exchangers in condensing boilers are usually manufactured from stainless steel or aluminium. Due to the cool temperatures of the flue gasses, pluming will occur at the flue exit point and care must be taken to avoid nuisance.

So, the flue gasses on a standard boiler are in the region of 170/250°C, on a high efficiency boiler they are approximately 50/90°C because we have taken heat out of them to increase the temperature of the returning water. We know that this is called sensible heat. There is also something called latent heat, this is the heat released when steam is turned back into a liquid (55°C). Quite simply, the heat that is required to turn a liquid into steam will be released when steam condenses back into a liquid.

To help us understand this we need to look at the following:

If we had a gram of water, which had a temperature of 50°C we would require 2382 joules of heat to turn this water into steam. But on a standard boiler we already have this steam, so if we could condense it back to water it will release its energy – at a rate of 2382 joules/gram.

We know that an 18kW boiler (60,000 btu/hr), produces 1.5 litres of condense when the water enters the secondary heat exchanger at 50°C. Using this information we can now calculate the “free heat” that can be utilised from this process.

1.5 litres weighs 1.5 kg = 1500 grams.

Each gram produced will release 2382 joules.

Therefore 1500 x 2382 = 3,573,000 joules.

If we then divide by the number of seconds in an hour – 3600 – we would have an answer in joules/second (one joule/second is equal to one watt).

3573000 = 992.5 joules = 992.5 watts = (0.99kW).

3600

If we express this additional energy as a percentage of the boiler size we can see that 0.99kW is 5.5% of 18kW.

Due to the extra area of the secondary heat exchanger, a high efficiency boiler is still 6% more efficient than a standard boiler when it is not condensing (sensible heat). With a return temperature of 50°C, the boiler is an extra 5.5% more efficient (latent heat), therefore at 50°C a high efficiency boiler is 11.5% more efficient than a standard boiler.

April 2002 saw the introduction of SEDBUK (Seasonal Efficiency Domestic Boilers United Kingdom), this measure looks at the annual seasonal efficiency (summer & winter) and shows us that a Grade A boiler at 90% is 13.7% more efficient than a Grade D boiler at 78%.

The simple graph below shows us that the cooler the return temperature, the more efficient the boiler.