COMBUSTION EFFICIENCY

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The efficiency of a heating appliance or application is dependent on the efficiency of the combustion process. Complete combustion with the appropriate flame is necessary to release the maximum amount of energy available. The efficiency of combustion is affected by the ratio of air to fuel, the degree of atomisation of liquid fuels, the degree of air and fuel mixing that takes place in the combustion zone, the flame shape, temperature and speed. The setting of these variables requires skill and instrumentation and is best automated.

INTRODUCTION

The process of combustion must be optimised in order to achieve the best possible efficiency of a heating appliance or application. To optimise the combustion process, knowledge of the factors that affect combustion is necessary. Combustion in its most simple terms is the process of chemically converting fuel, which consists of carbon and hydrogen in the presence of oxygen, into carbon dioxide (CO_2) and water (H_2O), thus releasing heat in the process. The process becomes less efficient when there is incomplete combustion, which results in the formation of carbon monoxide (CO), and excess air that uses up sensible heat. The factors that lead to incomplete combustion are described below and acceptable limits are given.

AIR TO FUEL RATIO

The process of combustion depends on an optimum mixture of air and fuel such that there is just enough oxygen to chemically bond with every carbon and hydrogen atom in the fuel. This ratio is known as the stoichiometric ratio. Unfortunately, in practice, it is virtually impossible to achieve the degree of fuel and air mixing required to ensure every molecule of oxygen finds a carbon or hydrogen molecule. Thus a certain amount of excess oxygen is required to ensure that every carbon and hydrogen molecule is found by an oxygen molecule. The range of excess oxygen required to achieve complete combustion is generally 1% - 5%, depending on the combustion appliance. This implies an excess air requirement of 5% - 25%, as there is approximately 21% oxygen in air. The oxygen (O_2), CO and CO_2 can be measured in the combustion gas stream in the flue or stack.

When setting up the air to fuel ratio in a combustion appliance, the starting point is a rich mixture (excess air) which is then tuned back until the CO starts reading at 5 – 10 parts per million (ppm). At this time the CO_2 should be peaking and the oxygen content should be at its lowest practical limit. It is expected that boilers would have excess oxygen of 2% - 3%, glass furnaces 1% - 2% and sand driers/stone heaters 3% - 5%.

Diagram-I shows the theoretical increase of oxygen and CO as the percentage of air moves away from the stoichiometric point for a typical heavy furnace oil. The reason for ensuring the minimum amount of excess air is that the excess air is heated up in the appliance and thus takes up and carries away some sensible heat. Typically the energy loss due to excess air is in the order of 1,2% for every 10% of excess air by volume.
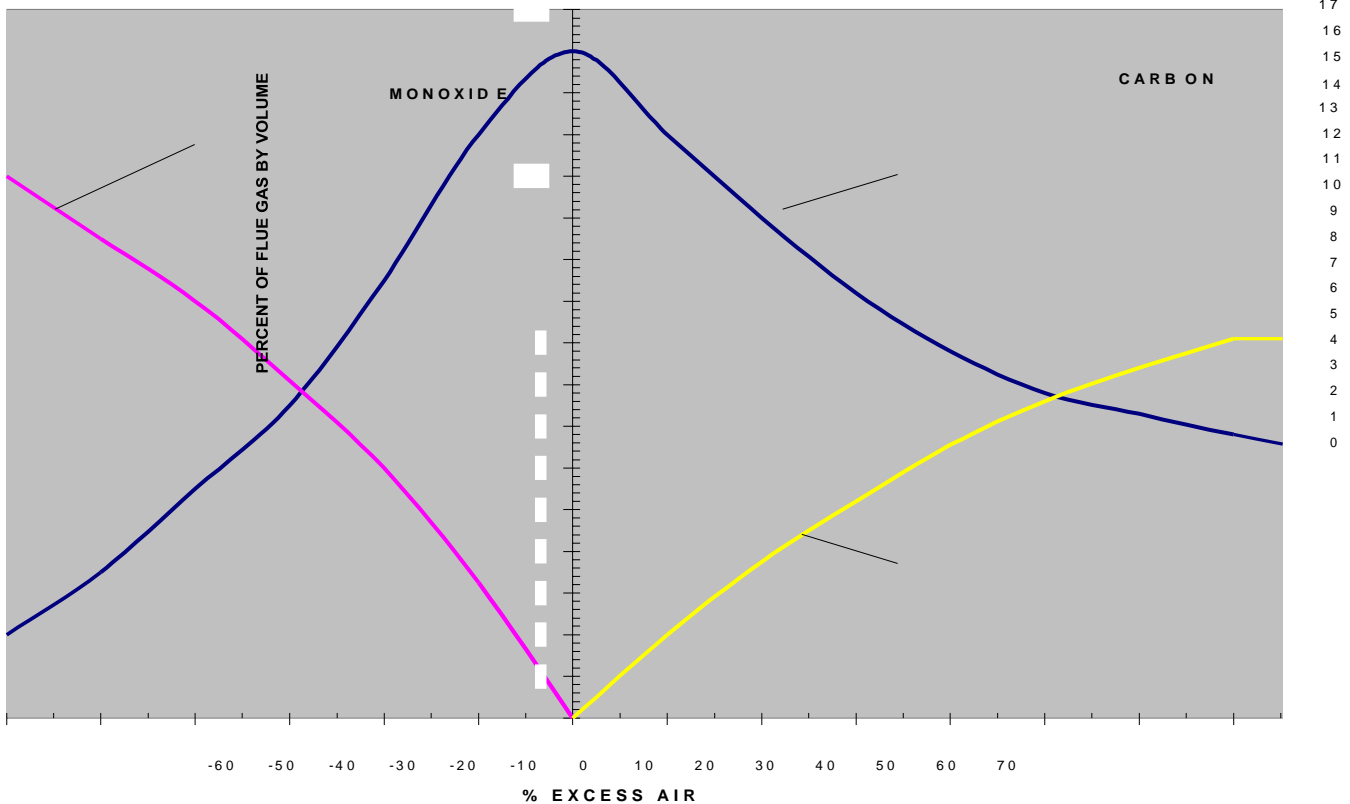
FLUE GAS ANALYSIS

Diagram-I

ATOMISING

To achieve complete combustion of a liquid fuel, the oil must be dispersed into the combustion air in an even spray of fine droplets. The droplets must be sufficiently small to allow for the combustion process to take place in the available time within the flame. The degree of atomisation achieved is a function of the burner design, the pressure of the fuel supply to the burner, the pressure of the atomising air or steam and the viscosity of the fuel. It is generally accepted that the viscosity of the fuel must be below 20 centiStokes (cSt) for adequate atomisation to be achieved. This limit is dependent on the effectiveness of the burner design, especially of the burner nozzle. Although fuel oils differ in viscosity at a given temperature, an increase in temperature will reduce their viscosity. Thus, heavy fuel oils, with high ambient-temperature viscosities, can be used by simply pre-heating the fuel oil before it is fed to the burner.

The pressure of the fuel oil and the atomising air or steam at the burner is also vitally important. The range of fuel oil pressures is entirely dependent on the burner design and can range from 200 – 3000 kPa. The burner manufacturers supply the pressures required for their burners.

It is again generally accepted that the droplet size required must be less than 50 microns, although this figure has almost no practical value as it is exceedingly difficult to measure the droplet size in operation. Ensuring the effectiveness of atomisation is thus an observed and deductive process in practice. If the droplets are too large then this will be visible as sparklers emerging from the end of the flame and as black smoke emissions. This is caused by un-burnt fuel, which will give high CO readings and may result in deposits in the combustion chamber, even when there is sufficient excess oxygen present.

The primary causes of poor atomisation are as follows:

1.   Worn nozzles
2.   Insufficient fuel-oil pressure
3.   Excessive fuel oil viscosity or insufficient fuel oil temperature
4.   Insufficient atomising air or steam pressure
5.   Incorrect burner nozzle size (excessive turn-down)
6.   Poor burner nozzle design
7.   Excessive turn-down (low flame)

The most common efficiency losses in practice are from a failure to routinely replace worn nozzles and worn pumps.

FUEL-AIR MIXING

The mixing of the fuel and air is another critical process that must be optimal to ensure that efficient combustion takes place. The fuel, whether gas or liquid, must be evenly dispersed in the combustion air stream such that the fuel and air can make intimate contact. Failure to achieve this results in un-burnt or partially burnt fuel. The burner design attempts to achieve this using a variety of techniques. What is important to the user is that the burner is kept in good working order and the settings recommended by the burner manufacturer are adhered to. This is particularly important with respect to swirl plates and grooves that introduce the necessary turbulence.
The main causes of poor mixing are:

1.   Imbalanced fuel oil and atomising air/steam pressures
2.   Incorrectly set up burners (settings, alignment)
3.   Worn burner parts
4.   Damaged or badly made burner tile or quarl.
5.   Dirty or blocked swirl plates

FLAME SHAPE AND SIZE

Combustion appliances require, and different burners provide, a variety of flame shapes and sizes. The combustion appliance design will dictate the required size and shape of the flame. The flame should be sized and shaped to reach the heat transfer zone without impinging on the refractory or firing tube. Thus a short bushy flame that does not extend over the radiant heat transfer area will not be as efficient as a longer flame that does. A glass furnace requires a long lazy flame that covers the surface of the melt bed, while an air heater may require a short bushy flame to save combustion chamber space. A flame that impinges on the wall of the combustion appliance will usually cause damage from localised overheating, resulting in costly repairs. Impingement can usually be seen if the appliance has strategically placed peepholes and occasionally from white smoke emissions.

Heavy fuel oils require more time to achieve full combustion than light oils and gas (*0,1 seconds for HFO, 0,01 seconds for a light oil and 0,001 seconds for gas*). Thus the length of the flame or combustion zone is important. Flame shape is thus important as short flames may not provide sufficient residence time for complete combustion and "woolly" flames result in un-burnt fuel escaping from the sides of the flame.

Burner settings can be used to change the flame shape. An increase in the fuel-air pressure will broaden the flame, while and increase in the primary air will shorten the flame. High velocities and good mixing will produce short bushy flames, while low velocities and poor mixing will produce long lazy flame of high radiance.

The burner tile or quarl is important as it determines the initial shape of the expanding flame. If the initial angle is too wide the flame may not be sustainable and this will result in un-burnt or partially burnt fuel. The quarl, firing tube and refractory all help to stabilise a flame and improve the combustion efficiency.

Heat losses
Useful heat is lost in the following ways:
1. Poor combustion 0% - 20%
2. Insufficient radiance 5% - 15%
3. Wall loss from poor insulation 2,5% - 15%
4. Out of the stack 2% - 10%
5. Excess air 0,5% - 3%

Stack Losses
The heat load in the combustion gas exiting the stack is a loss of useful energy. Therefore the stack temperature should be kept as low as possible. This can be achieved with adequate routine cleaning of the heat transfer surfaces and by limiting the amount of excess air introduced. Stack temperatures should be measured and recorded to plan such routine cleaning and to achieve optimum efficiency. If the stack temperature, the O_2 and the CO_2 content are known, the amount of heat loss can be read from Diagram-2 as shown below for a typical heavy fuel oil. Entering the graph from the left with the measured amount of CO_2 of 10,9% on a dry basis, then moving down from the dry CO_2 curve to the 220°C stack temperature interpellation curve, gives a percentage loss on the right-hand scale of 11%. If the stack temperature were to increase to 420°C then the stack loss would increase to 21%, or a further 10%.
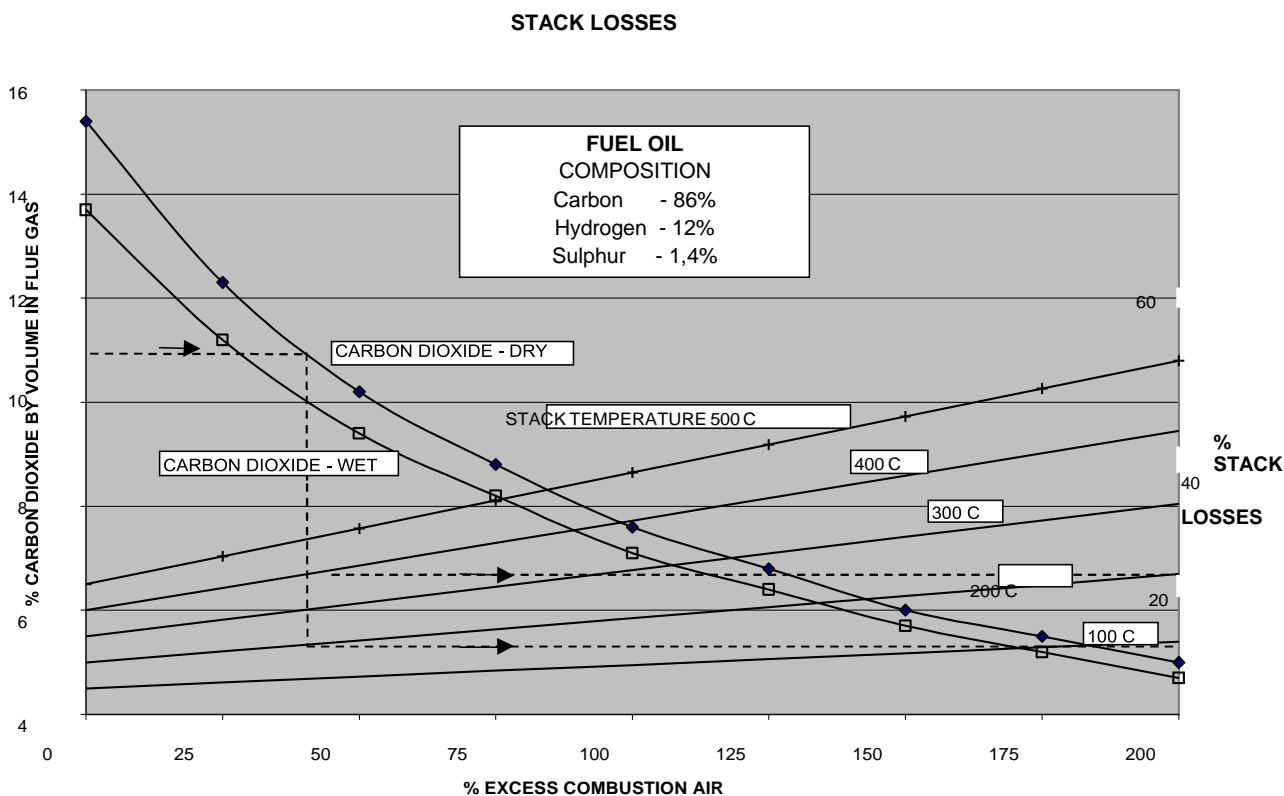
STACK LOSSES

Diagram 2

MEASUREMENT

It is virtually impossible to set the air:fuel ratio of a burner to achieve maximum CO_2, minimum CO and minimum excess air by human eye alone. Different fuels produce different flame colours, impurities change the flame colour and the human eye is not able to detect CO or O_2. It is thus imperative that some form of measuring device is used on a regular basis. The old chemical dragger gas devices such as the Fire Rite is useful for spot sampling, but there are any number of electronic devices available on the market that will provide continuous readout and recording of the stack temperature, CO_2, CO and O_2. More importantly these instruments can be used to automatically control the air:fuel ratio even with a modulating burner. Such a system can save a significant amount on the fuel bill and will quickly pay for itself.

CONCLUSION

From an operational point of view, the combustion process is simple enough for all to understand to the level required to run an efficient system. The measurement and data logging capabilities of modern instrumentation allow for cost effective control and management of heating appliances. Very significant cost savings can be made by optimising the combustion efficiency.

REFERENCES

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