COMBUSTION TRIM FOR BOILERS

This Infosheet contains information about:

- *the areas where energy is lost;*
- *combustion efficiency;*
- *determining gas flue losses; and*
- *the costs and benefits of oxygen trim systems.*

For boilers, oxygen trim systems can usually reduce energy consumption by 1.5–2%, typically resulting in a payback period of 18 months–3 years.


Picture courtesy of Novatech Controls P/L

Introduction

Fuel-burning appliances need to achieve an optimum fuel-to-air ratio so they can maximise the efficiency of the combustion process whilst maintaining safe (minimisation of carbon monoxide) and stable operation.

Many boiler installations could presently be operating at less than optimum conditions; indeed, fuel efficiency could be more than 5% below optimum. This represents a significant economic cost as well as an unnecessary contribution to carbon dioxide emissions.

Maintenance of the oxygen trim leads to the economical and safe operation of the combustion system and so sets the economic limits for boiler efficiency. The savings made as a result of installing this system will, in the end, outweigh the capital outlay. The costs associated with installation should be weighed against:

- potential fuel savings;
- increased output capacity for the same level of fuel consumption;
- potential benefit and avoided cost associated with environmental compliance; and
- potential avoided cost associated with dangerous incidents.

This Infosheet concentrates on the potential fuel saving benefit, although other benefits should not be ignored.

Flue losses

Considerable energy is lost through flue exhaust in the heat exhausted by the products of combustion, and by unburnt combustibles due to incomplete combustion. Generally, losses due to unburnt combustibles are negligible. More air than the theoretical minimum requirement for complete combustion is usually supplied for the following reasons.

- To ensure stable combustion and prevent the formation of carbon monoxide (CO) which is highly poisonous and explosive.
- To allow for variations in the required air-to-fuel ratio due to combustion air temperature, pressure and humidity changes.
- To allow for slight variations in the chemical composition of the fuel gas and its supply pressure.
- To provide good air–fuel mixing in order to ensure complete combustion over the operating range of the burner.
- To allow for operating range inconsistencies of fuel-to-air ratio control equipment, such as valves, linkages and regulators.

In Victoria, the Office of Gas Safety recommends that the minimum excess air for most industrial natural gas burners be 22.75% when adjusted at an ambient temperature of 20°C. This can be lower for a high quality burner with continuous flow metering and/or continuous on-line flue gas analysis.

Typically, large commercial and industrial boilers with natural gas firing in the range of 5 MW and above will have automatic combustion control systems fitted and could be operating with more than 22% excess air. With an exhaust temperature of about 210°C, the level of oxygen in flue combustion products may sit at around 5% (see figure 1).

In such circumstances, the flue gas loss is about 18%. If the level of excess air is reduced so that the level of oxygen is around 2%, the respective flue gas loss will be reduced to 16%. The result is a potential reduction in flue gas loss of around 2%.

If we allow for boiler efficiency of 80% this can represent a reduction in fuel consumption of around 2.8% (2%/0.8). This would be a practical target and it represents a gas saving of potentially 2500 GJ per year and around 150 tonnes of CO_2 per year for a 5 MW boiler.

To achieve optimum combustion efficiency losses must be minimised. Combustion losses are either fuel losses that increase toward the fuel-rich end, or air losses where heat energy is wasted by heating excess air that is lost through the flue. Excess air results in the flue gases containing 'free' oxygen. The percentage of oxygen in flue gas will increase with increasing excess air, and the proportion of carbon dioxide will correspondingly fall. This trend is depicted in flue gas loss charts for natural gas (see figure 1).

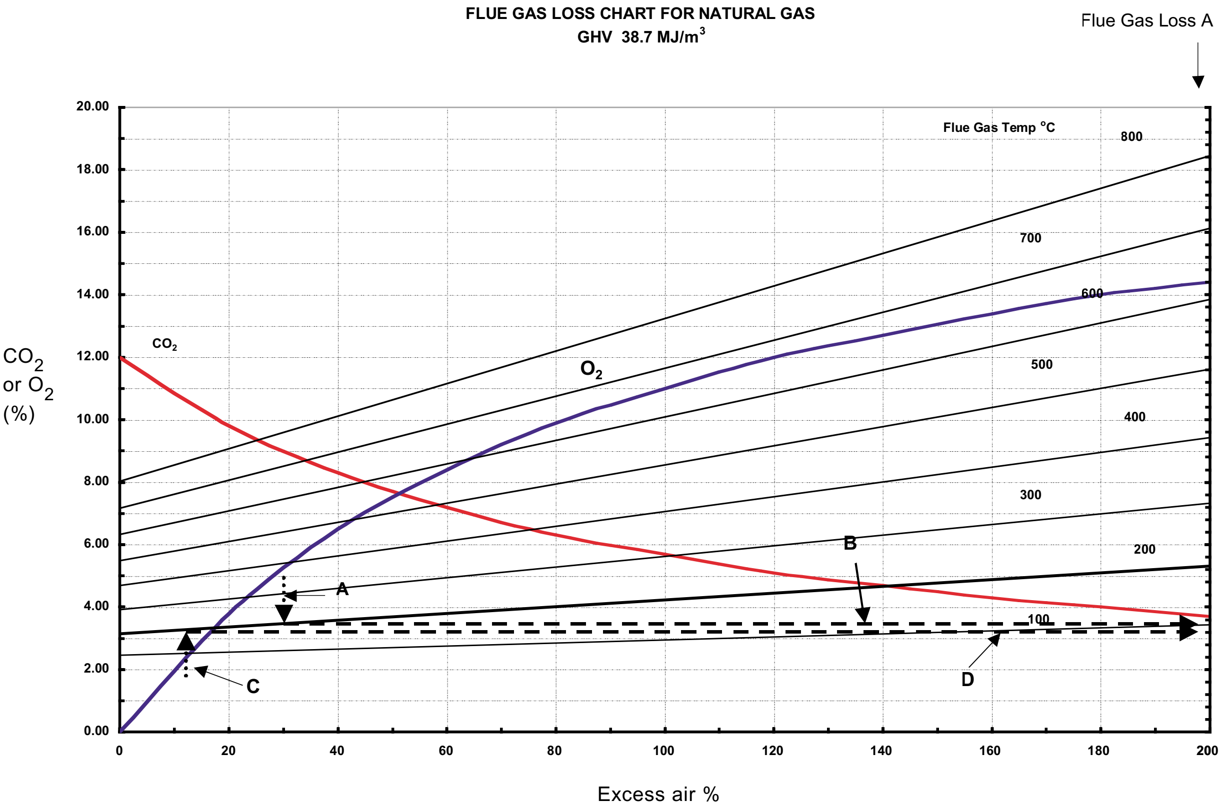
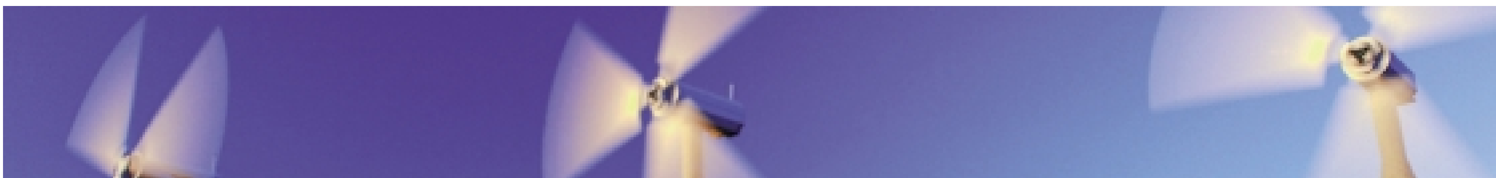


Figure 1: Flue gas loss charts for natural gas

To read the chart, folow these steps:

- Find the 'oxygen' curve and follow it to the point where it correlates to 5% on the left axis.
- Track a line vertically to the 200°C curve (A) and the trace a line horizontally across to the right axis and read 18% 'flue loss' (B)
- Follow the 'oxygen' curve down to 2% on the left axis.
- Track a line down vertically to the 200°C (C) curve, and again trace a line horizontally across to the right axis and read ~16% 'flue loss' (D).



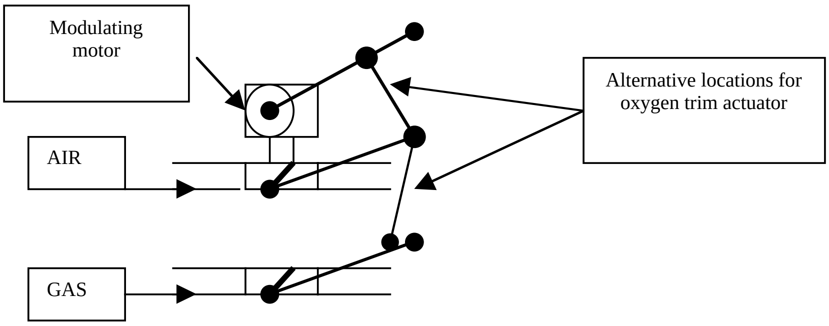


Figure 2: Linked valve air–gas ratio control

Combustion efficiency

Combustion efficiency is a measure of how much of the chemical energy of the fuel is converted into useful thermal energy. Combustion efficiency can be determined by reference to flue gas loss charts and is expressed as:

% Combustion efficiency = 100 – % Flue gas loss.

It needs to be remembered that combustion efficiency does not allow for leaks, radiation and other losses from the boiler and so is not the same as the overall thermal efficiency of the boiler. It gives an indication of the quality of the combustion process as a chemical reaction.

Flue gas analysis

In order to determine the flue gas loss, the flue gas oxygen or carbon dioxide content and temperature must be measured. The carbon monoxide content is also measured to show incomplete combustion, which may be due to poor mixing of air and fuel, flame quenching or incorrect setting of the air–fuel ratio.

The most common and inexpensive gas analyser systems are the chemical absorption carbon dioxide and oxygen analysers. These are test kits that are used for periodic checking and adjustment of the combustion tuning system. Modern flue gas analysers provide direct read-outs of the percentage of oxygen and carbon dioxide. These systems usually use zirconia sensors, which generate an electrical potential through an electrochemical process. The electric potential produced is proportional to the level of oxygen present in the sample space where it is fitted. It should be strategically placed in an appropriate location within the exhaust flue path of the boiler.

These systems come with programmable controllers which capture the measurement of oxygen and flue gas temperature. They then provide an output signal to a modulating actuator which can be programmed to fine-tune the air–gas mixture (normally managed by the air–gas ratio control system of the boiler).

Generally, burner management systems employ combustion management systems where air and gas flows are controlled in the correct ratio, by two or more linked valves, to provide identical area-to-flow characteristics.

The term ‘trim’ refers to oxygen trim, whereby the level of excess air in a boiler can be precisely managed. This can be achieved through the insertion of an actuator placed in the link between the burner management modulating motor and the combustion air damper (see figure 2).

Costs

The costs of oxygen trim systems vary, depending upon the quality and capital cost of the sensing probe, its controller and the complexity associated with the fitting of the trim actuator. The typical installed cost is around $7500.

Note: This depends on the delivered cost of fuel ($4.00/GJ to around $6.00/GJ for natural gas) in the de-regulated natural gas market in Victoria. This would suggest that should a fuel saving of around 3% be achievable, then the simple payback associated with such capital investment may be between one and three years, depending on the size of boiler and the prevalent fuel cost.

The tables over page show the potential capital and operating cost impact of the installation of on-line oxygen trim control. We have assumed that the potential saving in fuel is 2.8% and that these boilers operate for 24 hours per day over 350 days per year and have a duty cycle of 60%. We have allowed for a capital and installation cost of the boiler trim system of $7500. The variations in Tables 1 and 2 are related to the delivered cost of fuel.

BOILER CAPACITY (MW)	FUEL SAVING (GJ/pa)	FUEL SAVING ($/pa)	CO_2 (TONNES/ pa)	SIMPLE PAYBACK (YEARS)
0.5	318	1272	19	5.9
0.75	476	1904	28	3.9
1	635	2540	37	3.0
2	1270	5080	75	1.5
3	1905	7620	112	1.0
4	2540	1016	150	0.7
5	3175	1270	187	0.6
6	3810	1524	224	0.5
7	4445	1778	262	0.4
8	5080	2032	299	0.4
9	5715	2286	337	0.3
10	6350	2540	374	0.3

Table 1: Assumes gas cost of $4.00/GJ

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1	635	2540	37	3.0
2	1270	5080	75	1.5
3	1905	7620	112	1.0
4	2540	10 160	150	0.7
5	3175	12 700	187	0.6

Table 2: Assumes gas cost of $6.00/GJ

Conclusion

Ensuring that fuel burning appliances are set to achieve the optimum fuel-to-air ratio maximises the safety, stability and efficiency of the combustion process. This reduces energy consumption, costs and carbon dioxide emissions.