Chapter one

Introduction

1.1General

One of the greatest opportunities for industrial energy conservation today is to improve the combustion efficiency of industrial fuel burning equipment. Most industrial fuel burning equipment, such as boilers, process heaters, kilns, dryers, incinerators, and steam generators, were designed and installed at a time when fuel costs were only a fraction of what they are today. As a result of rising fuel prices and improved technology, the stage is set for a revolutionary improvement in the operating efficiency of industrial fuel burning equipment.

Boilers are used for a variety of purposes in an assortment of applications. Common uses include producing hot water or steam for heating, producing steam for use within a plant such as atomizing oil for oil-fired burners and producing steam to generate power in large power plants. Applications range from small single-burner uses in hospitals, schools, and small businesses up to large multi burner boilers in power plants. The burners used in boilers are typically regulated because of their proliferation and widespread use in applications involving the general public [1].

For boiler combustion to occur, fuel, oxygen (air), and heat must be present together, that means we need to control Air/Fuel Ratio for complete combustion.

The availability of reliable, inexpensive flue gas analyzers insures that combustion may now be controlled with precision. Both excess oxygen and excess fuel can be measured as they leave the burner and stack. Analyzers provide either exact amounts of these elements or percentages of the whole. With these numbers, air dampers can be opened or closed and fuel flows can be adjusted. [2]

Combustion analysis should be performed weekly checks (monthly at a minimum) with a portable combustion analyzer and for large boilers we can use gas analyzer with continuous monitoring and automatic trim control with the economic justification. Controlling the efficiency of combustion processes is as important today to the operators of large power boilers for an electrical utility as it is to the person who runs a small furnace or water heater in a residential dwelling. The steady increase of fossil fuel prices over the past two decades has made energy conservation an important way to control costs. The amounts of oxygen and combustibles that are being allowed to flow out of a smokestack can be measured in a number of different ways. These measurements are facilitated by a new generation of microprocessor-based analyzers with self-diagnostic systems that are easier to calibrate and operate. To make sure that the right gas analyzer is used for the job, plant operators and engineers must understand both the mechanics of combustion and why the amounts of excess oxygen and fuel leaving a stack should be kept to a minimum. [3]

When a boiler is tuned, the goal is to maximize combustion efficiency by providing just enough excess air to assure complete combustion but not too much to reduce efficiency. How much excess air is enough to assure complete combustion? That varies with the design and condition of the burner and boiler, as well as with the different firing rates of the burner. Excess air must also be adjusted to allow for variations in temperature, density, and humidity of the boiler combustion air throughout any daily and seasonal variations. It's desirable to maintain a constant amount of excess air across the entire firing range. The important idea to remember is that complete combustion is critical to ensuring efficient boiler operation. Incomplete combustion of the fuel can significantly reduce boiler efficiency by 10% or more, while increasing excess air by 10% may only impact boiler efficiency by about 1%.[4]

The increase in all kinds of combustion is contaminating the environment with ever-greater concentrations of pollutants. Smog formation, acid rain and the growing numbers of allergies are direct consequences of this development. The solution to environmentally sound energy production must therefore involve reducing pollutant emissions. Pollutants in flue gas can only effectively be reduced if existing plants operate as efficiently as possible or noxious boilers are shut down. Flue gas analysis offers a means of determining pollutant concentrations and adjusting heating installations for maximum efficiency.

For economic relevance optimization of a combustion process through plant operation at the most effective excess air level has, besides reduction of emission levels, the objective of saving fuel costs.

Flue gas analyzer is used both for efficiency, fuel saving and emissions purposes.

1.2 Problem Description:

No doubt boilers are very important in sugar industry because they represent the heart of the factory that produces steam which is used in all the process steps. Here in Kenana boilers in 2007 boiler control room burnt, all the boilers are operating without gas analyzers the operators controlled the air-fuel ratio manually according to boiler load only which is affecting in the combustion efficiency.

1.3 Problem Importance:

The study of this problem is important because it can improve combustion efficiency by means of controlling combustion air ratio; insufficient amount of air in combustion produces carbon monoxide, soot, smoke, incombustible fuel and less energy. The combustion efficiency is low. On the other side too much air incurs more loss.

1.4 Research Methodology:

The study will show the old boiler combustion control system and make a modification after that make a comparison between the old and the new control system.

1.5 Objectives:

1. Make a modification for boiler combustion control system.
2. To increase the combustion efficiency.

1.6 literature review:

Robert C. Molloy (1981) made analysis on combustion monitoring by using OXYGEN and CO gas analyzers. It reported that when unburned combustibles are exhausted from the stack exit, fuel is literally going up the stack with a resulting high loss of combustion efficiency. The air pollution occurs from excess fuel (insufficient oxygen) results in the formation of carbon monoxide (CO), smoke and solids. Particulate emissions are a major cause of the adverse health effects of air pollution including: respiratory ailments, smog, and gas phase reactions with other air pollutants. It conducted a simulation between fuel/air mixture ratio and combustion efficiency. It showed that at higher excess air levels, for everyone percent reduction in excess oxygen, a one percent improvement in combustion efficiency can be achieved. At lower excess oxygen levels (less than three percent), for everyone percent reduction in excess oxygen, approximately a one half percent improvement in combustion efficiency can be achieved. Also result that the ideal flue gas measurement system simultaneously measure opacity, oxygen, and CO. Measure opacity to meet EPA guidelines and as a secondary measure of excess fuel conditions. The simultaneous measurement of excess oxygen provides a direct measure of "combustion efficiency". Then better relative combustion efficiency.

Muller (2001) talked about how to monitor flue gases, Water treatment and flue gases temperature. The result showed that boilers operating with excess air consume more fuel. It is common practice, however, for boilers to use 50-100 per cent excess air reducing the efficiency of the boiler by five per cent if the boiler does not have a flue gas analyzer.

Modern Industrial Assessments (2003) developed a research in heat. It was reported in chapter five that it is necessary to carefully monitor the performance of boilers and tune the air/fuel ratio quite often. Best performance is obtained by the installation of an automatic oxygen trim system which will automatically adjust the combustion to changing conditions. It is recommended that the portable flue gas analyzers be used in a rigorous program of weekly boiler inspection. It was reported that the cost of such an analyzer is about $500 and it can simply payback 8-10 month by Savings in Fuel.

Prof. Sorour (2008) studied the reasons and methods of reducing the heat losses that are carried by the flue gases for different reasons and those due to combustion and gas side factors. He showed the major parameters that need to be controlled and monitored for boiler combustion control. He conducted that combustion efficiency test should be done in full and in part load. Reducing the excess air or oxygen to the minimum safe level is the most important step in reducing energy consumption. He resulted that the amount of excess O2 is about directly proportional to the efficiency lost; that is, 3% excess O2 means 3% efficiency drop.

Innami (2011) tried a new type of combustion control based on Coal fired boiler, by measuring real-time CO concentration data near furnace with a TDLS analyzer. It is reported that Fuel savings and CO_2 emission reduction can be calculated from the measured data conforming to a Japan Industrial Standard. The results indicate that use of TDLS analyzers to measure CO concentrations realized a new approach to combustion control, enabling optimization of the fuel-air ratio and thereby protecting the environment by achieving enormous reductions in CO_2 emissions.

Chapter two

Boiler systems, classifications and control

2.1 Preface:

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred to water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and inexpensive medium for transferring heat to a process. When water at atmospheric pressure is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be equipment that must be treated with most care. The boiler system comprises of: a feed water system, steam system and fuel system. The **feed water system** provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair. The **steam system** collects and controls the steam produced in the boiler. Steam is directed through a piping system to the point of use. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The **fuel system** includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system. The water supplied to the boiler that is converted into steam is called **feed water**. The two sources of feed water are:

1-**Condensate** or condensed steam returned from the processes

(2) **Makeup water** (treated raw water) which must come from outside the boiler room and plant processes. For higher boiler efficiencies, an

economizer preheats the feed water using the waste heat in the flue gas, see figure (2.1). [5]

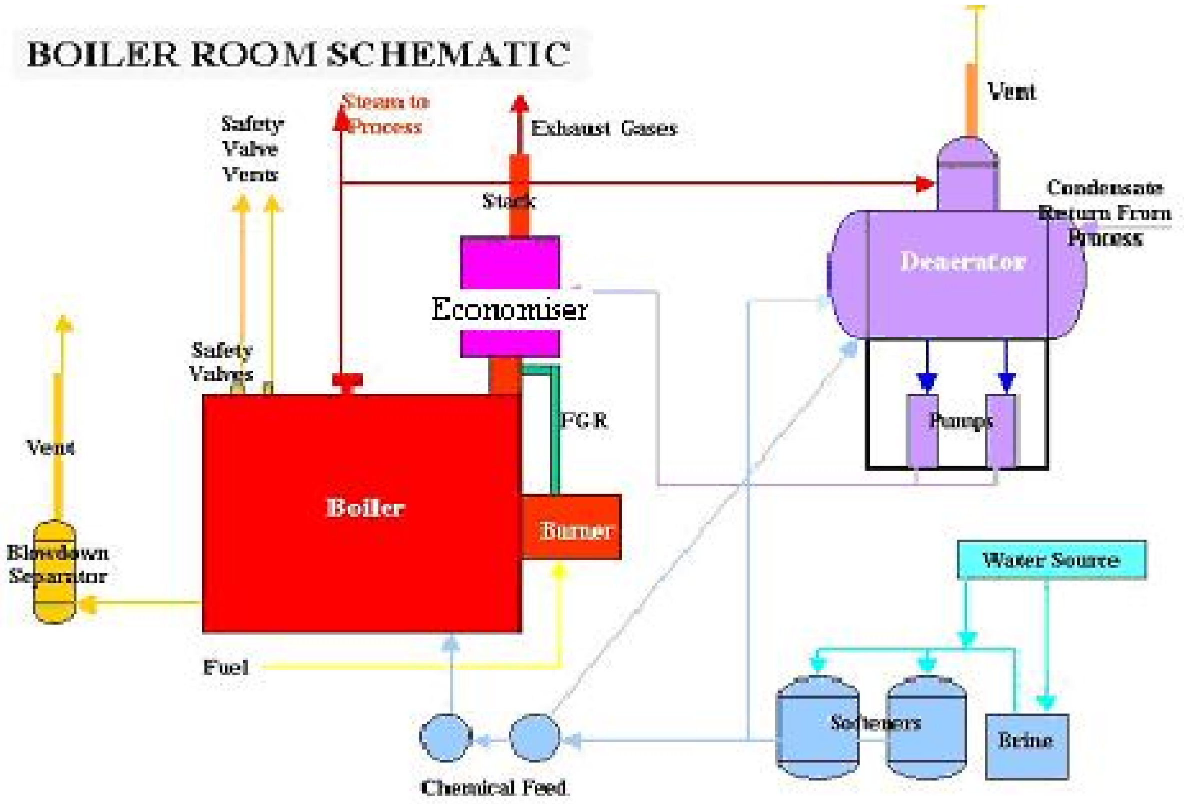


Figure (2.1) Schematic diagram of a Boiler Room

2.2 boiler types and classification

Broadly, boilers found in SME industries can be classified into four types: fire tube boilers, water tube boilers, packaged boilers, and fluidized bed combustion boilers.

2.2.1 Fire tube boilers:

Fire tube or "fire in tube" boilers contain long steel tubes through which the hot gases from a furnace pass and around which the water to be converted to steam circulates. It is used for small steam capacities (up to 12000 kg/hr).

The advantages of fire tube boilers include their low capital cost and fuel efficiency (over 80%). They are easy to operate, accept wide load fluctuations, because they can handle large volumes of water, produce less variation in steam pressure and efficiency (over 80%). They are easy to operate, because they can handle large volumes of water, produce less variation in steam pressure. [6]

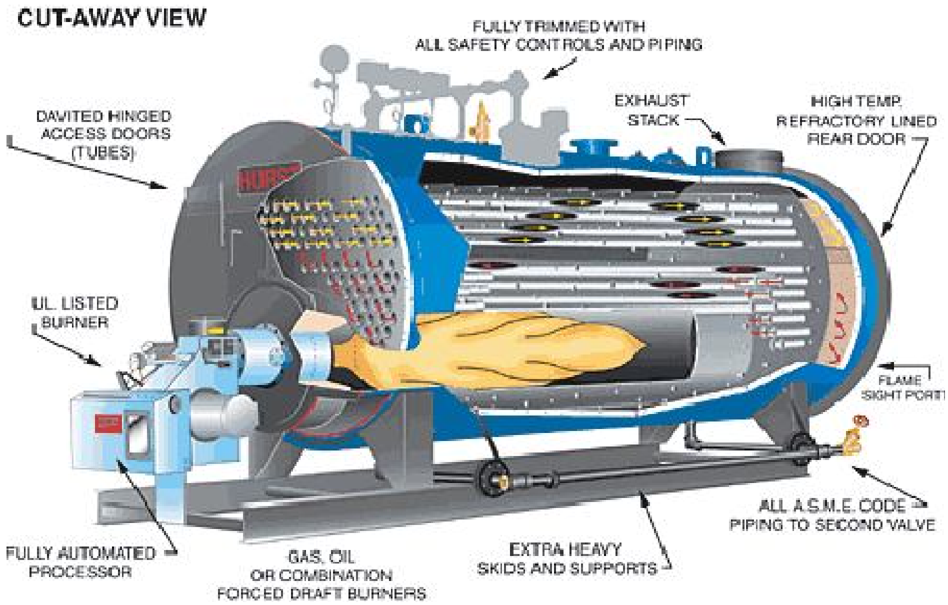


Figure (2.2): Fire tube Boiler (image source: www.hurstboiler.com)

2.2.2Water tube boilers:

In **water tube** or "water in tube" boilers, water passes through the tubes and the hot gasses pass outside the tubes. These boilers can be of single- or multiple-drum type. They can be built to handle larger steam capacities and higher pressures, and have higher efficiencies than fire tube boilers. They are found in power plants whose steam capacities range from 4.5–120 t/hr, and are characterized by high capital cost. These boilers are used when high pressure high-capacity steam production is demanded. They require more controls and very stringent water quality standards. [6]

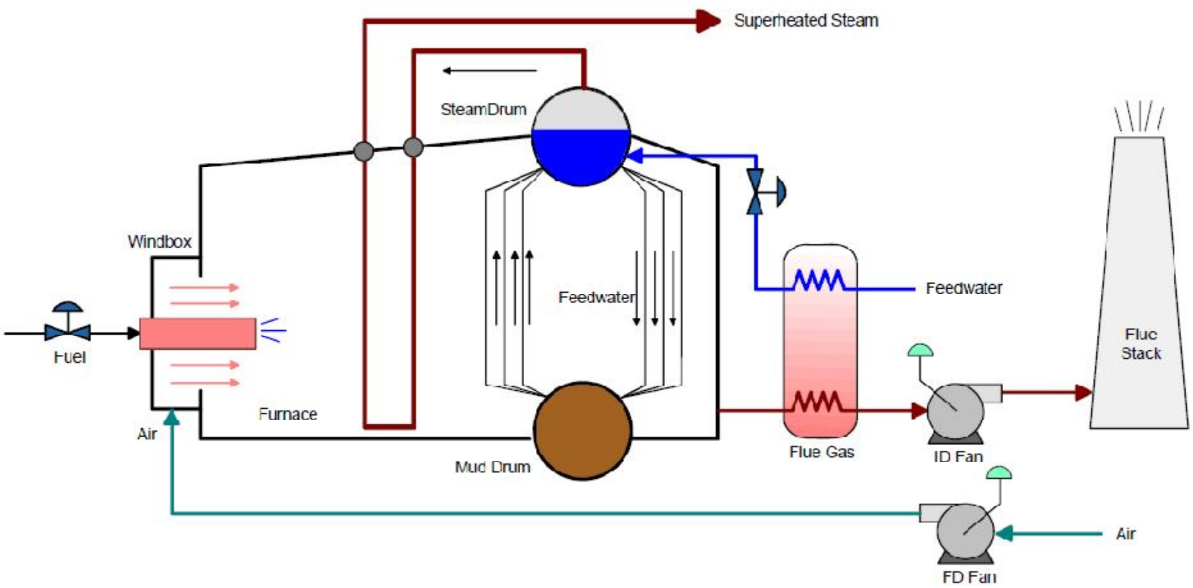


Figure (2.3): Boiler configuration. (7)

2.2.3 Packaged boilers:

The **packaged boiler** is so called because it comes as a complete package. Once delivered to a site, it requires only steam, water pipe work, fuel supply and electrical connections in order to become operational. Package boilers are generally of shell type with fire tube design so as to achieve high heat transfer rates by both radiation and convection. These boilers are classified based on the number of passes (the number of times the hot combustion gases pass through the boiler). The combustion chamber is taken as the first pass, after which there may be one, two, or three sets of fire tubes. The most common boiler of this class is a three-pass unit with two sets of fire tubes and with the exhaust gases exiting through the rear of the boiler. [6]

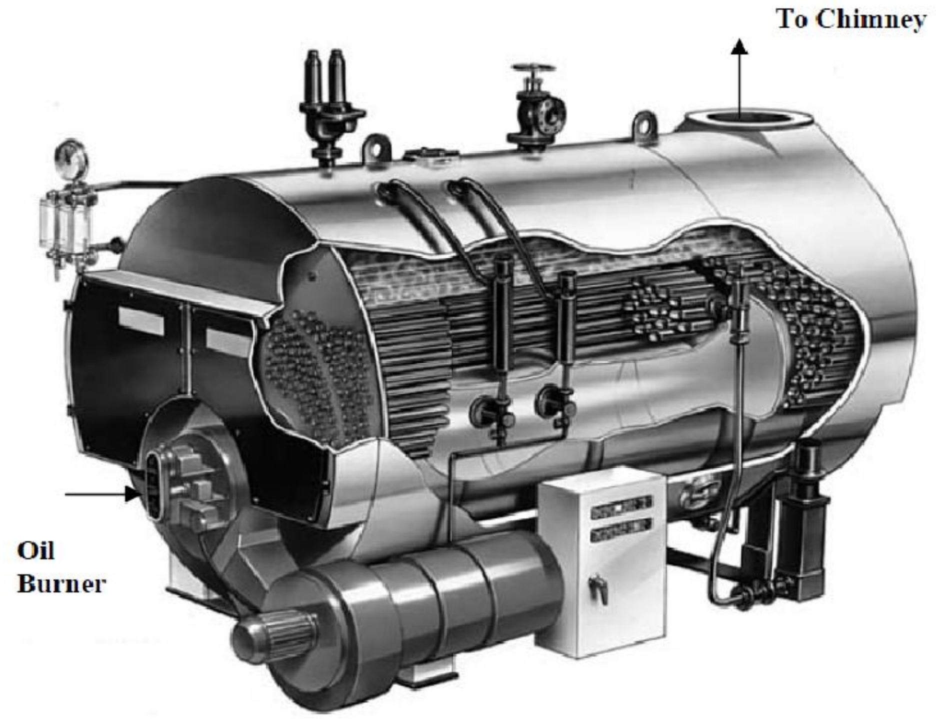


Figure (2.4): A typical three Pass Oil fired (image source BIB Cochran, 2003)

2.2.4 Fluidized bed combustion (FBC) boilers

In **fluidized bed boilers**, fuel burning takes place on a floating (fluidized) bed in suspension. When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream. A further increase in velocity gives rise to bubble formation, vigorous turbulence, and rapid mixing, and the bed is said to be fluidized. Fluidized bed boilers offer advantages of lower emissions, good efficiency, and adaptability for use of low calorific-value fuels like biomass, municipal waste, etc. [6]

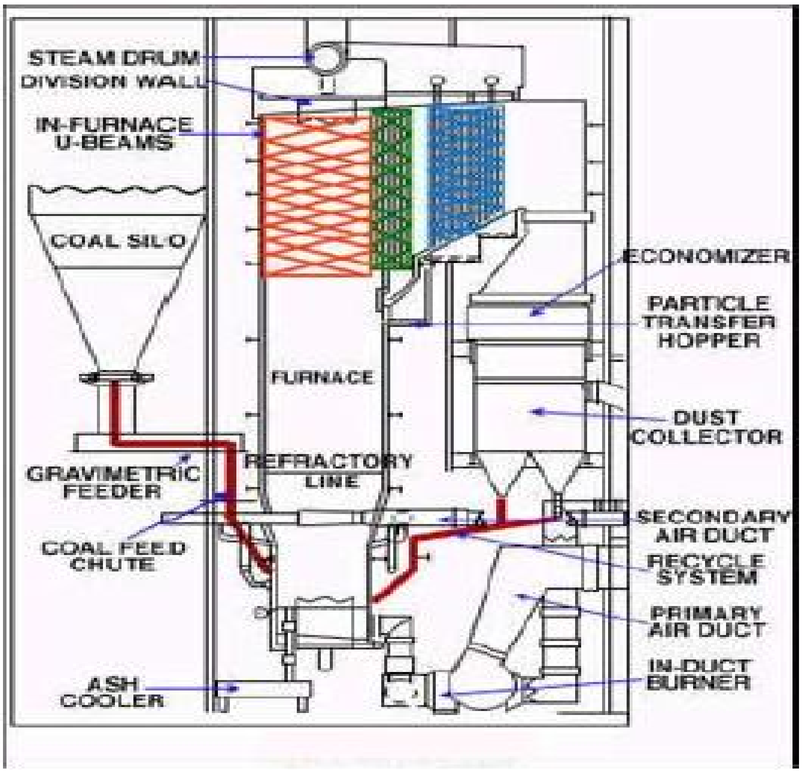


Figure (2.5): CFBC Boiler (image sourcewww.tbwindia.com).

2.3 boiler control:

A boiler is the single most expensive item in a sugar factory. Because of the high operating pressure and temperature, it is also one of the potentially most dangerous pieces of equipment. For these reasons alone proper boiler control is imperative.

There are normally three main control loops to provide this control, a water level control, a master pressure control and a furnace pressure control figure (2.5).

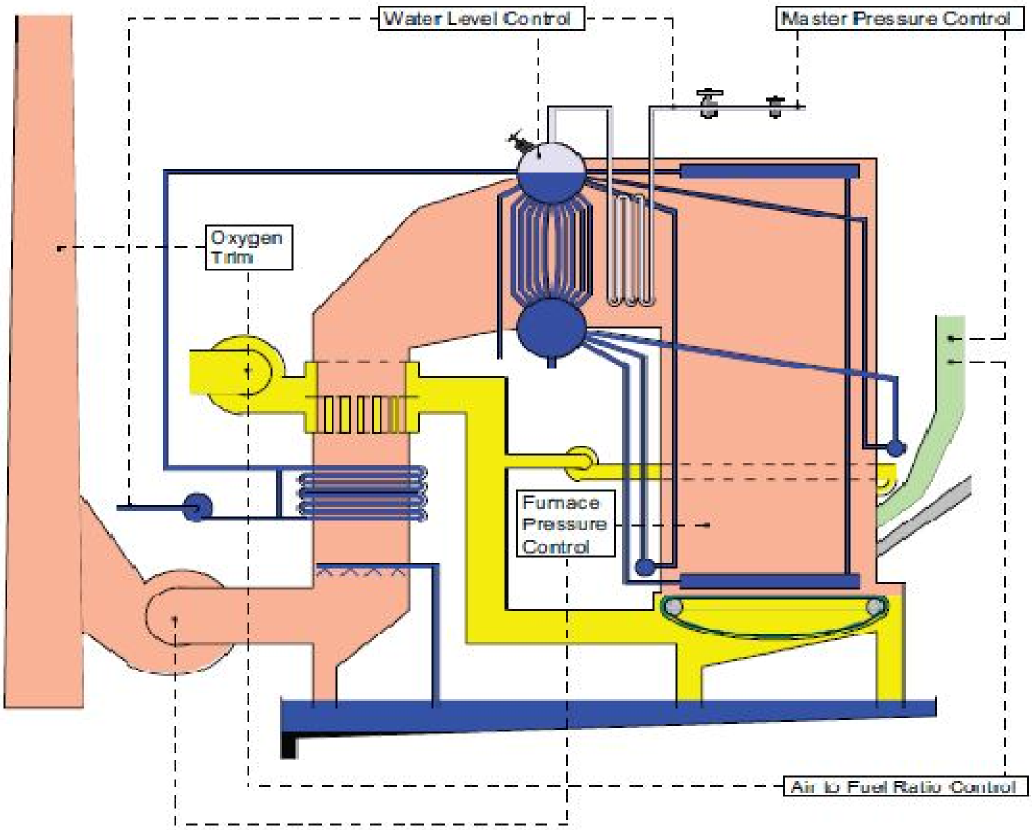


Figure (2.6): boiler control

2.3.1 *Water level control:*

An important variable to measure and control in a continuous boiler is the level of water in the "steam drum" (the upper vessel in a water-tube boiler). In order to safely and efficiently produce a continuous flow of steam, we must ensure the steam drum never runs too low on water, or too high. If there is not enough water in the drum, the water tubes may run dry and burn through from the heat of the fire. If there is too much water in the drum, liquid water may be carried along with the flow of steam, causing problems downstream. In this next illustration, you can see the essential elements of a water level control system, showing transmitter, controller, and control valve:

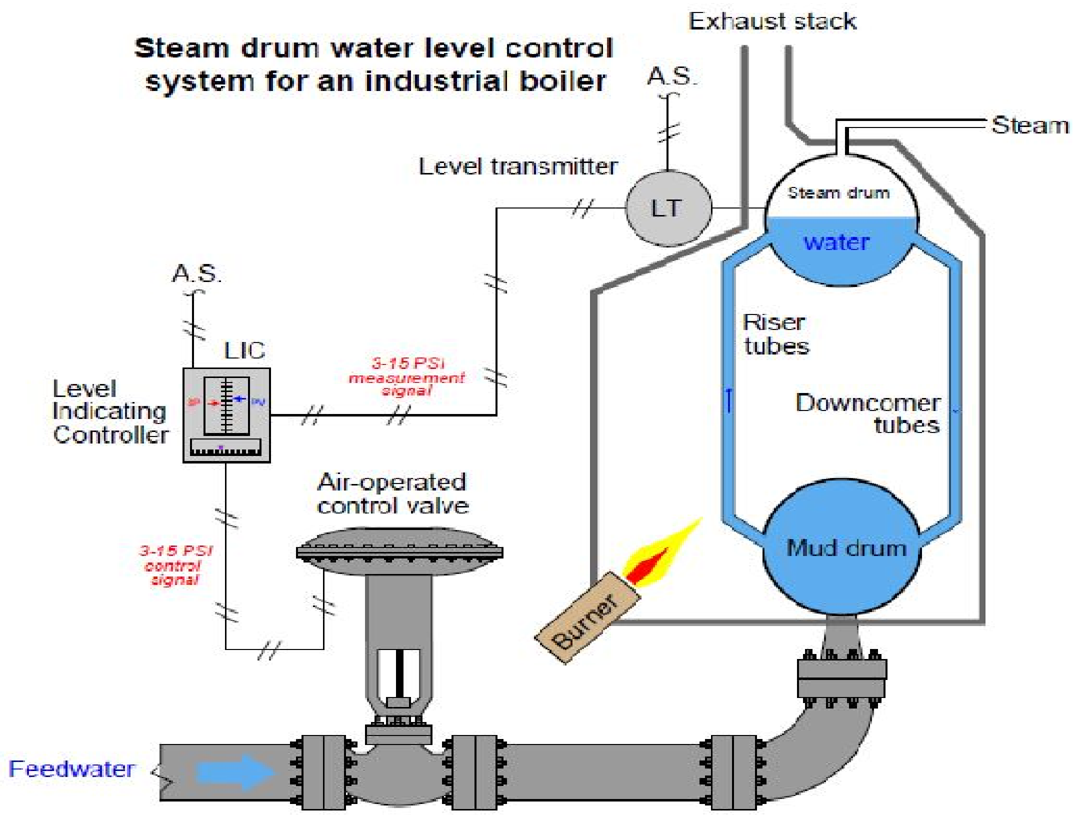


Figure (2.7): water level control

The first instrument in this control system is the level transmitter, or “LT”. The purpose of this device is to sense the water level in the steam drum and report that measurement to the controller in the form of an instrument signal. In this case, the type of signal is pneumatic: a variable air pressure sent through metal or plastic tubes. The greater the water level in the drum, the more air pressure output by the level transmitter. Since the transmitter is pneumatic, it must be supplied with a source of clean, compressed air on which to run. This is the meaning of the “A.S.” tube (Air Supply) entering the top of the transmitter. This pneumatic signal is sent to the next instrument in the control system, the level indicating controller, or “LIC”. The purpose of this instrument is to compare the level transmitter’s signal with a set point value entered by a human operator (the desired water level in the steam drum). The controller then generates an output signal telling the control valve to either introduce more or less water into the boiler to maintain the steam drum water level at set point. [8]

2.3.2 Master pressure control

The steam pressure controls the combustion rate by altering the speed of the fuel feeders. At the same time a ratio controller maintains a constant air to fuel ratio by adjusting the air supply by the FD fan. It is common practice to monitor the oxygen levels in the flue gas and trim the air to fuel ratio when necessary. Acceptable oxygen levels are between4 to 6% on a dry volume basis.

Pressure control loops may be used for the control of boiler pressure or fuel oil pressure. For the control of boiler pressure, the final control element regulates fuel flow to the boiler in response to boiler drum steam pressure. For the control of fuel oil pressure, the final control element is usually a pressure reducing control valve that regulates in response to downstream pressure.

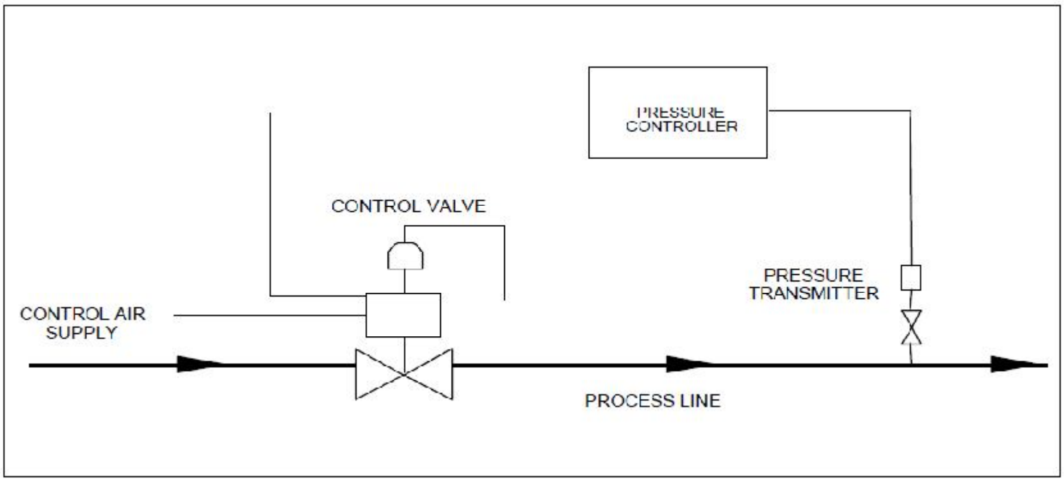


Figure (2.8): a typical pressure control loop

2.3.3 Furnace pressure control

The furnace pressure is controlled by altering the speed of the ID fan. Both a positive and a negative pressure reduce boiler efficiency. Ideally the pressure should be just below atmospheric.

Note: In some boiler installations the air to fuel ratio control operates on the ID fan while the furnace pressure is regulated by the FD fan. It is not clear what the advantages are of the one system compared with the other.

Besides that, the controllers also control Furnace Pressures by sensing the pressure and manipulating exhaust air dampers. [9]

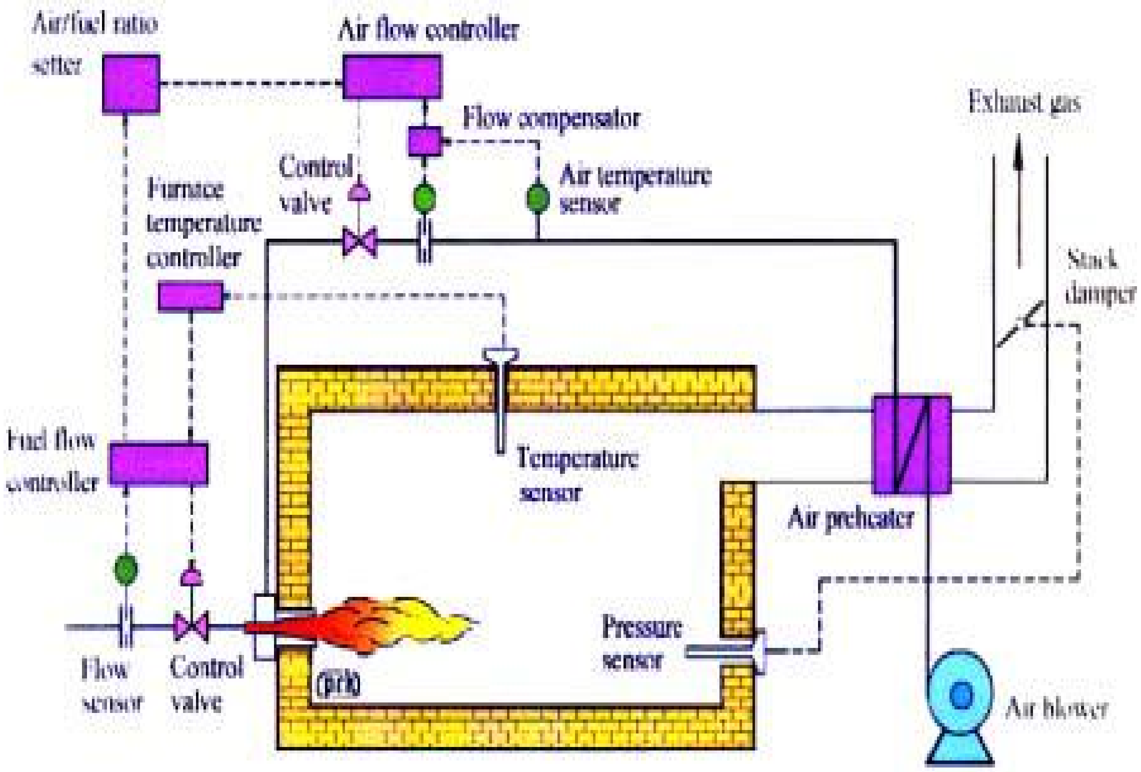


Figure (2.9): Furnace control

Chapter three
Boiler combustion

3.1 Preface:

Combustion is a chemical process in which an oxidant reacts rapidly with a fuel, liberating stored energy as thermal energy, usually in the form of high-temperature gases. In the majority of applications the oxidant used for combustion is oxygen (O2) in air.

For the sake of the environment and the sustainability of civilization these processes must be well managed. Conventional fuels are comprised of various hydrocarbons, meaning that they consist mainly of carbon (C) and hydrogen (H). Combustion of hydrocarbons produces mainly carbon dioxide (CO2) and water (H2O) (figure 3.1).

For combustion to start, the ignition temperature of the fuel must be reached. Also, the proportions of the fuel and air must be in the proper range for combustion to begin. For example, natural gas does not burn in air concentrations less than 5 % or greater than 15 %. Components before reaction are called reactants and components after combustion are called products. (10)

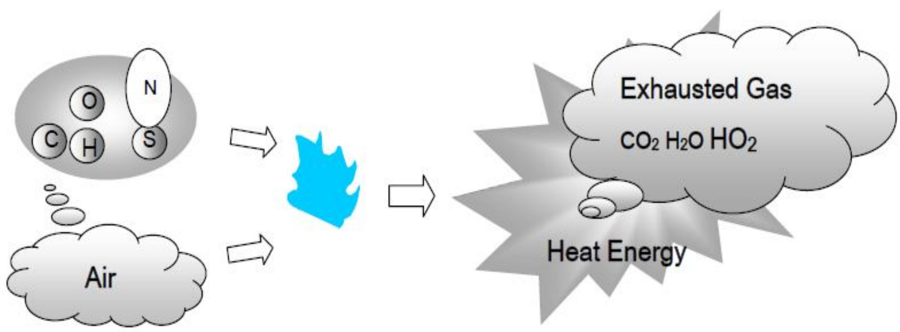


Figure 3.1combustion (9)

3.2 Combustion basics:

3.2.1 Stoichiometric Combustion

The ideal combustion process during which a fuel is burned completely is called stoichiometric combustion. After stoichiometric combustion all carbon, sulfur, and hydrogen is oxidized and forms only H_2O, CO_2 and SO_2.

Stoichiometric air, sometimes also referred to as theoretical air, is the exact amount of air needed for complete combustion. In practice stoichiometric combustion is seldom realized because of imperfect mixing and finite reaction rates. Combustion processes therefore operate with some excess air (11).

3.2.2 Complete Combustion

Combustion is complete if all carbon in the fuel burns to CO_2, all hydrogen burns to H_2O and nitrogen and sulfur forms NO_2 and SO_2, respectively. Oxygen for combustion is normally obtained from air, which mostly contains nitrogen, oxygen, water vapor, carbon dioxide, argon and other gases. A complete combustion generally requires some amount of excess air or excess oxygen beyond the theoretical amount (10).

3.2.3 Incomplete Combustion

Incomplete combustion is when the combustion products contain any unburned fuel or components such as C, H_2, CO or OH. For example, hydrocarbon that is not completely oxidized forms partially oxidized compounds, such as carbon monoxide, instead of water and carbon dioxide. Oxygen has a greater tendency to combine with hydrogen than with carbon so fuel normally burns to completion forming H_2O. As a result, some carbon ends up as carbon monoxide or just plain carbon particles, soot, in the products. Incomplete combustion means that fuel is used inefficiently and can even be hazardous due to formation of carbon monoxide (11).

Insufficient amount of oxygen is an obvious reason for incomplete combustion.

Other reasons are too low flame temperatures, insufficient reactant residence time in the flame and insufficient mixing in the combustion chamber during the limited time that fuel and oxygen are in contact (10).

3.2.4 Excess Air

In order to enable complete combustion in an actual process, the amount of oxygen has to exceed the theoretical level by a certain percentage. The amount of air that exceeds the theoretical amount is referred to as excess air figure (3.2).

It is in fact impossible to predict an actual combustion and to estimate the excess air needed without measuring the products of the combustion. Excess air is not only important to ensure complete combustion, thereby ensuring that fuel is not wasted, but is also a key factor for safety reasons, for example to minimize the formation of hazardous gases like carbon monoxide (11).

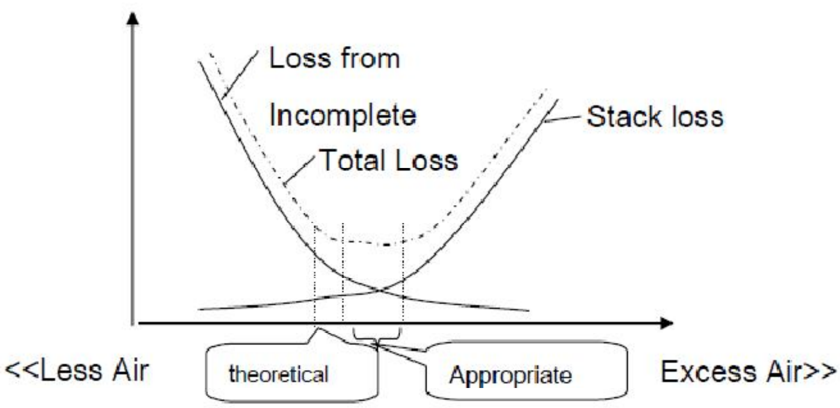


Figure 3.2 Appropriate air ratio for combustion (9)

Appropriate air in each type of fuel can observe from oxygen content and carbon dioxide content in exhausted air as shown in Table 3.1 (9)

Table 3.1: Appropriate air for fuel

Type of Fuel	Oxygen (%)	Carbon dioxide (%)	Carbon monoxide (ppm)	Excessive air (%)
Fluid fuel	3-4	12-14	<200	10-20
Gas fuel	1-2	9-10	<200	10-20
Solid fuel	12-13	12-13	<200	50-70

3.2.5 Combustion Gases

Combustion gases, also called flue gases, are the result of any complete or incomplete combustion and contain products from the combustion as well as excess air. If the combustion gases are cooled below a certain temperature, called dew point, some of the gases condense. It is important to be able to predict the dew point temperature since water droplets often combine with the sulfur dioxide that may be present in the combustion gases, forming sulfuric acid, which is highly corrosive (11).

3.3 Fuels

The choice of fuel has a great impact on furnace performance. Fuels are divided into their physical state, i.e. solid, liquid and gas. Some systems are designed to use more than one type of fuel. Fuel properties differ in many aspects such as energy content, availability and how easy even distribution of the fuel is established in the boiler. Commonly used fuels are shortly introduced in the following sections.

3.3.1 Solid Fuel

A large variety of solid material can be used as fuel in a combustion process. In principle most combustible waste can be utilized as fuel. Most commonly used are coal, bio fuel, peat and waste fuels. Domestic garbage is a heterogeneous fuel which differs a lot in its composition. It can contain different types of materials, such as food, plastic, wood, paper, glass and metal. This results in high demands in combustion equipment and flue gas filtering to reduce emissions. Waste is therefore mainly used as fuel in district heating production (11).

Coal is formed in a process where organic material is under pressure during long periods of time. The process is very slow and coal is therefore considered a non-renewable energy source. The most common type of coal for energy production in Sweden is bituminous coal, or black coal. In Sweden, coal is mostly used in industry and in large combined heat and power plants.

A common name for wood products, straw, reed and energy crops is bio fuel.

Bio fuel can be transformed into woodchips, pellets, briquettes or powder, for example to make transport easier or make the fuel more uniform in shape.

The combustion efficiency of pellets is very high compared to wood since the pellets are extremely dense and have low moisture content. The uniform shape also enables automatic feeding of fuel. Wood chips are small uniform pieces of wood made from waste wood and residuals from landscaping, logging and sawmills.

Peat forms in wetland bogs and consists of partially decomposed organic matter and can be transformed into pellets, briquettes or powder. Peat is still considered as a fossil fuel within emissions trading (11).

3.3.2 Liquid Fuel

Most liquid fuels are based on petroleum, produced by the refining of crude oil which has formed from plants and organisms under high temperature and pressure under the bottom of seas and oceans. The major constituents of oil fuel are carbon and hydrogen. Other constituents are nitrogen, sulfur, ash and other impurities. The classification of oil differs between countries but it is often divided into six classes according to its physical characteristics. Fuel oil classes 1-2 have low density and thereby also lower viscosity and are called distillate oils. Diesel fuel belongs to this category. The most common fuel for burners is class 1 type of oil. Distillate oils are lighter and are relatively clean fuels, primarily used for home heating where factors such as ash and low content of sulfur are important. Classes 3-6 have higher density and are called residual oils (11).

Residual oils with high density and high viscosity must be preheated since heavy fuel oils have the tendency to solidify when cold. One common cause of poor oil burner performance is too high oil viscosity due to inadequate preheating of the oil. Sometimes distillate oils are blended with the higher viscous residual oils to create a desired mixture. Some liquid bio fuel also exists such as palm oil and canola oil, produced from crushed rapeseeds. Bio oil usually has lower energy content than fuel oils.

3.3.3 Gaseous Fuels

Gaseous fuels are easy to evenly distribute in order to achieve a complete combustion of the fuel. The combustion process is therefore easier to control in comparison with using solid or liquid fuels. A more exact temperature control makes it possible to affect the formation of NOx, flue gas temperature and achieve optimal control. Gaseous fuels contain little carbon in relation to the amount of energy compared to other fuels, which results in relatively low emissions of carbon dioxide. Emissions of sulfur dioxide, carbon monoxide and soot particles are minor. Examples of gaseous fuels used for energy production through combustion are natural gas, town gas and biogas. Town gas, produced from petroleum was previously distributed in the Swedish gas distribution network. Today this has been replaced by natural gas, which is also a fossil fuel, but result in lower emissions of carbon dioxide. (11)

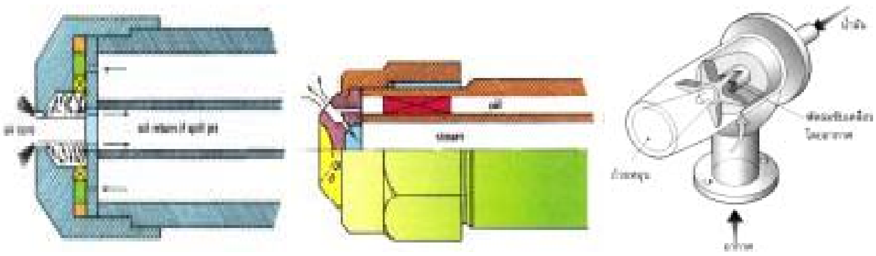
Natural gas is a gas mixture with methane as basis. The gaseous hydrocarbons are formed by anaerobic decomposition of organic material and are pumped up either together with oil or from separate gas wells. The composition varies depending on the source, usually with methane concentrations of 70 % and higher. Natural gas in the Swedish gas distribution network consists of 90 % methane, 6 % ethane and 2 % propane. Hydrogen sulfide is always removed from gas distributed through the public system due to the high toxicity both of the gas and its products. Biogas refers to gas produced by biological degradation of organic matter, normally from wastewater and landfills, in the absence of oxygen. The produced gas mainly consists of methane and carbon dioxide and is considered to be a renewable energy source which does not contribute to pollution since the gas is a part of the natural cycle. To add biogas into the natural gas distribution net, the gas has to be upgraded to a higher energy content which is done by extracting carbon dioxide. Biogas is primarily used in heat production, followed by being used as vehicle fuel (11).

3.4 Burner Technology

Burners are devices which feed fuels and air to combust. One objective of burners is homogenous bend of fuel and air to achieve high combustion efficiency. (9)

3.4.1 Oil Burners

There are 3 types of oil burners, Pressure burners, Air/Steam atomizing burners and Rotary Cup burners. Fig 3.3shows each type of burners. (9)



a. Pressure type   b. Steam/Air type   c. Rotary Cup type

Fig 3.3 Oil burners

3.5 Energy Content

An important parameter to compare fuels for combustion systems is the heat release rate. Heating value, or calorific value, is the quantity of heat generated by complete combustion of a unit of specific fuel. Table 3.2 shows fuel heating values

If gas is supplied through a fixed nozzle the flow rate will vary with the density which will give different release rates. A better parameter to compare gases by is the Wobbe index where the higher heating value in MJ/m3 is divided by the specific density relative to air. Gases with similar Wobbe index will produce the same heat release in the furnace when supplied through the same nozzle at similar supply pressure (11).

Table 3.2: Heating Values

Types of fuels	Fuels	Heating value (British)	Heating Value (SI)
Solid	Bituminous	6,297.16 kcal/kg	26,,366.21 kJ/kg
	Lignite	2,500.24 kcal/kg	10,468.50 kJ/kg
	Saw Wood	2,598.14 kcal/kg	10,878.41 kJ/kg
	Paddy rice	3,438.72 kcal/kg	14,397.92 kJ/kg
	Bagasse	1,798.16 kcal/kg	7,528.90 kJ/kg
Liquid	Gassoren	8,245.76 kcal/L	34,525.00 kcal/L
	Diesel	8,697.10 kcal/L	36,414.76 kcal/L
	Heavy Oil Type A	9,857.66 kcal/L	41,274.02 kcal/L
	Heavy Oil Type C	9,117.38 kcal/L	38,174.47 kcal/L
Gas	NG	8,763.96 kcal/Nm3	36,694.47 kJ/Nm3
	LPG	11,992.53 kcal/kg	50,220 kcal/kg

3.6 Emissions

A byproduct of the industrial revolution in Western Europe was severe atmospheric pollution, both from visible pollutants, such as particulate material and emissions of poisonous materials, such as lead, arsenic and mercury.

Since the industrial operations have seen increasing scrutiny and regulation to control these emissions. In the beginning, these regulations mostly applied to things that could be seen, felt or smelled. With the constant advances and the increasingly sophisticated ability to detect and measure very small quantities of chemicals these pollution legislatures cover more and more of the chemicals that are harmful to either humans or the environment. The latest manifestation of pollution is the climate change, caused in lesser or greater degree by human activity resulting in an increased amount of radioactively absorbent gases in the atmosphere. Some of the main pollutants associated with combustion processes are listed in Table 3.3, and a number of these are discussed in greater detail in the following sections (11).

Table 3.3: Emissions from combustion systems and their effects

Emission Effect	Source/effect
Carbon Dioxide (CO2)	Complete combustion of Carbon in fuel / Global warning
Carbon Monoxide (CO)	Incomplete combustion of carbon in fuel / Smog
Sulfur Dioxide (SO2)	Combustion of sulfur in fuels / Smog acid rain .
Nitrogen Oxides (NOx)	Byproduct of most combustion

	processes / Acid rain.
Nitrogen Dioxide (NO_2)	Byproduct of most combustion / Global warning
Water vapor (H_2O)	combustion of hydrogen / Localized fog In fuel
Particulate Matter (PM)	Unburned or partially Smog unburned carbon and hydrocarbons / dirt and ash in fuel

3.6.1 Nitrogen Oxides

Nitrogen oxides (NOx) are amongst the primary pollutants emitted into the atmosphere during the combustion process. The term NOx refers to the cumulative emissions of NO_2, NO_3 , and trace amounts of other species (12).

The majority of NOx is initially formed as NO and is then oxidized further to form NO_2, either immediately within the combustion chamber or as the flue gases are discharged into the atmosphere. When NOx reacts with volatile organic compounds in the presence of sunlight they form ground level ozone (O_3), which is a major ingredient of smog. When NOx reacts with water and air it forms very dilute nitric acid (HNO_3), causing acid rain. The formation of NOx is generally controlled by three routes, thermal NOx, fuel NOx and prompt NOx. Thermal NOx refers to the NOx that is formed through high-temperature oxidation of nitrogen in the combustion air. The thermal NOx formation rate is strongly correlated to temperature. At temperatures above 1400 C the levels of NOx formed become significant and the formation rate increases exponentially. A typical method to control the NOx formation is to reduce the peak and average flame temperatures. This approach is contrary to the traditional methods of assuring complete combustion, but some compromise is needed between combustion efficiency and the formation of thermal NOx. Fuel NOx refers to the conversion of fuel-bound nitrogen found in nitrogen bearing fuels, such as oils and coal, to NO formed during the combustion process. The conversion to NO is strongly dependent on the fuel-to-air ratio but only weakly dependent on combustion zone temperature. This means that techniques such as fuel-air mixing can reduce fuel NOx emissions significantly.

Prompt NOx refers to NOx that is formed very early in the combustion process. It appears through the formation of intermediate nitrogen cyanide (HCN) species that is followed by the oxidation of HCN to NO. The formation of prompt NOx is normally only weakly temperature dependent, but this dependency can become stronger in fuel-rich conditions (12).

3.6.2 Sulfur Dioxide

Sulfur is present in most fossil fuels and primarily originates from the decay processes of plants and animals. The combustion of fuels containing sulfur results in creation of SO2, and when it oxidizes in the atmosphere it converts to sulphuric acid (H2SO4). The emissions of SO2 are a significantly larger contributor to acid rain than NOx. SO2 by itself is highly corrosive and harmful to the environment. A significant amount of the SO2 discharged into the atmosphere is further oxidized to SO3 when mixed with air and then combines with water vapor to create a persistent visible plume, i.e. acid mist (12).

Several methods can be used to reduce SO2 emission. One solution is to simply switch to a fuel with less sulfur content but this may have adverse effects on the boiler performance since the fuels may differ significantly in heating value. This can also affect the flame stability, change emissions and may require changes to be made in fuel handling. If switching to a low-sulfur fuel is not a viable option the use of wet or dry scrubbers may be more suitable. These scrubbers are a post-combustion method for controlling SO2 emission very efficiently without making major changes in boiler operations. The by-products from scrubbing, calcium sulfate (CaSO4) or calcium sulfite (CaSO3), depending on the process, can be used as gypsum or placed in landfills(12).

3.6.3 Particulate Matter

In the combustion of a fuel that contains noncombustible materials, the result is the formation of ash. This ash along with any unburned carbon particles are often collectively referred to as particulate matter (PM) or fly ash. PM, such as smoke, dust, soot and haze, is emitted during the combustion process and the concentrations are dependent on the chemical composition of the fuel. In high concentration PM can contribute to poor visibility, such as haze, which is common around densely populated areas. It can also cause serious health problems since the small particles can penetrate deeply into the lungs and some can even get into the bloodstream. Particle size is measured in micrometers (m), and emission of PM is regulated separately for particles less than 10 m and particles less than 2:5 m. Before flue gas is discharged into the atmosphere it may require filtering to reduce the amount of PM (12).

3.6.4 Carbon Monoxide

Carbon monoxide (CO) is formed in the combustion process when carbon in the fuel does not burn completely. The CO gas is odorless, colorless and highly toxic. The greatest source of CO emissions is vehicles, which accounts for approximately 60 % of total CO emission in the United States. In some cities the emissions from automobiles can even reach 95 % of the total emissions of CO. Other sources of CO emissions are industrial processes, such as combustion boilers and incinerators (12).

The control of the combustion process is therefore important in terms of boiler efficiency since incomplete combustion results in increased emissions of CO and PM, which means that energy, is being wasted. In good combustion systems, CO should be limited to a few parts per million (ppm), normally in the range of 20-25 ppm. If CO exceeds 1000 ppm it is usually the result of air starvation or very poor fuel-air mixing and is the symptom of serious problems within the combustion process. The combustion of liquid and gaseous fuels generally generates significantly less CO emissions than the combustion of solid fuels. Therefore, combustion control is an important design and operating concern in solid fuel boilers (12).

3.7 Combustion Efficiency

Combustion efficiency is expressed as a percent and determined by subtracting individual stack heat losses, as percent of the fuel's heating value, from the total heating value of the fuel (100%). Dry gas loss and latent heat loss due to H2 in the fuel are typically the largest sources of stack loss. Others can be included, such as heat loss from moisture in the air and fuel and losses from the formation of CO rather than CO2. (13)

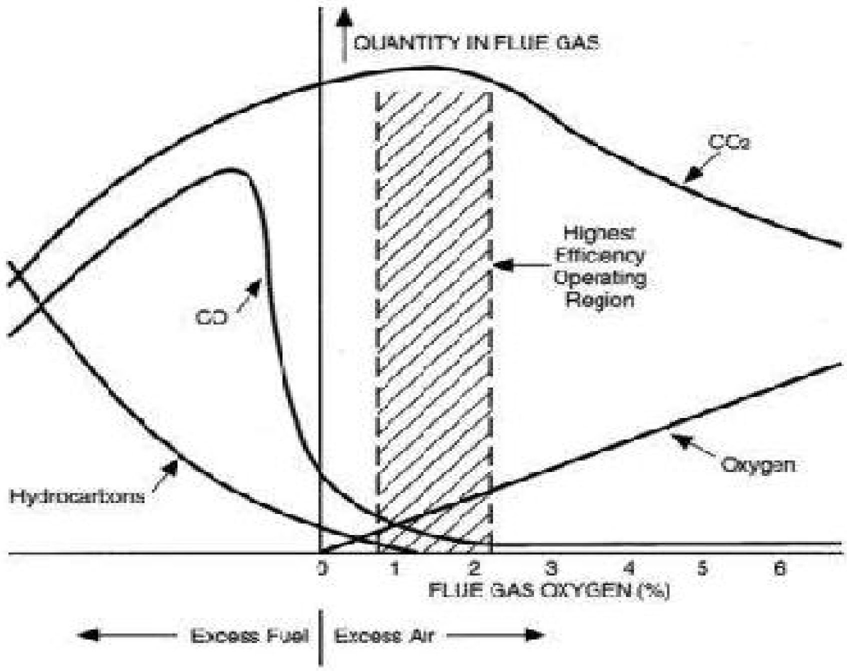


Figure 3.4 combustion efficiency and flue gases

3.7.1Heat Losses

It is vital to keep heat losses to a minimum so that efficiency is maximized and more energy is conserved. Heat losses are inevitable, especially through the stack, but great amounts of heat losses may be prevented with the proper measurement and control procedures. Total heat losses are normally tallied by adding the stack losses, the skin/shell losses, and the losses due to the un-burned fuel in ash collection hoppers. Stack losses will combine the sensible heat losses or dry gas losses and the latent heat losses. Sensible heat losses relate to the heat used to heat the combustion gases exiting the stack; the higher the volume and temperature of the flue gases the larger the dry gas heat losses. Latent heat losses are due to the water vapor in the flue gases (a large amount of energy is used as water evaporates). (13)

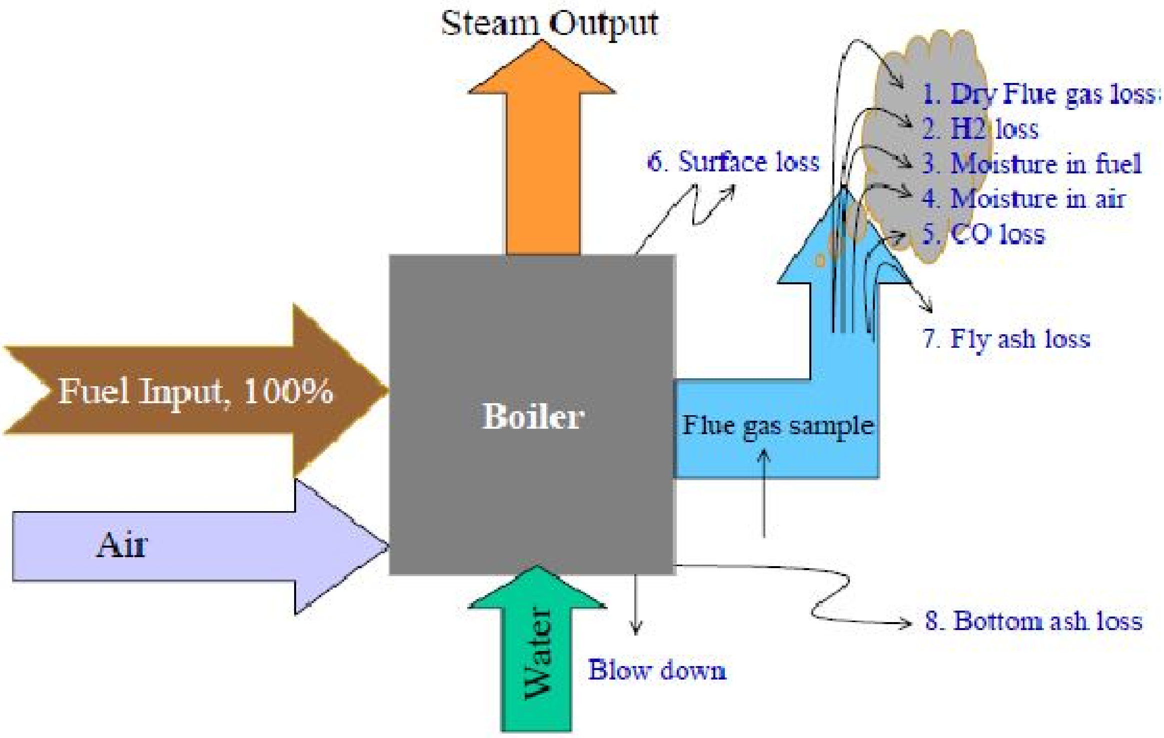


Figure 3.5 various heat losses occurring in the boiler

Chapter four

Optimum gas analyzer with trim system for combustion

4.1 Preface:

Oxygen analyzers are used to regulate the fuel/air ratio in furnaces, kilns and boilers, from small package boilers to large power station boilers.

Probes can be installed either in the high temperature combustion zone or in the lower temperature flue gas stream. For modulating burners, the system must be able to vary the flue gas oxygen level, depending on the firing rate of the burner. At lower firing rates, more excess air is required than at higher firing rates.

Oxygen trim systems automatically vary the oxygen level from low fire to high fire. The correct oxygen operating levels are normally established by measuring the CO level in the flue gas. The oxygen level is set so that the CO never exceeds about 300 parts per million. On very large installations, such as power stations, the correct oxygen level in the flue gas is normally determined from mass balance measurements. When operating at optimum efficiency; it is unusual for a power station to be generating any CO. When the oxygen measurement system is used for closed loop control, limits must be set so that it cannot produce dangerous fuel-rich conditions during system malfunction. On small installations, this is achieved with mechanical limits on the burner linkages. On larger installations, it is normally electronically limited. The oxygen signal is used as a trim signal with high and low alarms. Apart from savings in fuel costs, oxygen monitors and trim systems provide an early warning device for impending combustion problems. (10)

4.2 Measuring Oxygen in Flue Gases:

There are two methods currently in use to measure oxygen in flue gases orsat test and oxygen sensors.

4.2.1 Orsat test

One of the earliest methods of measurement, the manually performed Orsat test is still used today. A sample of flue gas, which has been conditioned (cleaned, dried and cooled), is passed through a series of pipets each of which contains a separate chemical reagent. The reagents each absorb a different chemical in the gasusually oxygen, carbon monoxide and carbon dioxide. As the gas passes through each pipet, its volume is measured. Any change in measurements indicates the amount of a particular gas that was absorbed.

Orsat device shown in Figure 4.1 contains some components (labeled) such as:

- Label A is straight burette which flow from bottom to top and contains 100 sections
- Label B is aspirator container
- Label D1, D2, and D3 are pipettes that are numbered 3 pieces comprising absorbents stuffed with beads or glass tubes intended for improving absorption areas. Each pipettes contains solution as follow:
- $CuCl2$ (cuprous chloride) in HCL intended for CO
- Alkaline pyrogallol intended for $O2$
- KOH (Potassium hydroxide) intended for $SO2$ dan $CO2$)

Each one pipette is linked to an unoccupied pipette lurking behind it so absorbent could subside directly into this when the gas is accepted. Label C is the primary separating cock pertaining to gas maintenance in the process in conjunction with Label F1, F2, and F3 which is 3 separating cocks intended for 3 pipettes. There are several disadvantages to the Orsat test. It is slow, repetitive work and its accuracy depends on the purity of the reagents and the skill of the operator. Also, there is no way to provide an automatic signal for a recorder or control system.

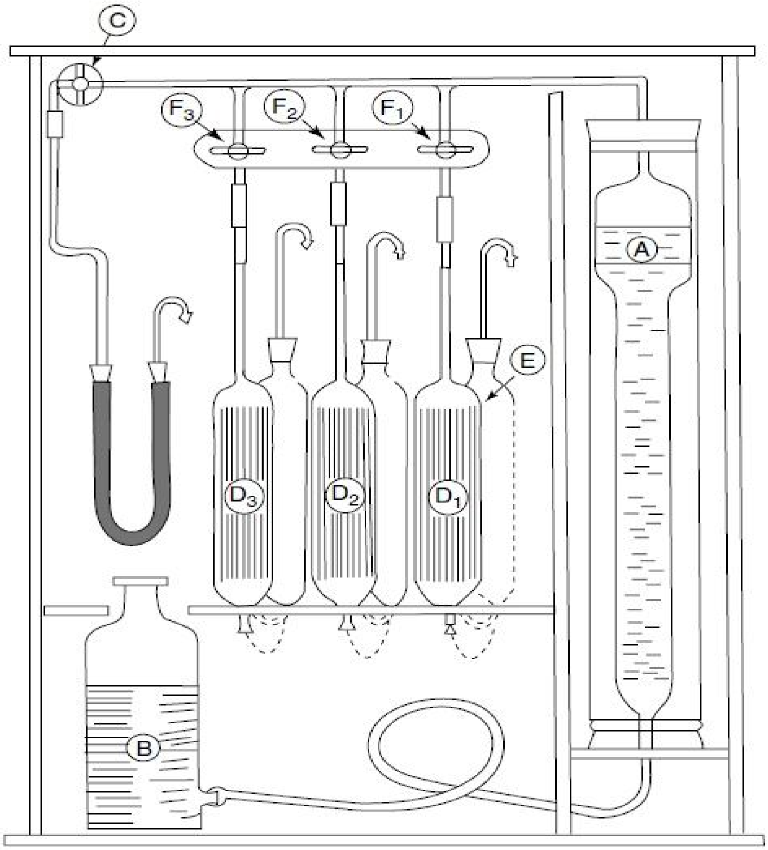


Figure 4.1 Orsat device

4.2.2 Oxygen sensor:

Oxygen sensor takes advantage of the fact that oxygen molecules are strongly influenced by a magnetic field. One common design uses two diamagnetic nitrogen filled quartz spheres connected by a quartz rod in a dumbbell shape. The dumbbell is supported and suspended in a non-uniform magnetic field. Since the spheres are diamagnetic, they will swing away from the magnetic field.

When a gas containing oxygen is introduced into the spheres, the dumbbell will swing toward the magnetic field across a distance that is proportional to the amount of oxygen in the gas. This movement can be detected either optically or electronically. Since it is a delicate process, paramagnetic sensors work best in a laboratory and not in an industrial setting. Any sample of flue gas used must be cleaned, dried and cooled before being put into the mechanism. Flue gas constituents, such as nitrous oxide and some hydrocarbons, have paramagnetic properties that interfere with the test results. There are two types of oxygen sensors:

4.2.2.1 Portable gas analyzer

Portable gas analyzers used to provide data which can be used for making periodic demonstrations of whether a combustion source is operating in compliance with applicable emission limitation. In order for the portable analyzer to give reliable measurements of stack gas concentrations, the instrument must be calibrated and maintained according to manufacturer and regulatory specifications, and stack gas sampling and conditioning system must be operated and designed according to manufacturer and regulatory specifications. FIG 4.2

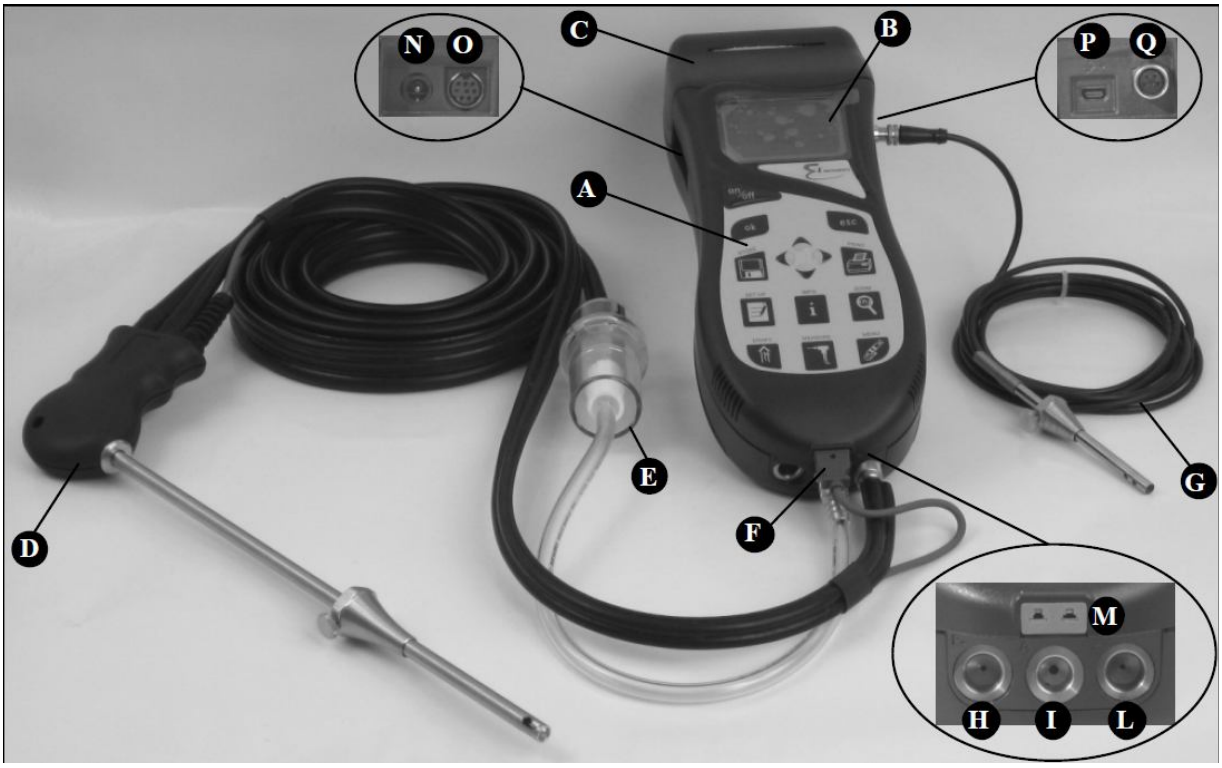


Fig (4.2) Overview of Flue Portable Gas Analyzer Components

Above figure shows the overview components of portable gas analyzer

Legend:

D Flue sampling probe

E Condensate separator and fine dust filter unit (Water Trap Assembly)

F Compensated male connector of the fumes exhaust temperature probe

G Combustion air temperature probe

H P- connector (negative input for measuring differential pressure)

I A connector (sample probe input by means of the water trap)

L P+ connector (positive input for measuring draft)

N Battery charger socket

O Serial cable socket for connecting to the draft gauge and to the ancillary probes

M Temperature female connector

P Mini-USB socket for connecting to a PC

Q Female connector for connecting the combustion air probe (Incoming Air — Condensing Units)

4.2.2.2 Oxygen gas analyzers

Oxygen and combustibles analyzers enable both measurements to be made at a single sample point. From this, the supply of excess air can be controlled on a continuous basis, minimizing heat loss and unburned fuel loss, and therefore ensuring the most efficient operation of your boiler.

It measures unburned oxygen levels in dirty, aggressive combustion applications, including:

• Boilers—all fuels and all types, including marine, recovery and utility

• Furnaces—all fuels and all types, including heat treating, glass and process. Fig (4.3)

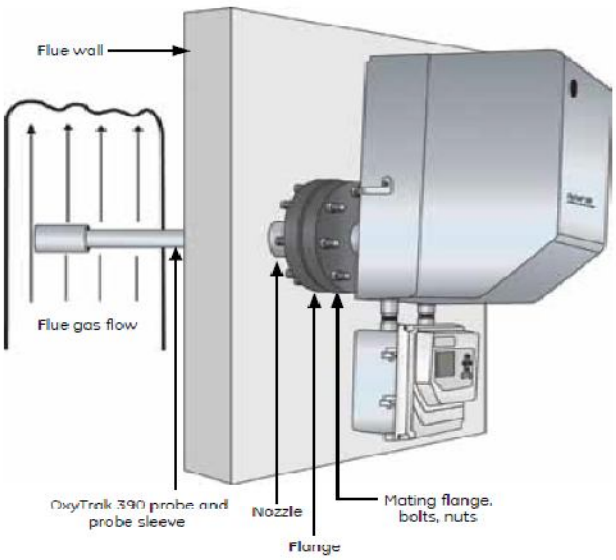


Figure (4.3) shows oxygen analyzer.

4.3 oxygen trim analyzers:

The amount of oxygen in the flue gas off of a boiler indicates how much excess air is in the flue gas mixture. The lower the amount of excess air is, the higher the boiler efficiency is. In other words, the more efficient your fuel dollars are being spent.

Air to fuel ratio is one of the main factors affecting boiler efficiency. Although the ratio is set during commissioning, it tends to drift after a while. Oxygen trim controls ensure the ratio is always at its best, saving you around 5% on fuel costs.

Oxygen trim controls which automatically monitor the oxygen or carbon monoxide concentration in boiler flue gases and vary the air and fuel supply to the burner to limit excess or low oxygen concentrations in the fuel/air mix.

4.3.1 Features:

- Continuous, on-line adjustment of fuel-air ratio
- Increased safety for personnel & equipment
- Reduced maintenance costs
- Savings in fuel consumption
- Enhanced environmental protection
- Electricity savings

4.3.2 System description:

A pre-engineered parallel positioning combustion control system with oxygen trim for single- or dual-fuel jackshaft boilers. It is ideal for upgrading older control systems that can no longer maintain the original design efficiency of the boiler. Trim system provides the instrumentation and preconfigured programs for continuous adjustment of the fuel-air ratio, for optimum combustion efficiency. Installing a trim system on a jackshaft boiler requires adding control of the air flow. Instead of the traditional and costly method of breaking the jackshaft, the trim system adds a Variable Frequency Drive (VFD) to the FD fan motor, and adjusts the air volume to demand by regulating the speed of the fan. The higher cost of a VFD is more than offset by savings in mechanical installation and lower electricity consumption. See fig 4.4

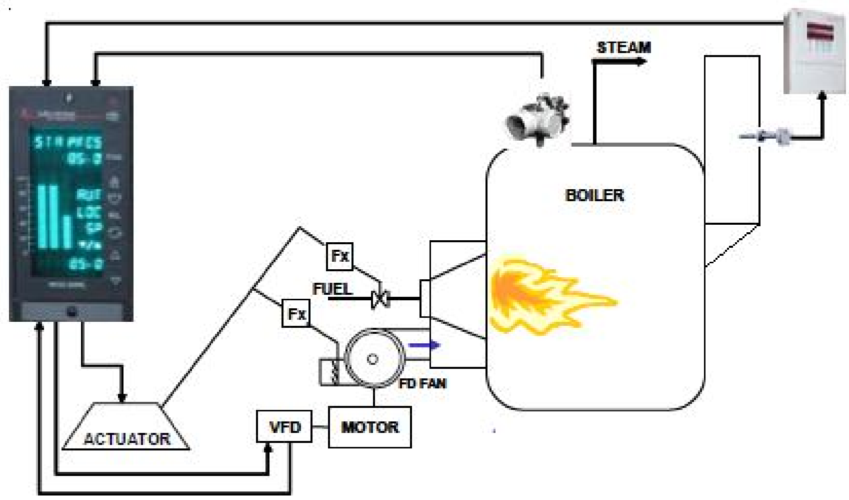


Figure 4.4 typical oxygen trim system

Installing a trim system on a jackshaft boiler requires adding control of the air flow. Instead of the traditional and costly method of breaking the jackshaft, the Trim system adds a Variable Frequency Drive (VFD) to the FD fan motor, and adjusts the air volume to demand by regulating the speed of the fan. The higher cost of a VFD is more than offset by savings in mechanical installation and lower electricity consumption.

The trim system provides a higher level of safety than traditional jackshaft control systems, including: output limits on the O2 controller; alarm and boiler trip on insufficient air; automatic switch to Manual on loss of steam pressure or O2 signal; and feedback signal with deviation alarm on fan speed.

The trim controller receives the steam pressure signal from the pressure transmitter and compares it with a pre-determined set point. The output of the steam pressure control loop represents fuel demand, and is connected to the jackshaft actuator to control fuel flow. The same signal is sent to lookup tables within the controller which contain the air settings for a certain fuel flow as determined during the combustion test. The signal from the oxygen analyzer is the process input for the excess air (O2) control loop, which compares it with the fuel demand from the lookup tables. The result becomes the set point for that loop.

The output of the O2 controller is used to trim the output of the pressure control loop. This adjusted signal is connected either to the VFD on the FD fan motor. In this way the boiler is always operating with the correct fuel-air ratio, eliminating the need for seasonal adjustments and compensating for changes in temperature and mechanical wear.

4.3.3 Equipment description

The trim system includes:

• Trim controller, pre-configured, with the I/O required for combustion control with O2 trim

• Oxygen analyzer with sensor (optional)

• Pressure transmitter (optional)

• All necessary documentation for the installation, startup and operation of the system.

The trim controller is a multi loop controller with flexible, isolated I/O. It has a high-visibility display with clear, informative screens for ease of operation. The basic controller includes the CPU, power supply, vacuum fluorescent display, and terminal block. The controller memory is non-volatile RAM which contains the configured database and all current process parameters. The terminal block provides direct connection of field wiring at the rear of the controller. The power supply is 85-250Vac or 24Vand the front panel has a NEMA 4 rating. The controller also provides failsafe and power fail-recovery settings for all configured parameters and output points.

Trim is part of the Steam series of pre-engineered boiler control packages. Each controller come network enabled, to connect to other packages in the Steam series, such as the plant master controller. This peer-to-peer network provides secure communications between Steam controllers to ensure your boiler stays up and running regardless of traffic or failures on the plant information network.

If the boiler isn't operating at design efficiency due to mechanical wear, old controls, or conservative fuel/air settings, upgrading your combustion control system to a trim can improve boiler efficiency 5% or more, with a resulting reduction in fuel consumption, or more available steam for the same amount of fuel. It also provides the additional benefits of reducing the need to replace refractory or tubing, and a reduction in the total amount of NOX and CO2 emissions and significant savings in electricity.

Chapter five

Old boiler control sysytem vs new one (a comparative study)

5.1 Preface:

Steam plant optimization is the overall improvement of the plant's operation. The most common strategies used to accomplish this task includes, and generally focuses on, the improvement of primary equipment operating efficiency, i.e. fuel and energy savings. In heavy commercial and industrial boiler applications these efficiencies are normally found in the application of waste heat recovery equipment, systems and process automation, and improved operating practices.

The use of more advanced automatic control systems for combustion control has proven to be an excellent example of systems and process automation success.

The new control systems available today help improve overall combustion efficiency and burner stability over varying loads and demands. The most sophisticated systems can eliminate the need for operator input during load changes while maintaining safe and reliable fuel/air ratio control. (14)

5.2 Kenana boilers control over view:

Kenana Sugar Company boilers when established it built upon single point positioning combustion control system, there for the controlling of boiler combustion not properly and the operator adjust the air / fuel ratio according to the load and drum pressure. There is no feedback signal from the chimney that shows exhaust gases content.

In this case the combustion process will not be completed and combustion losses will increased beside that it not possible to make efficiency test to now who match boilers efficiency are and pollution may be increased due to Co, Nox & Co2.

To combust a fuel, it takes fuel, heat and air. An excessive amount of air in the combustion mix is wasteful as it robs the burner's energy, taking Btu away from the heat exchange process, applying it to exiting stack gasses. In short, this results in dollars being blown up the stack. Normally, when setting up the fuel/air ratio on a modulating burner, the technician will attempt to hold the excess air at between 3-7% O2 throughout the firing range with the low side (3%) being at the higher firing rate and the 7% being at the low end.

Unfortunately, the technician or operator is not at the boiler every operating hour with an analyzer and wrench making adjustments as variations occur due to uncontrollable conditions. What are these varying conditions? They are:

- Relative humidity
- Barometric pressure
- Varying Btu value in the fuel
- Ambient temperature
- NOx control through Flue Gas Recirculation (FGR)

Of these, varying ambient temperature is probably the most common, and it's problematic because as the air temperature varies, the fire can go rich (too little air, sooting the boiler) or lean (too much air heating the excess nitrogen) depending on the density changes of the air due to the increase or decrease in temperature.

FGR is another common causal factor, especially when it is excessive (15-25% hot gas recirculation) as it often precipitates fuel/air ratio imbalance requiring a vigilant monitor to make the ongoing adjustments to compensate for the varying conditions.

Therefore, if you have a boiler room that can experience any of these uncontrollable changes, a quality oxygen trim system should be a serious consideration. It won't tune your burner, but once the burner is properly tuned, it will compensate for the uncontrollable variables. As a result, it will return wealth to the business by constantly monitoring the scarcity or excess oxygen, adjusting the fuel/air ratio accordingly.

Figure 5.1 Kenana boilers

The operator control boiler combustion by fuel control valve, forced draft fan damper and induced draft fan damper. See fig 5.2

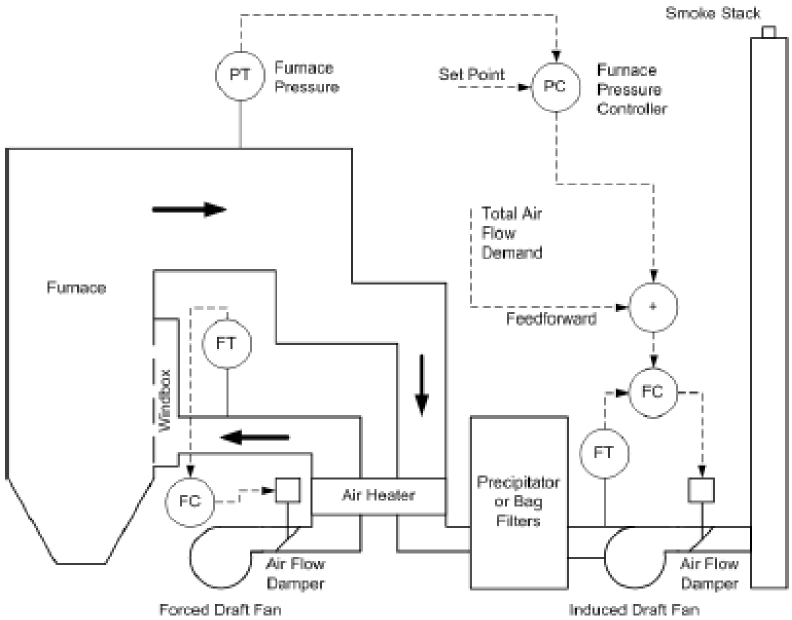


Figure 5.2 Kenana boiler combustion control

5.2.1 Single point positioning control system:

One of the most common combustion control system on oil and/or gas fired boilers is the single point positioning system, commonly referred to as a jackshaft. Refer to the drawing below. The fuel valve(s) and air damper are mechanically linked to a common rotating drive mechanism controlled by a master drive unit. Simple and safe, but requires a constant fuel pressure and BTU content. Maintaining the optimum air/fuel ratio throughout the load range is difficult.

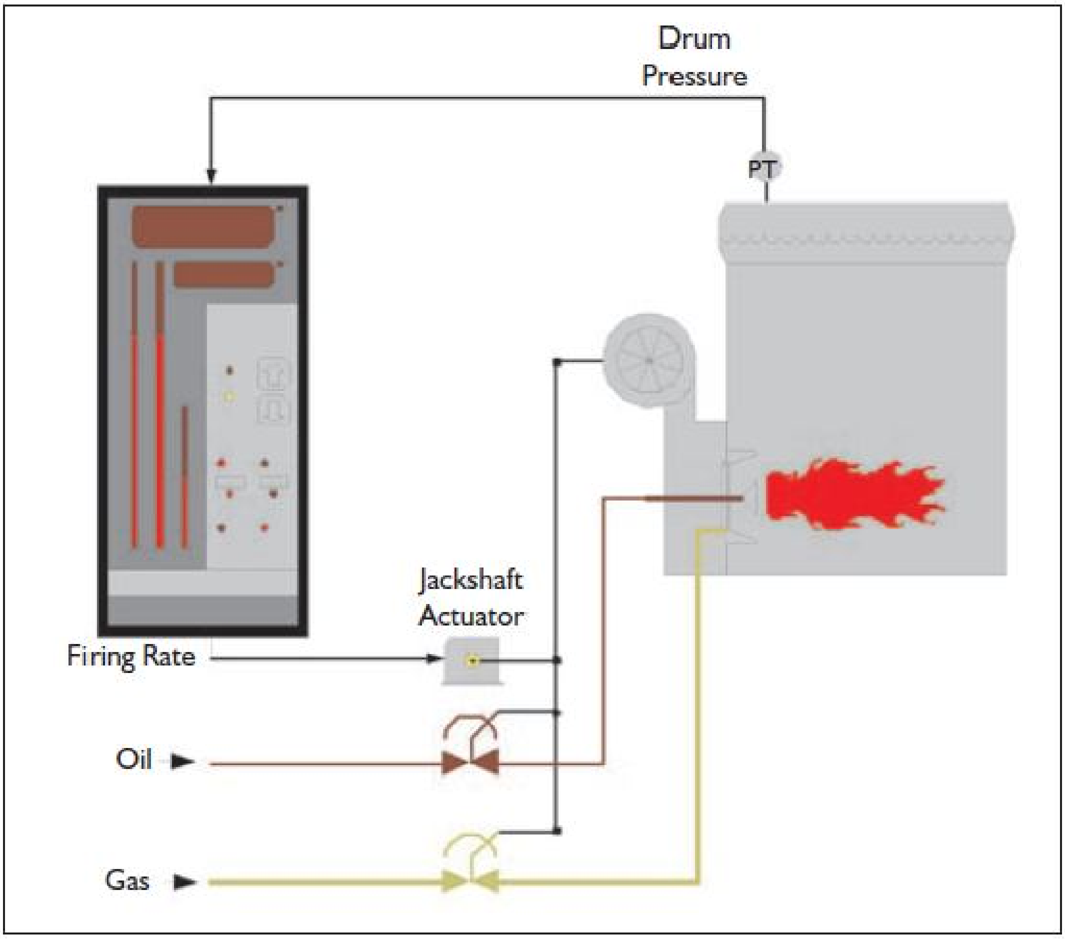


Figure (5.3) single position control system

The air and fuel control devices are connected to the jackshaft by a series of mechanical linkages and cams. As the actuator motor moves the jackshaft arm, the arms connected to the fuel valve and fan damper move with it. The relative movement can be varied by means of the cam adjustments, thereby determining the air/fuel ratio. For multiple-fuel burners, a second cam adjusts the standby fuel valve. See fig 5.4

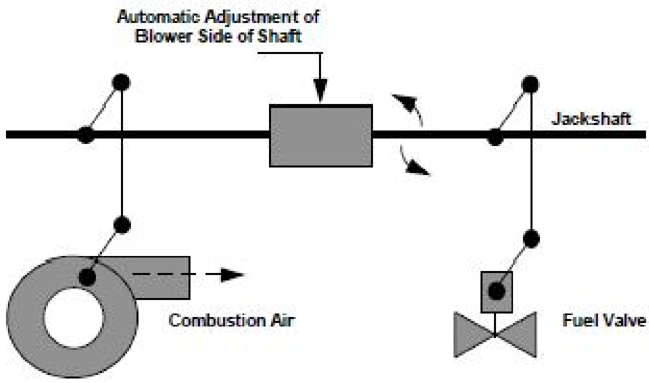


Figure 5.4 mechanical jack shaft

A mechanical jackshaft system does not include measurement of air flow or fuel flow, nor does it sense changing air temperature or fuel condition. It does not detect any play in the jackshaft and linkages. As a result it must be set up with sufficient air for safe operation under all conditions, which is usually more than the optimum for efficiency.

Common applications are small burners where the cost of more complex controls cannot be justified.

The simplicity of the single positioning control strategy makes it a very economical choice for small burners with modest firing rate changes however the fact that the fuel and air are fixed means that the fuel/air ratio is also fixed. Because of this fixed position arrangement the burner has no way to compensate for environmental changes such as combustion air temperature or fuel pressure. Additionally, the FPC strategy has no feedback to the control element to insure that the fuel and air end devices are actually functioning and in the correct position. This could lead to a crossover condition in which the fuel crosses over the air flow and results in a fuel rich furnace or other burner efficiency loses. (15)

5.3 new control optimization:

The objective of good burner combustion controls is to operate the burner in real-life conditions as close to these optimum conditions as possible despite changing boiler loads, varying ambient temperatures, and other environmental factors.

Fully metered combustion control systems or parallel positioning control systems monitor fuel and air flow and will adjust fuel valves and air dampers to keep burner flow rates constant despite changing conditions. Oxygen trim can be added to these systems to help ensure that the stack oxygen set point established during burner commissioning is maintained over time. In the past, fully metered combustion control systems were limited to large water tube boilers because of their high capital cost. Newer combustion control systems offer fully metered combustion control with oxygen compensation available off the shelf at substantially lower prices (Figure 5.5).

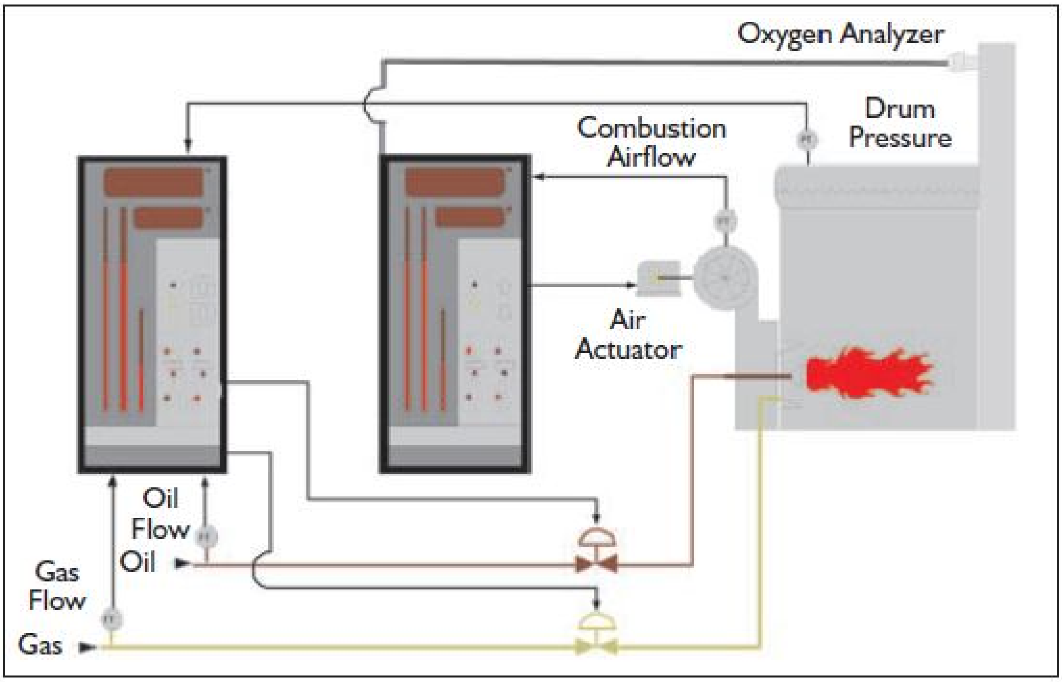


Figure 5.5 fully metered combustion control system

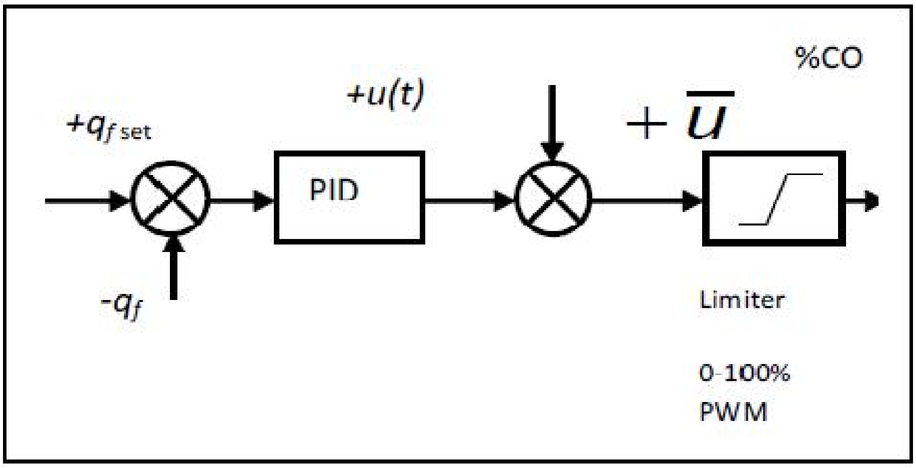


Figure 5.6 Air flow control

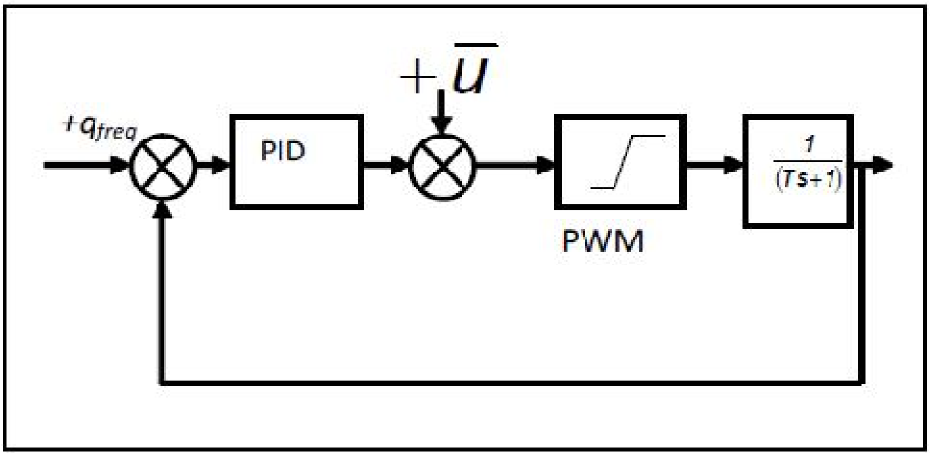


Figure 5.7 fuel flow control

A SIMULINK model has been developed for ratio control

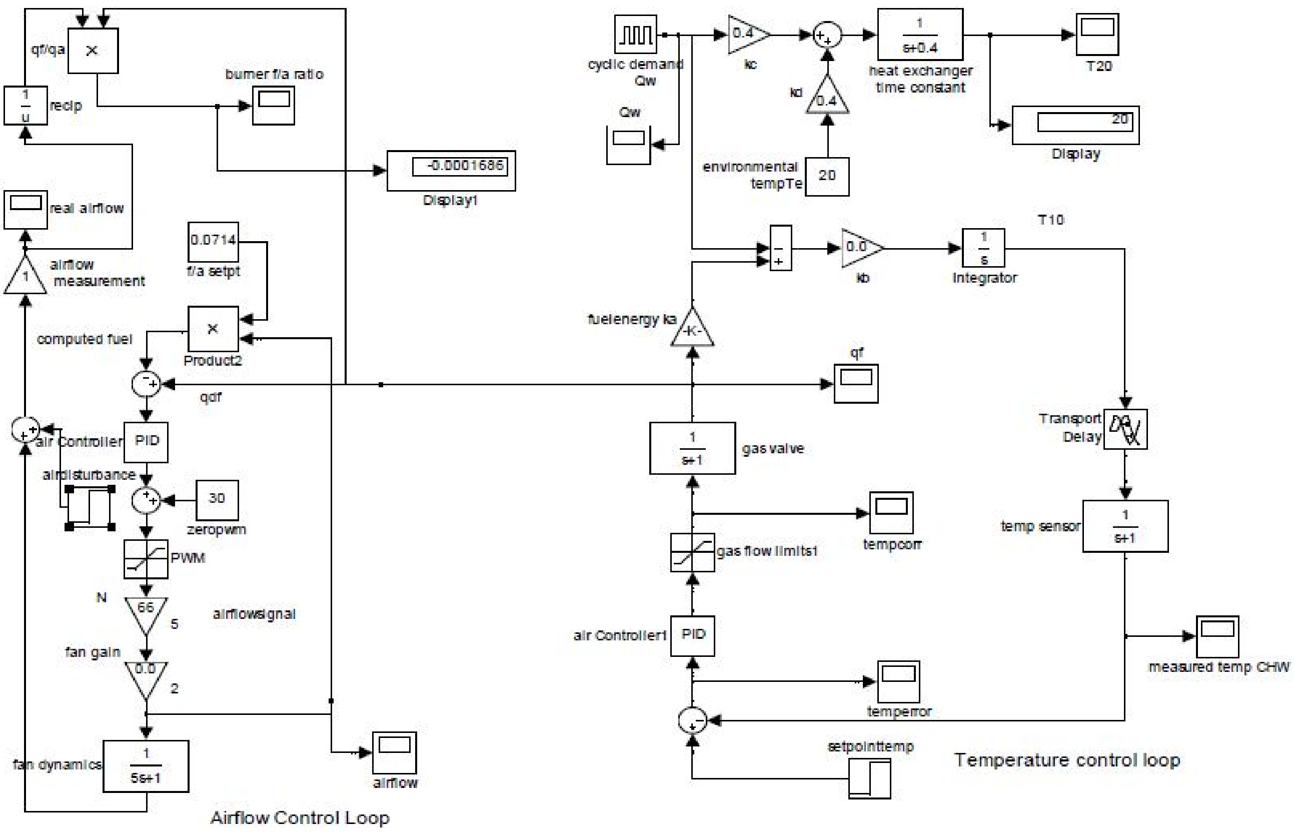


Figure 5.8Air/ fuel ratio control

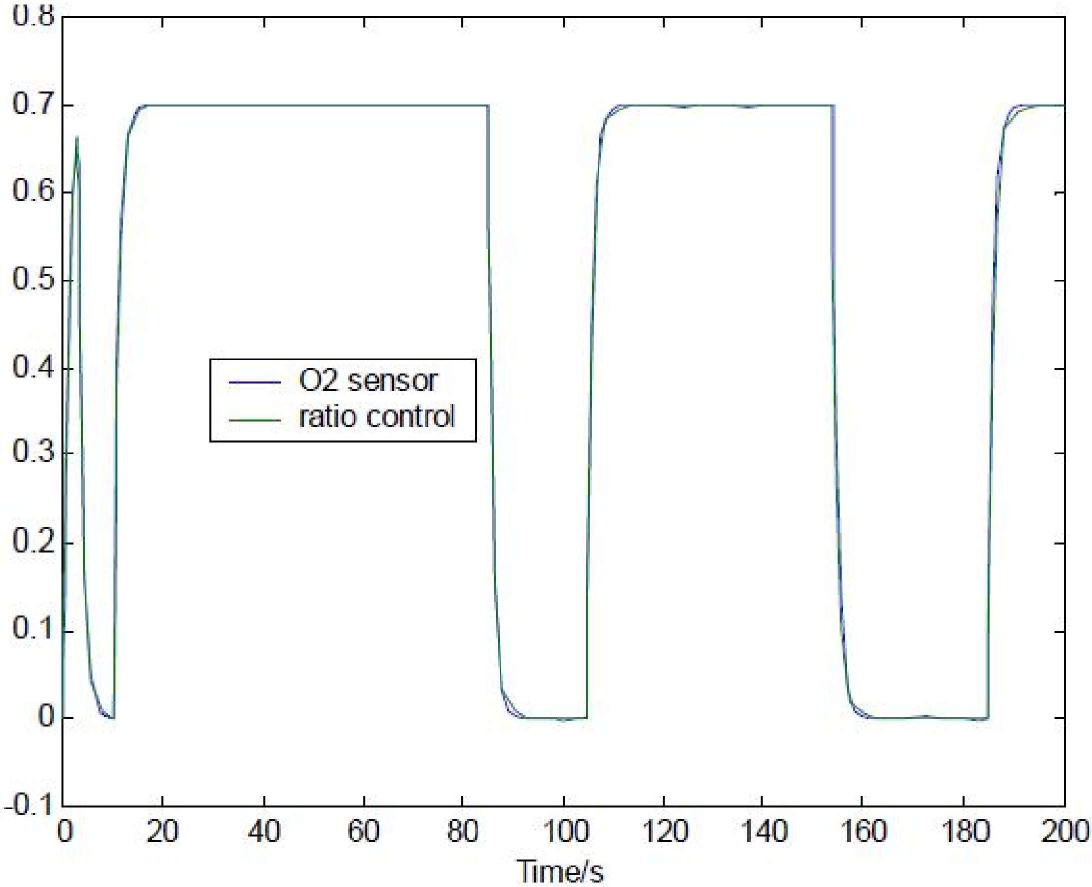


Figure 5.9Air/ fuel ratio control

5.4 Burner Turndown Affects Efficiency:

Burner turndown is important for fuel savings—especially during low-load conditions. The typical burner is designed for 6:1 turndown firing natural gas and 4:1 turndown firing oil (6:1 turndown means high-fire fuel flow is six times low-fire fuel flow). In practice, many burners operate at 3:1 turndown—meaning they light off at 33% of high-fire heat input. If 33% firing rate produces more steam (or hot water) than the plant load, the burner eventually shuts down on high steam pressure or high water temperature, and all the losses associated with post purge, standby and purge are incurred again. Frequent boiler cycling also introduces thermal shock to the boiler tubes and refractory to shorten boiler life.

Because boilers tend to be oversized (typically 5% for every engineer who touches the design), it is common for boilers to cycle on and off during low-load conditions. Each time a boiler cycles off, it drafts cold combustion air during the post purge and standby periods. When the boiler is cycled on again, it must go through a purge period when more cold air is cycled through the boiler to purge the furnace of possible combustibles prior to ignition. All the heat lost to this cold air has to be recouped by the burner when it lights off again. It is not uncommon to see small boilers cycle up to 10 times per hour during low-load periods.

A high-performance burner will operate safely at 10:1 turndown on gas and 8:1 turndown on oil. A turndown ratio of 10:1 means low-fire heat input is just 10% of high-fire heat input. (16)

Oxygen trim systems automatically vary the oxygen level from low fire to high fire. The correct oxygen operating levels are normally established by measuring the CO level in the flue gas. The oxygen level is set so that the CO never exceeds about 300 parts per million.

On very large installations, such as power stations, the correct oxygen level in the flue gas is normally determined from mass balance measurements. When operating at optimum efficiency, it is unusual for a power station to be generating any CO.

When the oxygen measurement system is used for closed loop control, limits must be set so that it cannot produce dangerous fuel-rich conditions during system malfunction. On small installations, this is achieved with mechanical limits on the burner linkages. On larger installations, it is normally electronically limited. The oxygen signal is used as a trim signal with high and low alarms. Apart from savings in fuel costs, oxygen monitors and trim systems provide an early warning device for impending combustion problems.

5.5 Improving Combustion Efficiency

Combustion efficiency is an indication of the burner's ability to burn fuel. The amount of unburned fuel and excess air in the exhaust are used to assess a burner's combustion efficiency. Burners resulting in low levels of unburned fuel while operating at low excess air levels are considered efficient. Well designed conventional burners firing gaseous and liquid fuels operate at excess air levels of 15% and result in negligible unburned fuel. Well designed ultra low emissions burners operate at a higher excess air level of 25% in order to reduce emissions to very low levels. By operating at the minimum excess air requirement, less heat from the combustion process is being used to heat excess combustion air, which increases the energy available for the load. Combustion efficiency is not the same for all fuels and, generally, gaseous and liquid fuels burn more efficiently than solid fuels.

The traditional goal of achieving best combustion efficiency is often being modified to accommodate two other goals:

- Minimizing the thermal NOx produced through the burner.
- O2 levels and flame temperatures are key indicators to the production of NOx.

Low NOx burners use internal flue gas recirculation, which results in less heat intensity in the burner, producing less thermal NOx

Lower greenhouse gas production - carbon dioxide (CO_2) is a natural byproduct of combustion, but the US EPA has been given authority to regulate its production as with more toxic flue gas emissions like SO_2 and NO_x. Indeed, the refining industry has been singled out for enforcement under the EPA's "National Petroleum Refinery Initiative". The Greenhouse Gas Mandatory Reporting Rule (GHGMRR) requires most refinery sources to measure either the carbon content of the fuel under Tier III rules, or to measure the actual CO_2 exiting the stack as part of a CEMS system.

Operating a furnace or boiler at its optimum efficiency minimizes the production of CO. This is counter-intuitive; CO_2 production actually peaks out around the stoichiometric fuel-air ratio. While one might be tempted to operate a bit lean of stoichiometry (with extra air), this extra air would have a quenching effect on the flame, and less energy would be produced. The furnace would have to run longer to make up for the losses, and more CO_2 would be produced in the end.

Chapter Six
Conclusion and recommendations

6.1 Results:

The goal of this thesis has been to investigate various techniques that improve the efficiency of boiler systems. Improvements in these control systems take different forms, such as changing signal positioning control system by parallel positioning control system via oxygen trim system also we can use portable gas analyzer and make efficiency test to know how much our boiler efficiency are and reduce the fuel consumption or reducing the emission of polluting gases to the environment.

6.2 Results Discussion:

The choice of which techniques covered in this thesis are best suited for implementation in a boiler combustion control system is dependent on oxygen trim system. Combustion efficiency will improve for single point positioning system through incorporation of an oxygen trim system. The oxygen trim system incorporates an oxygen analyzer and controller that adjust the airflow for improved efficiency. The analyzer measures the actual stack O2 and provides an input into the trim controller.

6.3Conclusion:

Boiler combustion efficiency can be improved by incorporating an excess air trim loop into the boiler controls. It is easy to detect and monitor excess air, as oxygen not used for combustion is heated and discharged with the exhaust gases. A stack gas oxygen analyzer can be installed to continuously monitor excess air and adjust the boiler fuel-to-air ratio for optimum efficiency.

Combustion efficiencies can be improved through:

- Lower excess air requirements,
- Precise and repeatable air-fuel metering, load following, and load response through parallel positioning systems and state-of-controller ,here I used PID controller,
- Reduction in boiler-burner cycling and off-cycle heat losses with high turndown burners,
- Over-fire and stack draft control by using gas analyzer which provides continues back feeding signals from stack.
- Boiler-burner staging in multiple boiler installations through microprocessor based lead-lag control systems.

6.4 Recommendations:

1- Conduct combustion efficiency test in full and in part load buy using portable gas analyzer.
2- If excess oxygen exceed 3% or combustion efficiencies values are low, consider modernizing the fuel/ air control to include an oxygen trim control system.
3- A new energy efficient burner should be considered if repair costs become excessive, reliability becomes an issue, and energy savings are guaranteed.
4- Change single positioning control system to parallel positioning control system for combustion control optimization.

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Appendix A. Energy Units

The common unit of heat measure in the U.S. is the British thermal unit or Btu. One Btu is defined as the amount of heat required to raise one pound of liquid water one degree Fahrenheit, specifically from a temperature of 59 degrees to 60 degrees.

The energy content of a fuel is typically given in Btus per pound of fuel. Fuel oil, for example, has an energy content of roughly 18,500 Btu/lb. For gaseous fuels, such as natural gas or propane, energy content is also expressed in Btus per cubic foot (Btu/ft3). For liquid fuels, such as fuel oil, Btus per gallon (Btu/gal) is commonly used.

When measuring the rate of fuel energy used, the input power or the rate of heat produced, the output power BTUs are given per unit time (e.g. Btu/hour). To convert from the rate of fuel used to power, the consumption rate is multiplied by the energy content of the fuel. This calculation is shown in the example below, where ten pounds of fuel with an energy content of 20,000 Btu/lb is burned per hour. The resulting energy consumed is 200,000 Btu per hour. 200,000 Btu/hr = 10 pound/hr x 20,000 Btu/pound

Boilers are often rated in “Boiler Horsepower” (BHP) rather than Btus per hour. One boiler horsepower is defined as the amount of energy it takes to convert 34.5 pounds of water to steam in one hour at 212 degrees Fahrenheit. A boiler HP equals 33,472 Btu/hour.

Metric Equivalents

Although common in the United States, the British thermal unit is not used universally. The metric units corresponding to Btus and pounds are kilo-

Joules (kJ) and kilograms (kg). The relationships between these measures are:

1 kJ = .948 Btu

1 kg = 2.204 pounds

1 kJ/kg = .429 Btu/pound

Appendix B: Fuel Specifications

Table 3 presents fuel specification values for a number of common fossil fuels used in commercial and industrial process boilers and heaters. For some electronic analyzers, these values are pre-programmed into the instrument for easy analysis. The fuel specifications are typical fuel values, and may not accurately represent the makeup of the fuel you are presently using. When available, fuel specifications supplied by the fuel vendor should be used.

Specifications	Nat. Gas	Propane	Oil #2	Oil #6	Coal	Wood (dry)	Bagasse	Coke
%Carbon	70.93	81.82	85.84	87.49	94.5	51.8	17.8	98.2
%Hydrogen	23.47	18.18	12.46	9.92	5.2	6.3	2.13	1.5
BTU/lb HHV	21869	21669	19512	18300	13388	9130	4500	16532
BTU/lb LHV	19693	19937	18357	17381	12903	8546	4303	16393
CO_2max	11.8	13.8	15.6	16.5	17	19.1	20.6	20.1
%Sulfur	0	0	1.6	1.40	0.034	0	0	0
Moisture	0	0	0	0	0.12	0	63.790	0.5

Table 6.1 fuel specifications for selected fuels

Appendix C. Calculations

List of Calculations described in this section:

1. Determining CO2 using the O2 concentration
2. Excess air calculation
3. Combustion efficiency calculation
4. Combustion calculations using the Siegert formula
5. O2 reference concentration calculation
6. Emission Rate calculations using dry gas factors
7. A general equation for the combustion of a simple hydrocarbon in air
8. Calculating CO2 max from the carbon content
9. Combustion air calculation

1. Determining CO2 using the O2 concentration

Instruments using electronic sensors determine the CO2 concentration in real time by measuring the
o_2 concentration in the flue exhaust and calculating CO_2.
The CO_2 concentration is determined using the following equation.

$$\%\ Co_2\ (by\ volume) = Co_2(max) \text{ x } \frac{(29.9 - \%\ \text{o}_2 \text{ measured})}{29.9}$$

CO2 (max) is the theoretical maximum concentration produced for the fuel used.

2. Excess air calculation

Excess air is determined by measuring the concentration of non-reacted O2 in the flue gas. A good approximation for excess air, expressed as a percent, can be calculated from the equation below.

This calculation is often used to automatically calculate % Excess Air in electronic combustion analyzers. O2 and CO concentrations are obtained from sampling the stack gas constituents.

$$\%\,Excess\ Air\ = \frac{\%\ \mathrm{o}_2 - \frac{\%\ \mathrm{co}_2}{2}}{29.9 - \left[\%\ \mathrm{o}_2 - \frac{\%\ \mathrm{co}_2}{2}\right]} \mathrm{x}100$$

3. Combustion efficiency calculation

Combustion efficiency is expressed as a percent and determined by subtracting individual stack heat losses, as percents of the fuel's heating value, from the total heating value of the fuel (100%). Dry gas loss and latent heat loss due to H2 in the fuel are typically the largest sources of stack loss. Others can be included, such as heat loss from moisture in the air and fuel and losses from the formation of CO rather than CO2. This basic form for calculating efficiency is described in the ASME Power test code 4.1 and is applicable for losses other than flue losses when determining total system efficiency by the Heat-Loss method.

$$\% \, Net\ combustion\ efficiency = 100 - \frac{\text{fuel heat} \frac{\text{losses}}{\text{Ib}} \text{fuel}}{\text{fuel heating} \frac{\text{value}}{\text{Ib}} \text{fuel}} \text{x100}$$

Flue heat losses = Lg + Lh + Lm + Lco (Individual heat losses are described in this section.)

Where:

Lg = heat loss due to dry gas

Lh = heat loss due to moisture from burning hydrogen

Lm = heat loss due to moisture in fuel

Lco = heat loss from the formation of CO

Heat loss due to dry gas (Lg)

Lg = Wg x Cp x (Tflue – Tsupply)

Where: *Wg* = the weight of the flue gases per pound of as-fired fuel.

Cp = specific heat of the exhaust gas mix.

Tflue = flue temperature

Tsupply = combustion supply air temperature

$$Wg = \left(\frac{44\ \text{co}_2 + 32\ \text{o}_2 + 28\ \text{N} + 28\ \text{co}}{12\ \text{x}\ (\text{co}_2 + \text{co})}\right) \text{x} \left(\text{Cb} + \frac{12\ \text{x S}}{32}\right)$$

NOTE:

The coefficients 44, 32, 28 are the molecular weights of the constituents.

CO_2, O_2, CO, N_2 are gas concentrations expressed as percent.

N_2 is determined by subtracting CO_2, CO, O_2 from 100%.

Cb is the carbon content, specific to the fuel.

S is the sulfur content of the fuel.

Cp is the specific heat that varies with temperature. Values are charted in the ASME PTC 4.1

Cp of the exhaust gas mix. A good estimate for the Cp, regardless of the fuel, is determined from

This simple equation: $Cp = .240 + .000038 \times (T_{flue} - 200)$.

Heat loss due to H_2O from combustion of hydrogen (Lh)

Where the fuel has a high hydrogen content, latent heat loss from the water formation can be very significant.

$$Lh = 8.936 \times H \times (hl - hrw)$$

Where:

8.936 = weight of water formed for each hydrogen atom

H = fractional hydrogen content of the fuel

hl = enthalpy of water at the exhaust temperature and pressure

hrw = enthalpy of water as a saturated liquid at fuel supply temperature

Heat loss due to moisture in fuel (Lm)

Moisture in the fuel is determined from lab analysis of the fuel and can be obtained from the fuel supplier.

Lm = fraction fuel moisture x (hl – hrw)

Where:
hl = enthalpy of water at exit gas temperature and pressure
hrw = enthalpy of water at fuel supply temperature

Heat loss due from the formation of carbon monoxide (Lco)

Carbon in the fuel reacts with oxygen to form CO first, then CO2, are generating a total of 14,540 Btu of heat per pound of carbon. If the reaction stops at CO because of insufficient O2 or poor mixing of fuel and air, 10,160 Btu of energy are lost.

$$Lco = \frac{\%\mathrm{co}}{\%\mathrm{co}_2 + \%\mathrm{co}} \mathrm{x} 10{,}160 \text{ x Cb}$$

Where: Cb = fractional carbon content

4. Combustion calculations using the Siegert formula

The Siegert formula is widely used in Europe to determine flue losses (qA) and efficiency.

$$qA = (T_s - T_a) \text{ x} \left(\frac{A_2}{21 - O_2}\right) + B$$

Efficiency = 100 – qA

Where:

qA = flue loss

Ts = flue temperature

Ta = supply air temperature

O2 = measured volumetric oxygen concentration expressed as a percent

A2, B = fuel dependent constants

The constants A2 and B are derived from the fuel composition. In Germany, the following values are prescribed for some common fuels:

Fuel Type	**A2**	**B**
Natural gas	66	0.009
Fuel oil	68	0.007
Town gas	63	0.011
Coking oven gas	60	0.011
LPG (propane)	63	0.008

Table 6.2 Siegert Constants

5 .O2 reference concentration calculation

$$Correct\ Gas\ Concentration(ppm) = gas\ conc.Meas.\ \text{x}\ \frac{29.9 - \mathrm{O_2\ reference}}{29.9 - \mathrm{O_2\ measured}}$$

6. Emission Rate calculations using dry gas factors

The emission rate calculation presented below is described in EPA Method 19. This uses the dry gas factor Fd. Dry factors are incorporated into the values found in Table 5 below. The table values (Ft), convert the measured concentrations of emission gases CO, NOx, and SO2 from PPM to pounds per million Btu of fuel.

$$E\ = Cg\ \text{x Ft x}\ \left(\frac{20.9}{29.9 - \mathrm{O_2\ measured}}\right)$$

Where:

E = Emission rate (pounds/MBtu of fuel)*

Cg = Gas concentration (PPM)

Ft = Emission rate conversion factor from Table 5 (below)

O2 measured = Oxygen concentration from flue measurement (%)

*To convert emission rate to metric equivalent units, kg/kJ, multiply E in the equation above by 2.236.

Ft**	Nat. Gas	Propane	Oil #2	Oil #6	Coal	Wood (dry)	Bagasse	coke
SO2	00145	00145	.00153	.00153	.00164	.00153	0.0016	0.00164
NOx	.00104	.00104	.00110	.00110	.00118	.00110	0.001	0.00118
CO	.00063	.00063	.00063	.00063	00072	.00067	0.00067	0.00072

Table 6.3 Emission rate conversion factors to convert from ppm to pounds per million btu of fuel for selected gases.

For those familiar with Method 19, *Ft* is related to *Fd* in the following way:

Ft is in units lbs/(MBtu ppm)

Fd is in units scf/MBtu

Ft = *Fd* x lb/(scf ppm)

7. A general equation for the combustion of a simple hydrocarbon in air

$$C_x H_y + \frac{(4x + y)O_2}{4} = x\, CO_2\, \mathrm{x} + (\mathrm{y}/2\,)\mathrm{H_2O}$$

Where: *x* and *y* are the number of atoms of carbon and hydrogen in the fuel.

8. Calculating CO_2 max from the carbon content

Complete combustion of a simple hydrocarbon $C_x H_y$ produces a fixed amount of carbon dioxide. If the theoretical air is used (i.e. excess air is zero) the concentration of CO_2 in the exhaust is at the maximum concentration. To calculate the maximum CO_2 concentration we assume water condenses out leaving only CO_2 and N_2 (from the air) as gases in the exhaust stream. Using the equation above for a simple hydrocarbon, we get.

$$\% \, Co_2 max = \frac{\text{moles } co_2}{(\text{moles } co_2 + moles \; N_2)} \text{ x } 100$$

$$\text{moles } co_2 = x \text{ moles}$$

$$moles \; N_2 = \frac{(4x + y) \text{ x } 3.76}{4}$$

9. Combustion air calculation

It is possible to predict the amount of air needed to completely burn one pound of fuel using the equation below. This calculates the theoretical air requirement.

Pounds Air/Pound Fuel = 11.53C + 34.34(H2 – O2/8) + 4.29S

C, H2, O2 and S are the fractions, by weight, of each chemical constituent of the fuel. (17)

Matlab program computes boiler efficiency:

```
% the indirect Method for determining boiler efficiency
% Input:
% the required data for calculation of boiler efficiency by using the direct
method are:
% Ultimate analysis of fuel (H, O, C, S), moisture content and ash content
% Percentage of Oxygen or CO2 in flue gas
% Flue gas temperature tf in C
% Ambient temperature ta in C
% Humidity of air in kg/kg of dry air
% Gross calorific value of fuel in kJ/kg (GCV)
% Mass of dry flue gas in kg/kg of fuel
% Output:
% L1 percentage heat losses due to dry flue gas
% L2 Heat loss to evaporation of water formed
% due to H2 in fuel
% L3 Heat loss due to moisture present in air
% L4 Percentage heat loss due to evaporation of moisture present if fuel
% moisture present if fuel
% L5 Percentage heat loss due to radiation and other unaccounted loss
% for a fired heater, these losses are between 2% and 5%
% Boiler efficiency
tf=input('Flue gas temperature in C,tf=:');
ta=input('Ambient temperature in C,ta=:');
GCV=input ('Gross Calorific Value of fuel, kJ/kg= :');
H=input ('percentage of H in fuel by weight, H=');
C=input ('percentage of C in fuel by weight, C=');
```

```
O=input ('percentage of O in fuel by weight, O=');
S=input ('percentage of H in fuel by weight,
S='); M=input ('moisture content in 1 kg of fuel, M=:');
M fuel=input ('mass of fuel supplied, (mfuel)=:');
h=input ('humidity of air, h=:');
% calculate the theoretical air requirement
Air= ((11.43*C) + (34.5*(H-O/8)) + (4.32*S))/100
% calculate the % excess air supplied (EA)
EA=O*100/ (21-O)
% calculate actual mass of air supplied /kg of fuel (AAS)
AAS= (1+EA/100)*air
% calculate mass of dry flue gas in kg /kg of fuel
% m (total of lue gas) =mass of actual air supplied(ASS) + ...
% mass of fuel supplied (mfuel)
m=AAS + mfuel
% Output:
% Estimate all heat losses
% percentage heat losses due to dry flue gas
L1=m*0.96*(tf-ta)*100/GCV;
fprintf('percentage heat losses due to dry flue gas %10.2e kJ/h\n',L1)
% Heat loss to evaporation of water formed due to H2 in fuel
L2=0.09*H*(2445.2+1.884*(tf-ta))*100/GCV;
fprintf('Heat loss due to evaporation of water
formed due to H2 in fuel %10.2e kJ/h\n', L2)
% Heat loss due to moisture present in air
L3=AAS*h*1.9*(tf-ta)*100/GCV;
fprintf('Heat loss due to moisture in air %10.2e kJ/h\n',L3)
```

```
% Percentage heat loss due to evaporation of moisture present in fuel
L4=M*(2445.21+1.8842*(tf-ta))*100/GCV;
fprintf('Heat loss to evaporation of water formed due evaporation of moisture present in fuel %10.2e kJ/h\n',L4)
% Percentage heat loss due to radiation and other unaccounted loss...
% for a fired heater, these losses are between 2% and 5%
L5=5;
fprintf('Heat losses due to radiation and other unaccounted loss %10.2e kJ/h\n',L5)
% calculate boiler efficiency by indirect method
E=100 - (L1+L2+L3+L4+L5);
End
```