PERFORMANCE OF SOLID FUEL BURNERS IN SRI LANKA

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DECLARATION

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ABSTRACT

The energy has been one of the main crises in the world; hence, it is essential to save and utilize it in its optimized form. One of the major fuels available in the world is fossil fuel. When harnessing energy from fossil fuel, burning process is used with the help of burners and boilers. The efficiency of these systems is very important to get the maximum energy conversion. Therefore, the performance of the burner and the boiler affect the fuel consumption. The old burners in industries will have to be evaluated for performance to decide whether they can be improved or weather to rehabilitate the burner unit. The performances vary with different factors which need to be found out in this thesis. Then the solutions can be introduced for the inefficiency in burner to get the optimum operation.

Burners use different types of firing technologies to harness the energy from the fuel. Its' technology, type of fuel used and size of the burner need to be identified in order to evaluate the performance of the burner. There are two methods used to evaluate the performances of burners. This research is focused on performance of solid fuel burners used in Sri Lanka. The existing burners can then be improved using performance results which is the focus in this research. Many burners used in country are conventional burners and they use basic technology for burning. Reduction of fuel wastage, improvement of safety and reduction of environmental pollution are some of the improvements from the performance evaluation.

The significant parameters that effect the performance of burner are identified using the indirect method. Those are moisture content of solid fuel, ambient temperature, carbon content of fuel, exhaust temperature and excess air supplied. Some of the parameters identified, can be optimized to improve the performance of burner as described. The direct method results and indirect method results are compared and it is evident that the indirect method interprets much descriptive results. The results are depend on specific heat capacity of flue gas but it won't depend on specific heat capacity of steam generated. Burners and boilers in other countries show more variations of efficiency with moisture content compared to the Sri Lanka's.

Key words: Fossil Fuels, Burner performances, fuel, efficiency.

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LIST OF ABBRIVIATIONS

Abbreviation	Description
ASME	American Society of Mechanical Engineers
BS	British Standards
CO	Carbon Monoxide
FBC	Fluidized Bed Combustion
GCV	Gross Calorific Value
IS	Indian Standards
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Dioxide group
PJ	Pica Joule
PTC	Performance Test Code
SCADA	Sequential Control and Data Acquisition
SO_2	Sulfur Dioxide
SO_x	Sulfur Dioxide group
TDS	Total Dissolve Solids
USA	United State Of America

CHAPTER 1: INTRODUCTION

1.1 Background

Solid fuel burner is one of the main fuel burning technologies used in the industry. They are used in boilers, kilns & large ovens. According to the modern advancement of technology, burning of solid fuel is well controlled and the burning process is almost perfect. Solid fuel burning is used in the industries such as power generation, building heating, food processing, oil refining, textile and manufacturing. Burner of the boiler or kiln is one of the major parts which largely determine the performance of the boiler or kiln. It mixes fuel and oxygen together to make proper combustion, controls the NO_x levels and control the fuel efficiency [2]. The solid fuels such as bio mass are readily available countries like Sri Lanka compared to the liquid fuel. The solid fuel boilers are law cost and light weight. These are the major factors to be effected to select solid fuel burners.

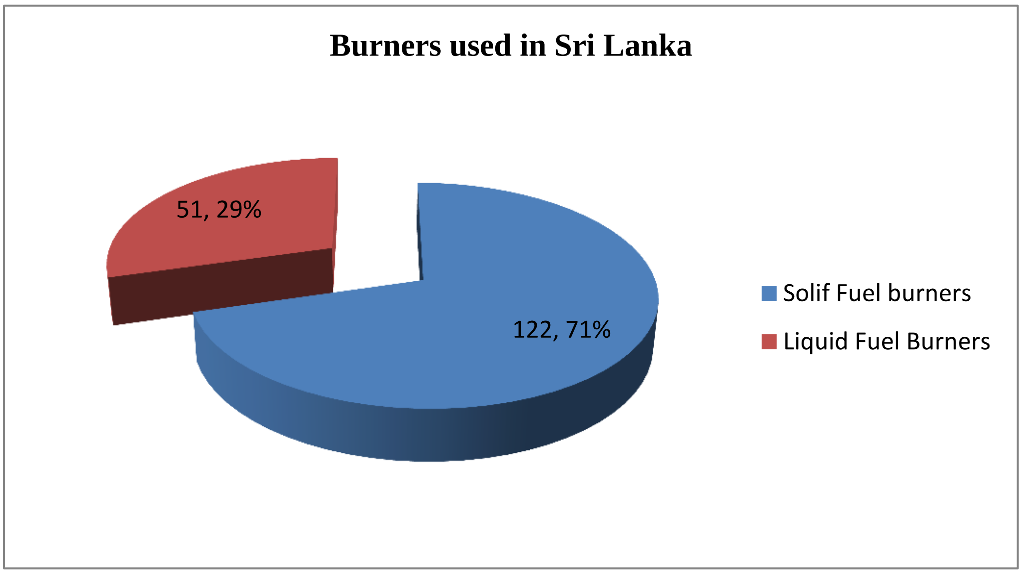

Figure 1.1: Solid Fuel Burners used in Sri Lanka[29]

The number burners used in the Sri Lanka is shown in figure 1.1.Sometimes, these amount more than this numbers due to the unrecorded burners. These are spreads all over the country in different industries. The solid fuel percentage used in Sri Lanka is 47% of total energy supplied as shown in figure 1.2. This shows the momentum of the solid fuel burning in Sri Lanka [29], [30].

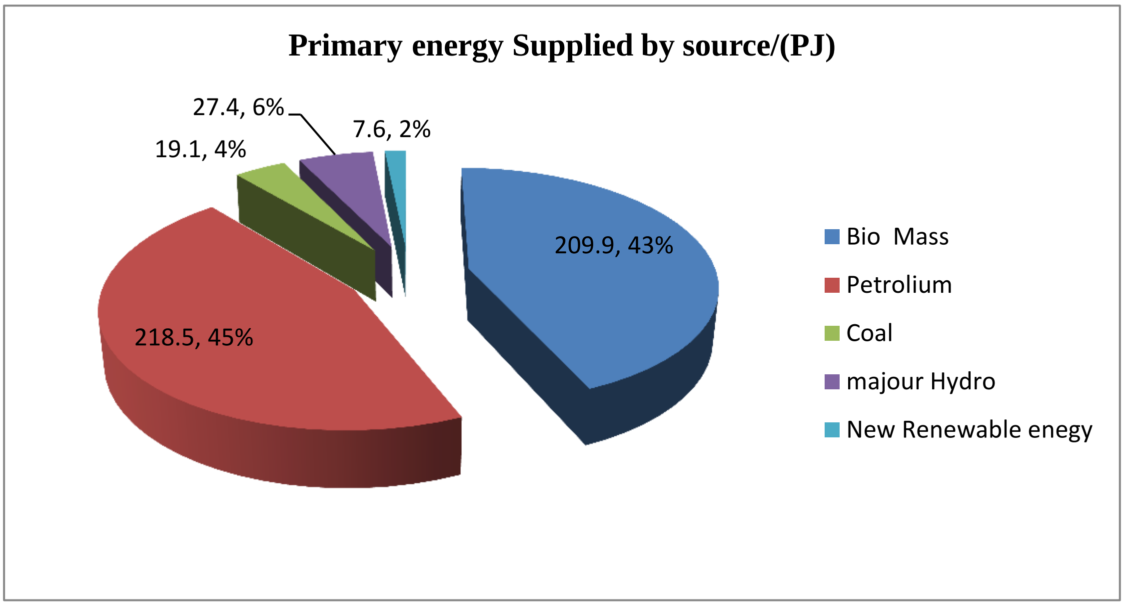

Figure 1.2: Primary Energy Supplied by source[30]

1.2 Motivation

Performance of the burner varies with time due to inferior fuel quality, poor combustion, depositing foreign materials of boiler tubes and poor operation, maintenance and unknown factors etc [1].There are many present issues in solid fuel burners which are long time operation without overhaul, lack of maintenance, high emissions such as NO_2, SO_2 & ash, energy loss due to various location, poor efficiency and unknown efficiency. The industries in Sri Lanka are not interested in finding out efficiency and saving the energy but only consider the emission due to the regulations. This may cause the huge loss of money and energy to their organization. As a country, this attitude is effecting the development of industries, increasing of the unit cost per product, harm to the work force, environment and quality of the output. Therefore there is a requirement to do a survey to identify the present performance level.

Performance of solid fuel burners reduce with time due to the different factors. It is necessary to find out the exact reasons to come up with a solution to enhance the performance of solid fuel burners. At the event of the searching of effected parameter, the physics of the burner has to be studied in details to cater the exact cause of the inefficiency.

1.3 Aim and objectives

The aim of this study is to performance enhancement of the solid fuel burners in Sri Lanka. The burners in different industries will be the focus of this study. The operating mechanism of the burner, the physical arrangement, firing method, heat transfer process, and safety conditions will be discussed to find out the performance [7]. Most of the burner’s performances have to be improved to get the maximum benefit from the fuel and the suggestions for the improvement of the burners are to be introduced at this research. The main objectives of the study are summarized as follows.

- Study the current performance of solid fuel burners in Sri Lanka.
- To evaluate the performance of the burners used in the industry for improvement activities.

1.4 Methodology

Various types of industries such as power stations, food and beverages companies, garments and manufacturing industries were considered for this study. The literature review was done to collect the required technical knowledge for thesis. The required data of the burners were found by referring design documents, professional organizations, test reports, experts in the fields, industries. The targeted institutes were visited to meet authorities to discuss for collecting information. Further information, the state of the art technologies, future trends and present issues related to burners were studies from published literature. Based on the data collected burner performances were estimated using standard methods. Having analysed the results, improvements are proposed.

1.5 Structure of Thesis

The main structure of the thesis is given blow.

- Chapter 02 describes the ways often used for classification of burners. Further it briefs the operation principles and technologies used for each type burners.
- Chapter 03 describes solid fuel burners and chapter 02 & 03 are from literature of review
- Chapter 04 describes the burner selection and solid fuel burners used in Sri Lanka
- Chapter 05 describe the performance evaluation of burners
- Chapter 06 calculate the performances of burners and chapter 05 & 06 are for evaluating the performance of the burners used in the industry for improvement activities which is first objective of the thesis
- Chapter 07 discuss the performance of burners and give suggestions to improve the burner performances in Sri Lanka
- Chapter 07 describes conclusion and future works

1.6 Contribution to knowledge

As a developing country, industry has not focused on the burner efficiency and this thesis targets to improve the knowledge of efficiency related matters. This thesis suggests the improvement to the existing burners. The feasible improvement has suggested by this thesis using the efficiency calculation by indirect method and direct method. Same times, the weakness of the existing boilers are identified in this thesis.

CHAPTER 2: CLASSIFICATION OF BURNERS

2.1 Introduction

The burner is one of the main parts of the boiler or furnaces whose purpose is to control, maintain and regulate the firing or in some type of furnaces, the burner is the place where firing takes place. The burners in solid fuel boilers are available either as separate units or they are combined with the firing area in the boiler. In most of burners, a separate firing system is not available and it is fired only at the initial stage in burner. It will propagate the firing automatically, after reaching the rated temperature. The burner is one of the main part of the boiler which controls the efficiency of the boiler. Most of the time, burner is contained inside the solid fuel boilers itself. Different designers use different type of shapes for the boiler burners. In this chapter, different types of burners, their applications, operating strategies and relative advantages and disadvantages are discussed based on the information available in the literature. In particular especial attention is drawn to burner types used in the Sri Lankan Industry. Further, details are given below.

2.2 Classification of Burner

Burner arrangement will be different according to the design and requirement of the industry. The burner types will be classified based on different factors such as fuel type, heating types, drafting system. Those factors are used to classify the burners as follows.

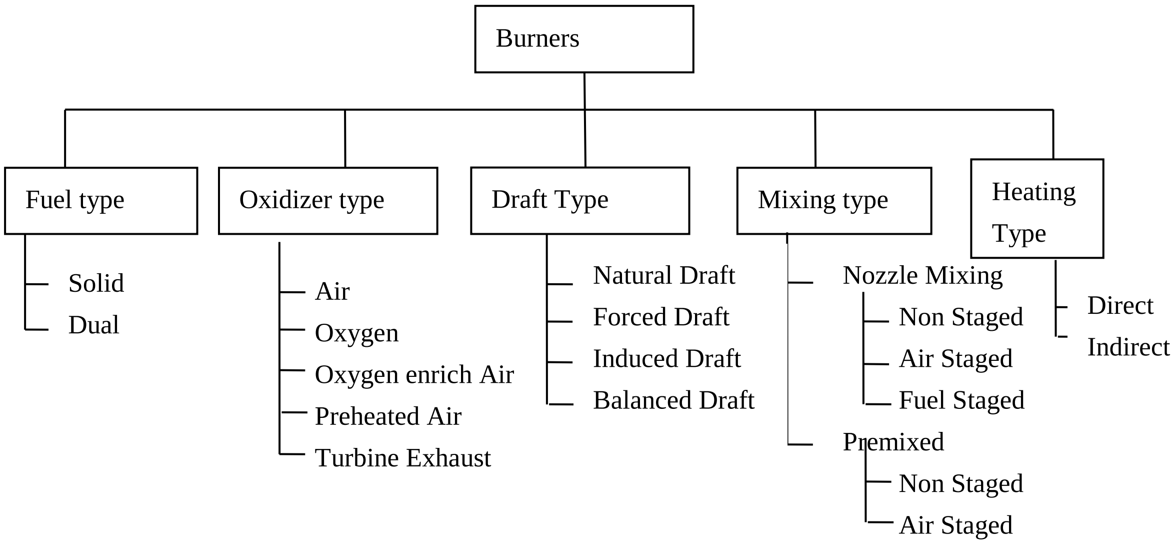

Figure 2.1: Burners Classification

Fuel type

In this classification, burners are classified based on physical status of the fuel such as solid burners, dual fuel burners as follows.

- **Solid fuel burners**

Solid fuels are used in industrial combustion applications such as power plants, food industries and tea factories to generate process heat required. The most common solid fuels are coal, bio mass and coke. Coal is usually used in power generation and primary energy source for metal production processes. Another type of solid fuel is sludge or solid waste and those are burnt in incinerator to generate electricity or get heat for the industrial process. The incineration is very important in solid waste management of urban cities [9]. Specially, incinerators are used to burn out the plastic and polythene based products at a specified high temperature to reduce toxic emissions.

Some burners are facilitate to use the dual fuel such as natural gas, fuel oil same time or separately. This is introduced to improve the economics of the fuel costs. This is very important in industries such as garment factories and food processing plants to keep the backup power system.

A single burner cannot be designed for different fuel type such as solid and liquid fuel. The backup fuel is typically fuel oil. Solid fuel burners can be classified furthermore as in Figure 2.2

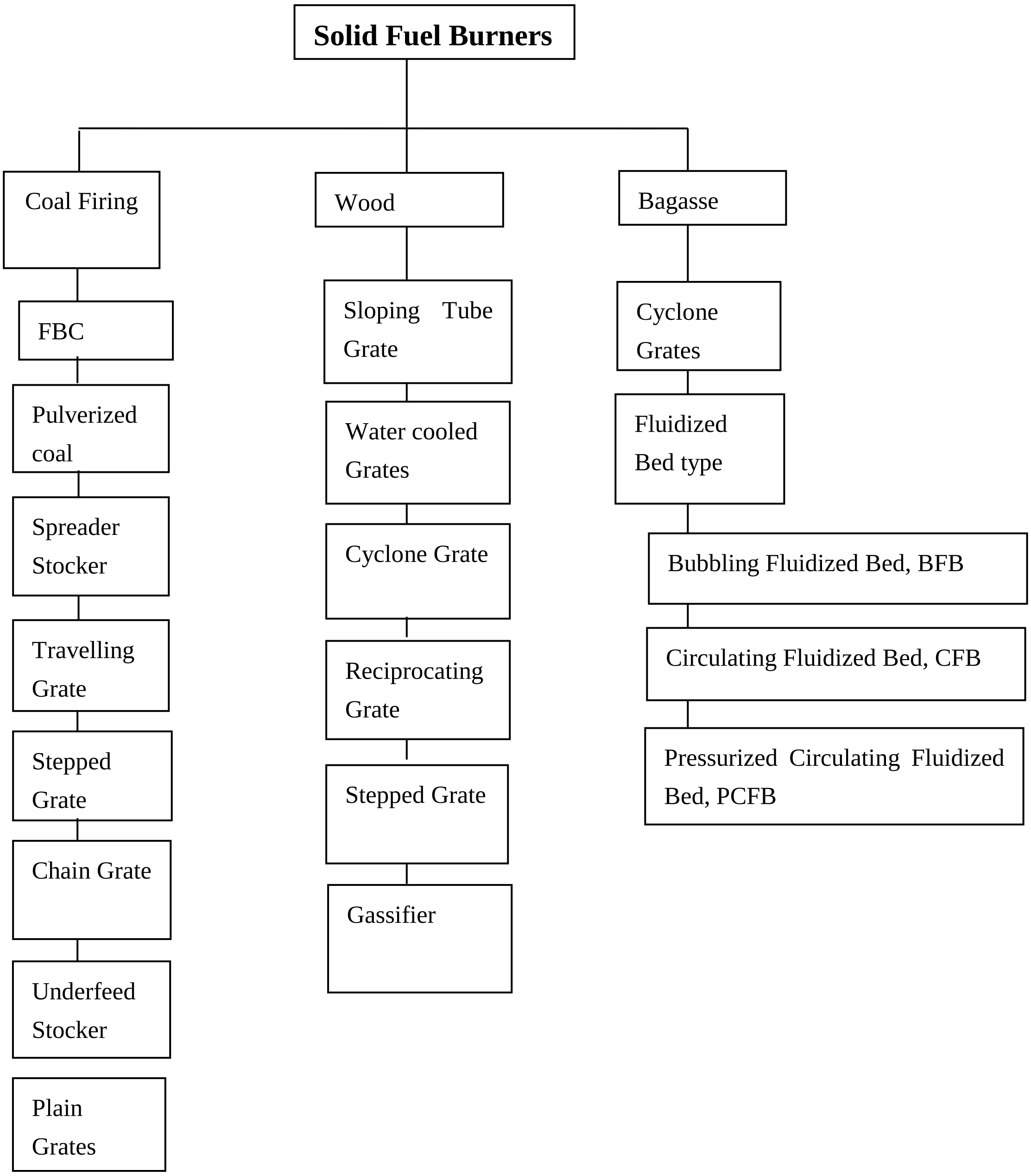

Figure 2.2: Solid Fuel Burners Classification

Oxidizer type

Burners are classified according to the type of oxidizer they use. The majority of industrial burners use air for combustion. In many of the higher-temperature heating and melting applications, such as glass production, the oxidizer can be pure oxygen. In other applications, the oxidizer is a combination of air and oxygen, often referred to as oxygen-enriched air combustion.

- **Air/fuel burner**

The air fuel burner is the most common type of industrial burner as shown in Figure 2.3. In most cases, the combustion air is supplied by a fan or a blower, although there are many applications in the petrochemical industry where natural-draft burners are commonly used. There are numerous variations of air/fuel burners differing from application to application. The air and fuel are mixed together in the chamber before it reaches the flame. This type of burner is used many application in petro-chemical industries. The overall cycle efficiency range will be 42-60 % [17].

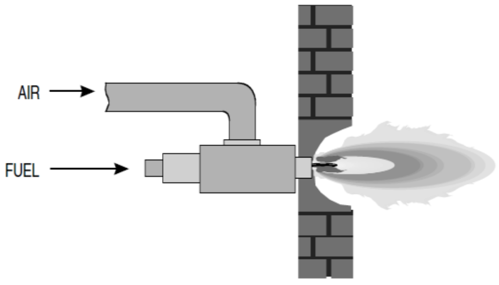

Figure 2.3: An air/fuel burner

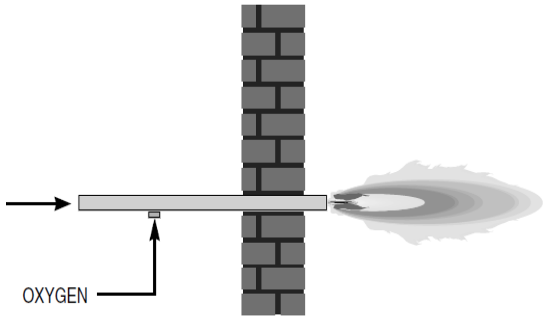

Figure 2.4: An Oxy/fuel burner

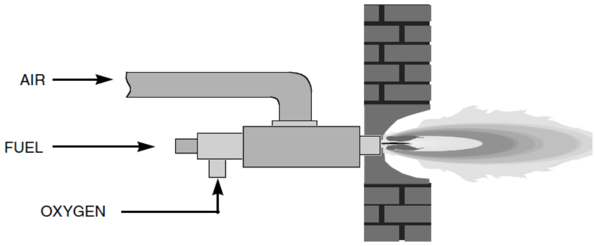

Figure 2.5: An air-oxy/fuel burner

- **Oxy/fuel burner**

In this burner, fuel and the oxygen are fed separately to the burner and both fuel and oxygen are not mixed until they reach the outlet of the burner called the nozzle mixed burner as shown in Figure 2.4. In this burner, the pre mixing is not used due to safety concerns, because if pure oxygen and fuel is premixed, it is extremely explosive due to the high reactivity of pure oxygen. The oxygen and fuel are mixed together before entering the flame of the burner [9]. Oxy/fuel combustion has the greatest potential for improving a process, but it also may have the highest operating cost. There are many practical application of oxy-fuel burner such as gas turbine, waste incineration and metal coating industries [17]. The overall cycle efficiency of the oxy-fuel burner is 60-80% [18].

- **Air-oxy/fuel burner**

In this process air and fuel are mixed and air is enriched with O_2 and shown in figure 2.5. This can be considered as low-level O_2 enrichment, or premix enrichment. Many conventional air/fuel burners can be adapted for this technology. The O_2 is injected into the incoming combustion air supply, usually through a diffuser to ensure adequate mixing. This is usually an inexpensive work that can provide substantial benefits. The added O_2 will shorten and intensify the flame. However, there may be some concern if too much O_2 is added to the burner, that the flame shape may become unacceptably short [17]. The higher flame temperature may damage the burner or burner block. Air oxy-fuel burner is used in furnaces and coal powered power stations. The overall cycle efficiency is more than 80%

Mixing Type

In the classification, the fuel air oxidizer mixing type is considered. The mixing of the air fuel is control by the arrangement of the burner which may lead to improve the efficiency.

- **Premixed Burner**

If the fuel and air are mixed completely before the combustion it is called the premixed burner Figure 2.6[9].

The fuel and air will be mixed before the firing. Fuel is fed to the burner at the center tube. The burner arrangement is shown in Figure 2.6. The premixed fuel is a bit turbulent and it gives a shorter and intense flame, compared to diffusion flames. Premix burner emits high NO_x emissions and non-uniform heat, high temperature flame. The premixed burner is used due to the high temperature of the flame and high rate of heat [9].

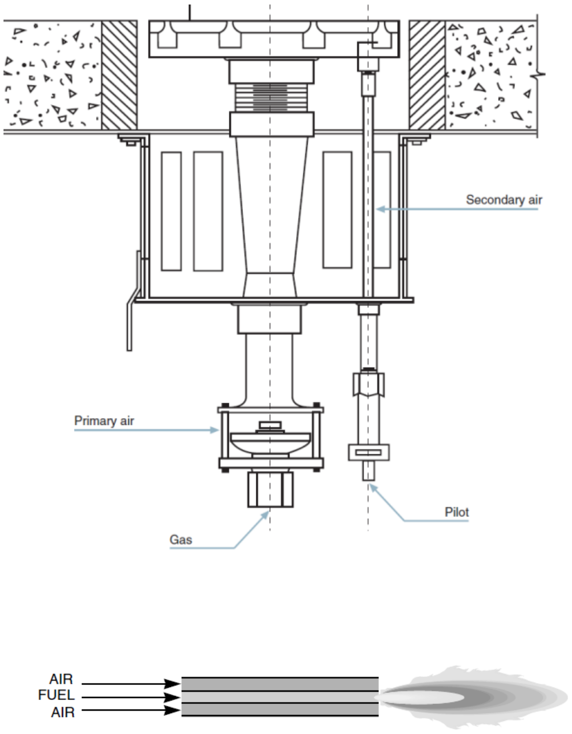

Figure 2.6: Premixed burner[19]

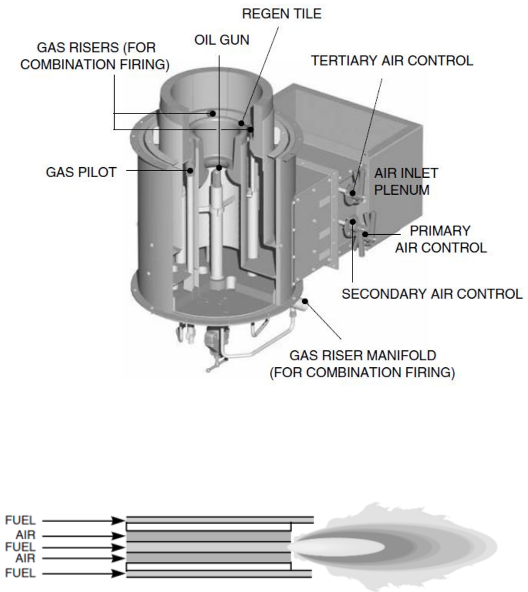

Figure 2.7: The staged-air process[19]

Figure 2.8: Diffusion mixed burner [19]

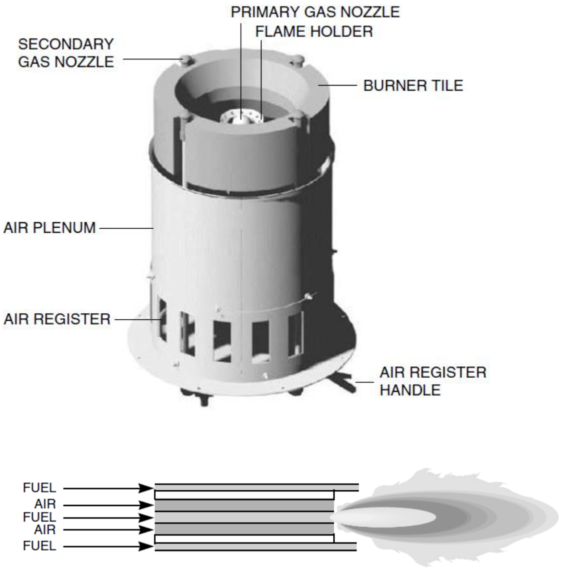

Figure 2.9:A staged fuel burner

- **Diffusion-mixed burners**

In the diffusion mixed burner fuel is fed separately before the combustion is started. The fuel and air is mixed in the flammable area as shown in Figure 2.8. The air and fuel are fed to the burner in separate tubes. In this burner, flashback or explosion can happen and its safety is less. The fuel mixing is done at the last moment in the flame and it results in raw gas release with exhaust. The diffusion mixed burner is giving uniform temperature distribution and low NO_x emissions.[9].

- **Staged air and staged fuel.**

Secondary and sometimes tertiary injectors in the burner are used to inject a portion of the fuel and/or the oxidizer into the flame as shown in Figure 2.7 &2.9. It is injected to the downstream of the root of the flame. Staging injection is used to control the heat transfer, to produce longer flames, and to reduce pollutant emissions such as NO_x. These longer flames typically have a lower peak flame temperature and more uniform heat flux distribution compared to non-staged flames. However, an additional challenge is that multiple longer flames might interact with each other and produce unpredictable consequences compared to single shorter flames.

Draft type

The draft is defined as how to supply oxygen supplied to the burner. The supply of the oxygen to burner is differed according to the requirement. Mainly, two types of drafting method are used in the industries that are forced draft burners and natural draft burners.

- **Forced Draft Burner**

Many of the industrial burners are known as forced-draft burners which mean that the oxidizer is supplied to the burner under pressure from a fan. In a forced-draft air burner, the air used for combustion is supplied to the burner by a blower [9].

- **Induced Draft Burner**

Induced-draft burners which mean that the exhaust gas is pull out from the burner under suction pressure from a fan located at the stack side. In induced-draft air burner, the pressure difference is maintained to suck the exhaust gas [9].

- **Natural Draft Burner**

Sometimes this blowing action is done by the burner itself. In natural-draft burners, the air used for combustion is induced into the burner by the negative draft produced in the combustor and by the motive force of the incoming fuel, which may be at a significant pressure. In this type of burner, the pressure drop and combustor stack height are critical in producing enough suction to induce sufficient combustion air into the burner. This type of burner is commonly used in the chemical industries [9].

Heating Type

Burners are often classified by whether they are of the direct or indirect heating type. The fuel is burnt by firing itself or fuel is burnet by heating from other source indirectly.

- **Direct Heating**

In direct heating, there is no intermediate heat exchange surface between the flame and the load as shown in Figure 2.10. Heat is passed from flame to the exchanger directly. Then, the heat loss to the outside may be reduced, but tube contamination will be high. The load is heated by the flame directly without any intermediate fluid.

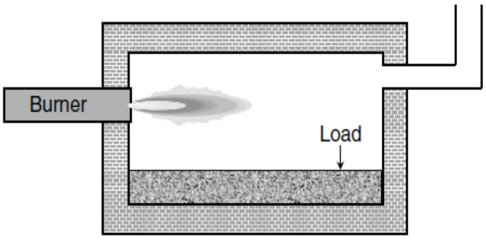

Figure 2.10: Direct fired process

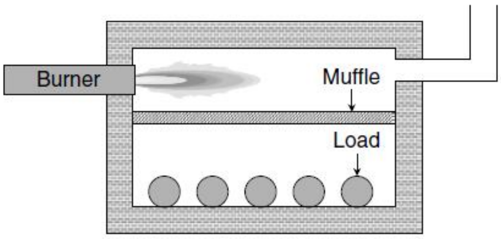

Figure 2.11: Indirect fired process

- **Indirect Heating**

In indirect heating, such as radiant tube burners, there is an intermediate surface between the flame and the load. This is usually done because the combustion products cannot come into contact with the load because of possible contamination. Radiation heat transfer from the flame to the product is the primary mode used in many industrial combustion systems. There are verities of burner designs that rely primarily on this mechanism as shown Figure 2.11.

The main aim of the present work is to investigate the performance of solid fuel burners in Sri Lanka, hence the chapter 3; the next chapter, is devoted to discuss in detail about the solid fuel burners.

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CHAPTER 03: SOLID FUEL BURNERS

3.1 Introduction

A common type of solid fuel burners are bio mass burner, gassifiers & coal burners which are used in power generation, steam/hot water generation and air dryers in many countries. Biomass burners are heavily used in garment industries, beverages industries, hotel industries, tea factories, sugar industries and power stations in Sri Lanka. The main advantages of the bio mass burner are the low capital cost and the low operation cost, but they have the disadvantage of needing a large storage capacity to keep the fuel in dry condition. Another major reason to promote the bio mass burner is that it can act as a neutral carbon emission which means the emission from bio mass burning can be recycled through absorption of CO_2 during the growth of biomass trees. The solid fuel burner and its performance in Sri Lanka are based on the biomass burners and coal burners.

The most important factor of the burner that controls the firing process is air to fuel ratio. The efficiency of the burners depend on the adjustment of the air to fuel ratio. The extra air entering to the burner will create loss of energy through un-burnt air and lack of air will result in waste of the fuel with exhaust air. It shows that the inlet air control (adjustment of air to fuel ratio) is very important factor in burning process. In the modern burners, the advanced computerized controlling technology is used to control the air to fuel ratio with help of set of measuring instrument.

3.2 Coal Fired Burner

There are different grades of coal having different properties. The coal power station used the fuel analysis to determine the coal properties and grade. The purpose of the fuel analysis is to

- To find out what type of grade fuel available for the station

- To establish the relative value of the fuel compared to high quality fuel
- To determine the allowable limit of the changing fuel
- To find out what type of equipment are used in processing of coal[12]

The important properties of coal are as follows

- Moisture content of coal
- Ash content of coal
- Swelling index
- Volatile matter
- Fix carbon content
- Sulphur content
- Heating Value
- Grindability
- Size of coal[12]

3.2.1 Processing of coal before entering to the burner

The coal handling is a complicated process which should be determined according to the coal properties. Most of the coal power stations are located in coastal areas. A coal power station located near the sea, will undergo following process.

- Unloading of coal from the ship

Coal unloading is done using barge, cart, railing or pipe lines to the storage facility according to the storage yard.

- Storage

The coal storage is very important due to the self-firing ability of coal at about 150°C [14]. Normally coal is unloaded to the storage yard as coal piles, silos or coalbunkers. Coal file is the ground storage in open atmosphere. There is a risk of spontaneous firing when there is enough concentration of oxygen which oxidizes the coal with a rise in temperature to the combustion point. Hence, coal shall be filed in a compacted manner to reduce the air trapped inside the coal. The other method of storage is the coal silo which is a type of tank used to store coal. It is possible to gravity discharge the coal from the bottom of the silo. Coal bunker is one of the most useful storage methods which is an overhead coal storage bin arranged for gravity flow of coal to the boiler.

- Preparation

Coal is required to be sized before it is sent to the boiler. Breakers and crushers are used to size the coal that has not undergone any previous sizing. The crushers are used for size reduction of coal in preparation to the boiler. Hammer mills or pulverizers are also used for crushing as shown in figure 3.3[12]. Raw coal is fed from top of the pulvarizer and it is sent to the classifier to remove debris and sort out the different sizes. Air is mixed with the classified coal and its fallen between roll wheel assembly and grinder. The grinded coal came out at top with air flow. The reduction gear system is located at the bottom.

- Conveying to the furnace

There are three methods of conveying coal to the furnace. They are belt conveyers, bucket elevators, and flight conveyers. The belt conveyer is used to transport coal in horizontal direction using an endless belt. The bucket conveyer can be used to lift coal vertically and inclined direction using an endless bucket belt. The flight conveyer is used to lift coal vertically and inclined direction using an endless chain conveyer. These applications can be selected according to the cost requirement and the geometrical requirement of the plant.

3.2.2 Coal Firing System

There are several methods of coal firing in the industry as shown in Figure 3.1.

Fluidized Bed Combustion (FBC)

This method is developed recently for combustion of solid fuels [13]. The main objective of this coal burning method is to reduce CO_2 and NO_x emission controlling by solid fuel burning. This process could be efficiently used to burn biomass and other low-grade fuels that are difficult or impractical to burn with conventional methods.

In this method of combustion, fuel is burned in a bed of hot inert, or incombustible, particles suspended by an upward flow of combustion air as shown in Figure 3.1. The primary air is injected from the bottom of the bed to keep the bed in a floating or "fluidized" state and fuel is fed from the fuel feeder. Then the fuel particles start to float and scrub on each other. This improves the combustion by increased contact with hot air. CO_2 and solids residue (char) is formed around the fuel particles and exhaust is taken out from the top of the burner. This process allows oxygen to reach the combustible solid material more readily and it increases the rate and efficiency of the combustion process. One advantage of mixing in the fluidized bed is that it allows a more compact design than conventional water tube boiler designs. The effective mixing of the bed makes fluidized bed boilers suitable for burning solid refuse, wood waste, waste coals, and other nonstandard fuels.

The fluidized bed combustion process provides a means for efficiently mixing fuel with air for combustion. When fuel is introduced to the bed, it is quickly heated above its ignition temperature, ignites, and becomes part of the burning mass [13].

The FBC has two types of mechanisms. They are bubbling fluidized and circulating fluidized bed and it will reduce the particles coming out of the bed. This FBC has thermal efficiency range of 85-95%.

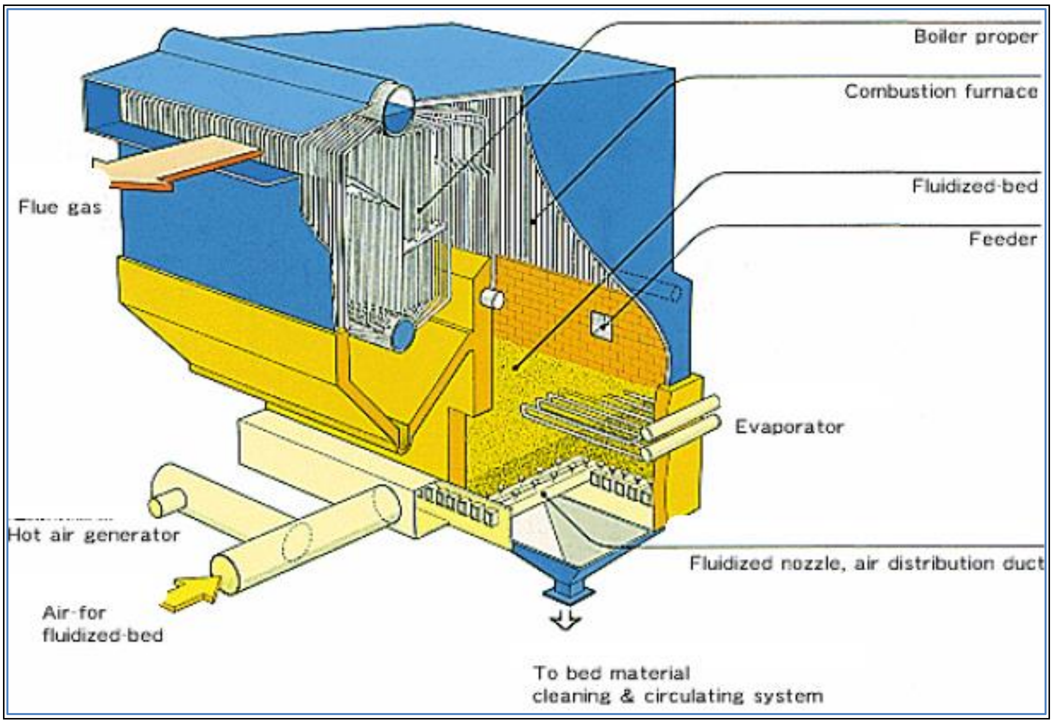


Figure 3.1: Fluidized bed combustion boiler [23]

- **Pulverized coal**

This system feeds milled fine coal to burner directly. Normally, it doesn’t have fuel storage; hence it can operate according to the fluctuated load. The most common system is the direct firing where the pulvarizer feeds directly to the burner [13].

The main equipment of this system is the pulverizer which feeds raw coal at proper rate, grinds coal to desired fineness and classifies the fine product. Grinding is done in the grinding mill which does the grinding, drying, and transporting to the burner. The Roll wheel pulverizer is shown in Figure: 3.2. Forced draft fan is used in this mill to produce enough pressure to carry out the job and it is used to transport pulverized coal to the burner and mill is kept under the negative pressure by externally mounted induced draft fan. The drying process, classifying the coal and transporting the product to the burner is done by the air as shown in the figure 3.2. Pulverized coal is filtered using about 50 µm mesh before it sent to the burner [12 & 13].

In this pulverized coal boilers, firing systems are of two types which are wall firing and tangential firing. Wall firing means that the firing flames are induced from the front, rear and side walls and in tangential firing fuel and air are introduced from delivery nozzles located on the four corner of the furnace. These burner systems are explained in the classification of burners (Chapter 2).

In the horizontal burners, coal and air mix through the center nozzle and secondary air is supplied around the nozzle to rotate the flow to obtain a uniform well mixed flow to the periphery of the finance. The adjustment of air in the burner is possible in the circumference of the furnace.

Tangential burners are the most common pulverized coal burners for corner firing in the industry. This burner with alternate fuel and air nozzles are located in the corner of the furnace. This burner can be used in large steam generation units in effective utilization of furnace volume, significant heat absorption, and low carbon loss [12]. The advantages of this burner are the simplicity and minimum exposure to the heat.

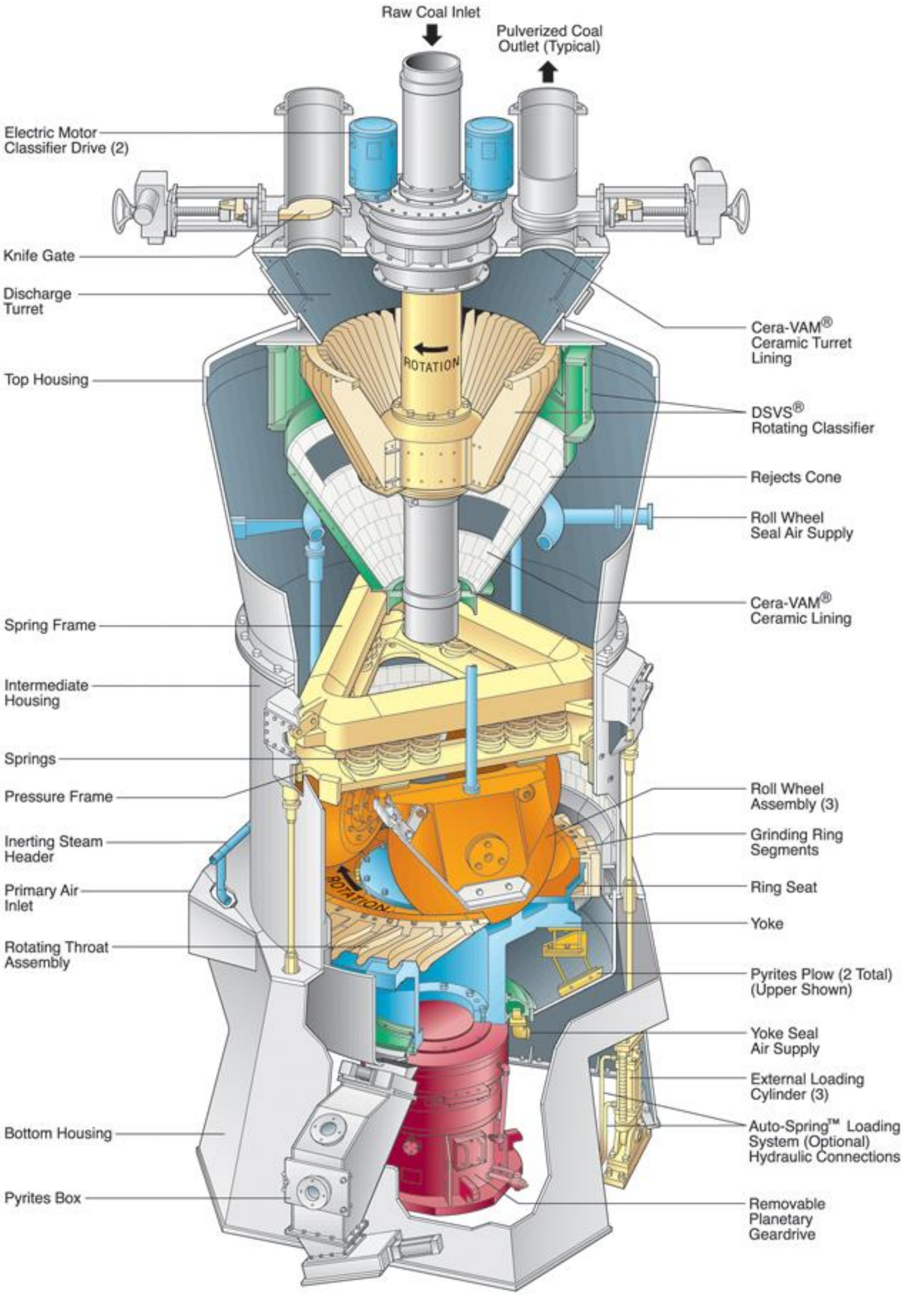


Figure 3.2: The Roll wheel pulverizer [23]

- **Spreader Stocker**

In the stoker, raw coal is spread over the burning bed. The large lump spread on the bed creates the fuel bed with suspension. It makes the layers such as distillation, reduction, oxidation and ash zones one top of each other [12]. There will be ash particles and emission particles mixed with the exhaust gas. Grate insulation and cooling may be effective. The load fluctuation can be achieved 20% to 30%.

This bed is widely used in industry due to its burning capacity of wide range of coals such as bituminous, lignite and brown coal. This type of coal burners are used in the capacity range of 25-120 MW.

- **Travelling Grate**

This is made up of a carpet of grates bars connected together which transports coal from the feed hopper to different zones of combustion. The travelling speed is about 0.7m/min which can be regulated. The primary air is supplied from the grates and the secondary air is supplied from the top of the burner [12]. Load can be regulated by the changing the grates height.

- **Chain Grate**

When the chain goes under the feed conveyer, it carries coal and passes it in to different fire zones which are dried, ignited, pyrolysis and combust the gas and coal as shown in Figure 3.3. The required air is taken from the chain grates. This type grate can be used to burn even fine coal particles. Chain grate is used for the boiler 2-10MW capacity [12].

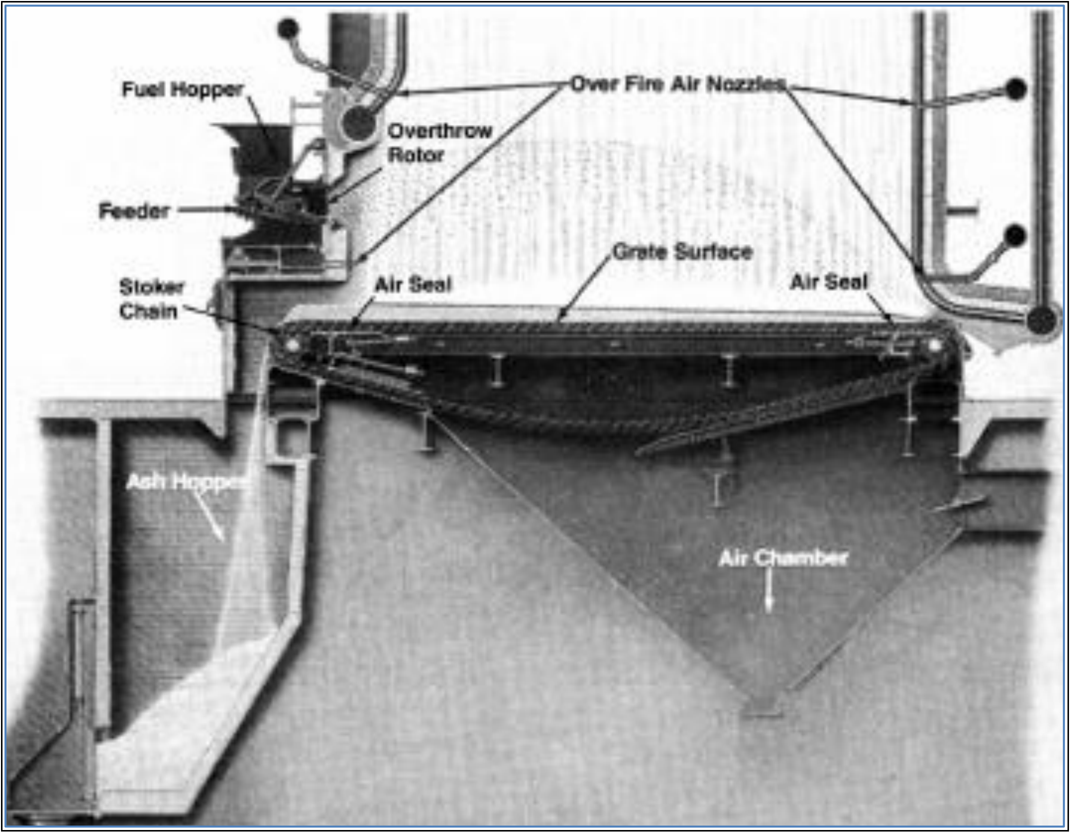


Figure 3.3: Chain Grate Arrangement [12]

- **Under feed Stacker**

In this under feed stocker, fuel and air are fed from the bottom of the stocker as shown in Figure 3.4. At the top of the stocker, fuel is exposed to the fuel bed. When the existing fuel is burnt it is removed and new coal is exposed to the bed and it dries out at the first stage. This type of grates are used for the 1-10MW sized boilers[12].

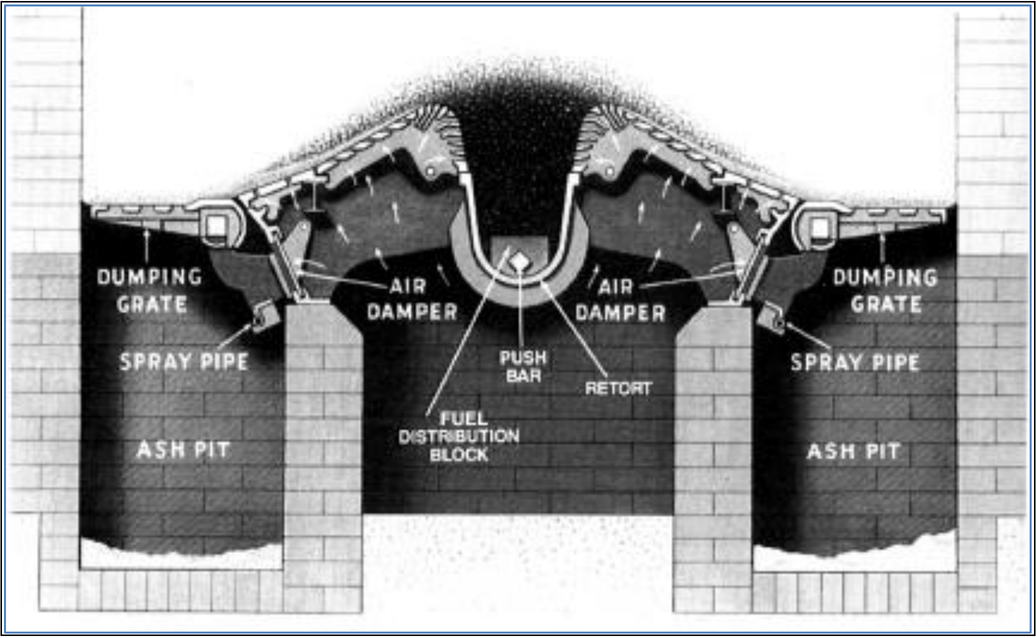


Figure 3.4: Under feed Stacker arrangements [12]

- **Plain Grates**

This is the straight plain bars arrangement is to make proper air space for fine burning. This type of grate can be used for fine material such as saw dust for efficient burning. There will be large number of holes to supply air, but there will be a tendency to drop of unburned particle into the ash pit.

3.2.3 Coal firing arrangement inside the combustion chamber

The coal firing arrangement is decided according to the arrangement of tubes which are fire tube or water tube boilers. Commonly, most of the coal fired power station boilers are water tube boilers. The combustion will take place at the temperature of 1300°C-1700°C for the 300μm pulverized coal particles, but this temperature largely depends on the coal grade [16]. There are two fuels that play a major role in fuel firing systems. They are pulverized coal and oil. Oil can be light diesel oil or heavy fuel oil. Oil burners are used to inject the oil into the combustion chamber. This burner atomizes the oil particles to nano scale. There are several reasons to use oil to fire the coal in the furnace. They are as follows [16].

1. It will supply the ignition energy to light off the coal burner.
2. Oil will help to stabilize the flame at low load of the boiler.
3. Oil is a safe start up fuel and it can control the heat at the light off time of the boiler.
4. Oil particles can be atomized easily to get complete combustion.

There are two types of coal firing, which are direct firing and indirect firing. In direct firing method coal is transported to the combustion chamber by hot air from the storage mill according to the load condition. In indirect firing coal is transported to the combustion chamber using an intermediate bunker system with the help of dry air. Load is regulated by the amount of fuel fed to the chamber [16].

Method of Fuel Firing

The firing system will be classified according to the firing orientation and geometry of the burner. There are four types of fuel firing used in the industry.

1. Vertical firing
2. Horizontal firing
3. Impact Firing
4. Corner or Tangential Firing

➢ Vertical Firing System.

Nozzle type fans are mounted vertically facing downwards in such a way that they cover the width of the furnace. The flame is directed downwards and the formed gases at the bottom pass through the full length of the flame giving a long path to the gases. This system is suitable for low volatile content coal.

- **Horizontal firing**

In this type of firing, turbulent type burners are set up at the front and rear wall of the furnace. The horizontal burner has an inner cone to supply primary air for burning. Fuel mixed with air resulting in a rotary motion at the entrance of the burner. Secondary air is also mixed with fuel before it is burnt.

- **Impact Firing**

This is the burner which keeps the ash at molten stage at the bottom of the furnace and it is removed as and when required.

- **Corner or Tangential Firing**

This is the most common type of firing system used in the power generation industry. Tangential firing creates a flame eccentric from the center and it generates the rotating fire at the center as shown Figure 3.5. It helps to mix air and fuel properly to give a complete combustion with uniform heat distribution inside the combustion chamber. In the combustion area, it generates a high turbulence due to flames impinge ting each other. The turbulence results in high efficient mixing of fuel and air. There are four burners at each corner directed towards the center. A set of this type of burners are located on the horizontal plane at each level. It is essential to set the burner nozzles at correct values for optimum operation. This type of firing is extremely rapid and results in short flame length. The coal nozzle is located at the four corners of the furnace and it is connected to the coal pipes. Coal nozzle is rectangular in shape and it is divided into several sections. This coal nozzle has a facility for tilting the nozzle to get different angles of injection [16].

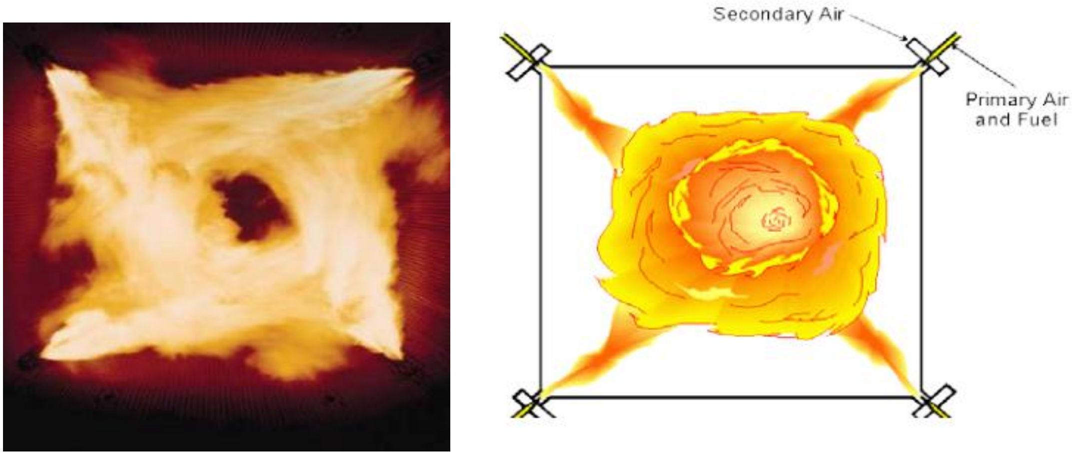


Figure 3.5: Tangential Firing of the Coal combustion chamber[16]

3.3 Bio Mass Burner

Bio mass is wide range of organic compound generated by the plant and animals. Biomass contains variety of compounds such as woody fuels, forestry residues, mill residues, agricultural residues, un-burnt woody, yard waste, dedicated biomass crops, chemical recovery fuels, animal waste, dry animal manure, wet animal manure, cereal straws etc. Due to this variation of bio mass type, the burning process is also differed compared to the other fuels. The bio mass burners are direct combustion method. The combustion chamber or burners are the place where the firing is take place[21].

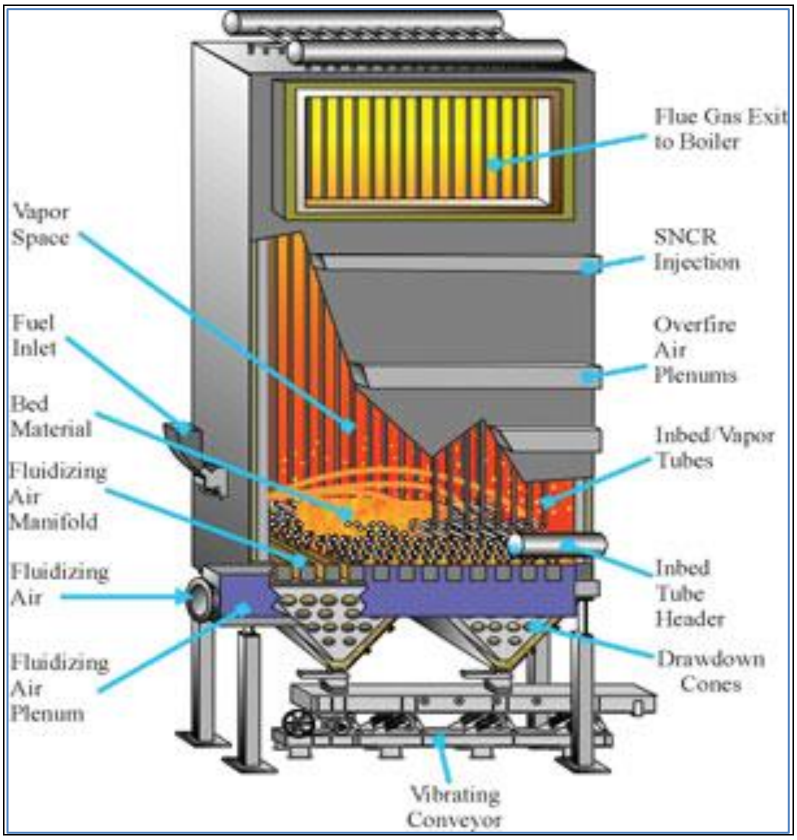


Figure 3.6: Biomass burner arrangement[16]

There are different types of bio mass burners used in industry to harness the energy from the burners. The bio mass burners are classified in Figure 3.7, based on the firing system. At the chapter 02, the major classification is done and this classification is focused on bio mass burners only.

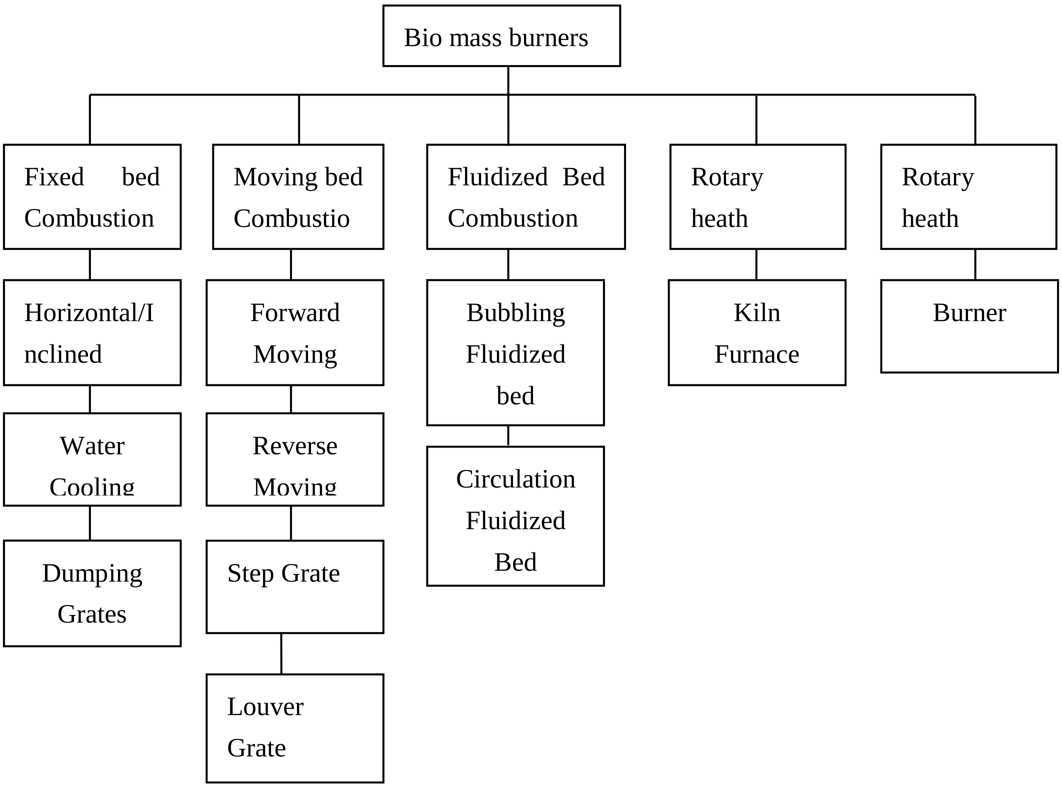


Figure 3.7: Classification of Bio mass burners[21]

3.3.1 Fixed bed combustion

The technology used in this fixed bed combustion is surface combustion and it will be taken placed on the grate using bio mass fuel. The practical application is batch furnace. The grate orientation is horizontal or angled. The exhaust contain little amount of ashes[21].

3.3.2 Moving bed combustion

In this type combustion, the two major regions of combustion can be seen which are combustion zone and after- combustion zone. The resistance comes due to the ashes is less, because of the continuous discharge of ashes from gradually moving grates[21]. The combustion efficiency is high and wide range of bio mass can be used as fuel such as chips and pallet.

3.3.3 Fluidized bed Combustion

This type combustion will be initiated on the sand bed. The sand and fuel will be formed the boiling condition to increase the thermal storage and heat transmission effect. The application is suitable for high moisture fuels.

3.3.4 Rotary Hearth Furnace Combustion

This combustion process is more suitable for the high moisture fuel such as food residue, organic sludge. It has to be check the fluidity condition before it uses in this combustion process.

3.3.5 Burner Combustion

Burner combustion is used the fine fuel such as saw dust, chips & bagasse etc. if the size of the fuel is law the burning process becomes easier and energy harness is efficient.

3.4 Gasifiers

Gasifier is the equipment that converts the solid bio mass in to fuel gas or chemical feedstock gas. Those gases are highly inflammable and burning is much easier than the bio mass. The gasifiers are designed in different geometry according to the requirement of the industry. But the gasifiers has to be maintained quality the process properly, otherwise gasification will not be successful. The process need to monitor closely to achieved the full efficiency. The process is the thermochemical process to form the gas[21].

The gasification process started with the evaporation of surface moisture. Then it started to evaporated the inherent moisture. The thermal decomposition will be started as next stage at 200-300 C. Same time, the H_2,CO_2,H_2O,CO are vaporized as gas. The thermal decomposition will be started and volatile matter will be transformed to the heavy hydrocarbons. Then the all raw material becomes heavy hydrocarbons and it will started to form char from hydrocarbon. The Char will be transformed to the CO and CO_2 with help of the surrounding temperature and gasification agent. This char transformation is called char gasification. Steam and Carbon will be react at the temperature of 750 C to form CO and H_2O[21]. The residue of the process is ash and it can be taken out at bottom as shown in Figure 3.8.

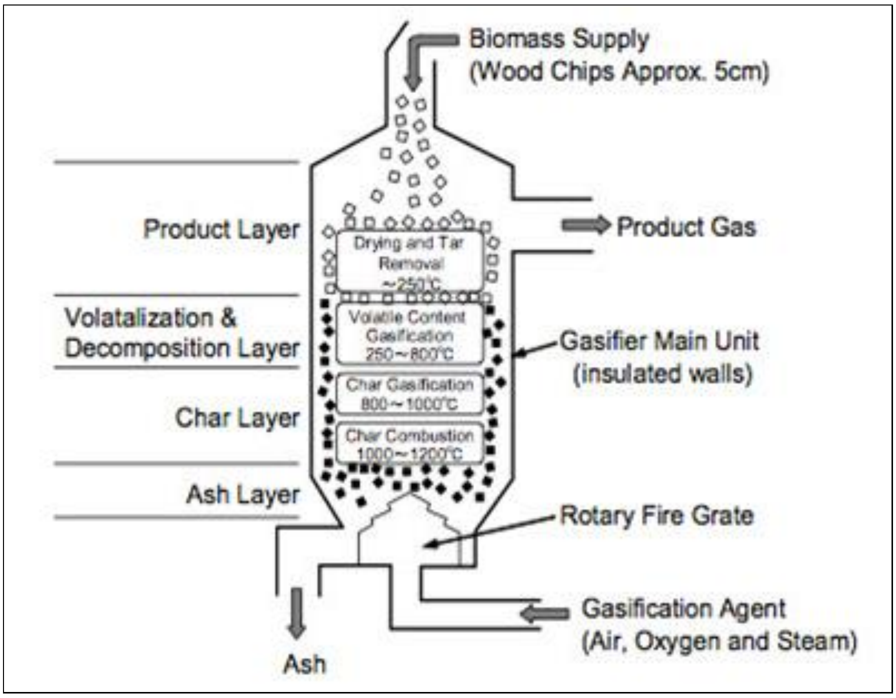


Figure 3.8: General Arrangement of Fix Bed Gassifier[21]

Most of the gassifiers use the direct gasification at atmospheric pressure. The raw materials (wood chips, corn stalks) are burnt to increase the temperature of the gassifiers. The temperature requirement is more than 800 °C. Air, oxygen and steam have to be supplied according to the requirement as gasification agent. The oxygen requirement for gasification is 1/3 of oxygen required for the fuel combustion of same amount of biomass. As a result of the gasification, it will be generated law calorie gas (calorific value 4-12 MJ/m^3), medium calorie gas (calorific value 12-28 MJ/m^3) and high calorie gas (calorific value more than 28 MJ/m^3). The direct gasification will generate law calorie gas. The solid bio mass shall be in small particle to generate gases. The maintenance of gassifier is difficult due to the complex arrangement of unit [21].

The gassifiers can be classified as shown in Figure 3.9 based on their basic properties.

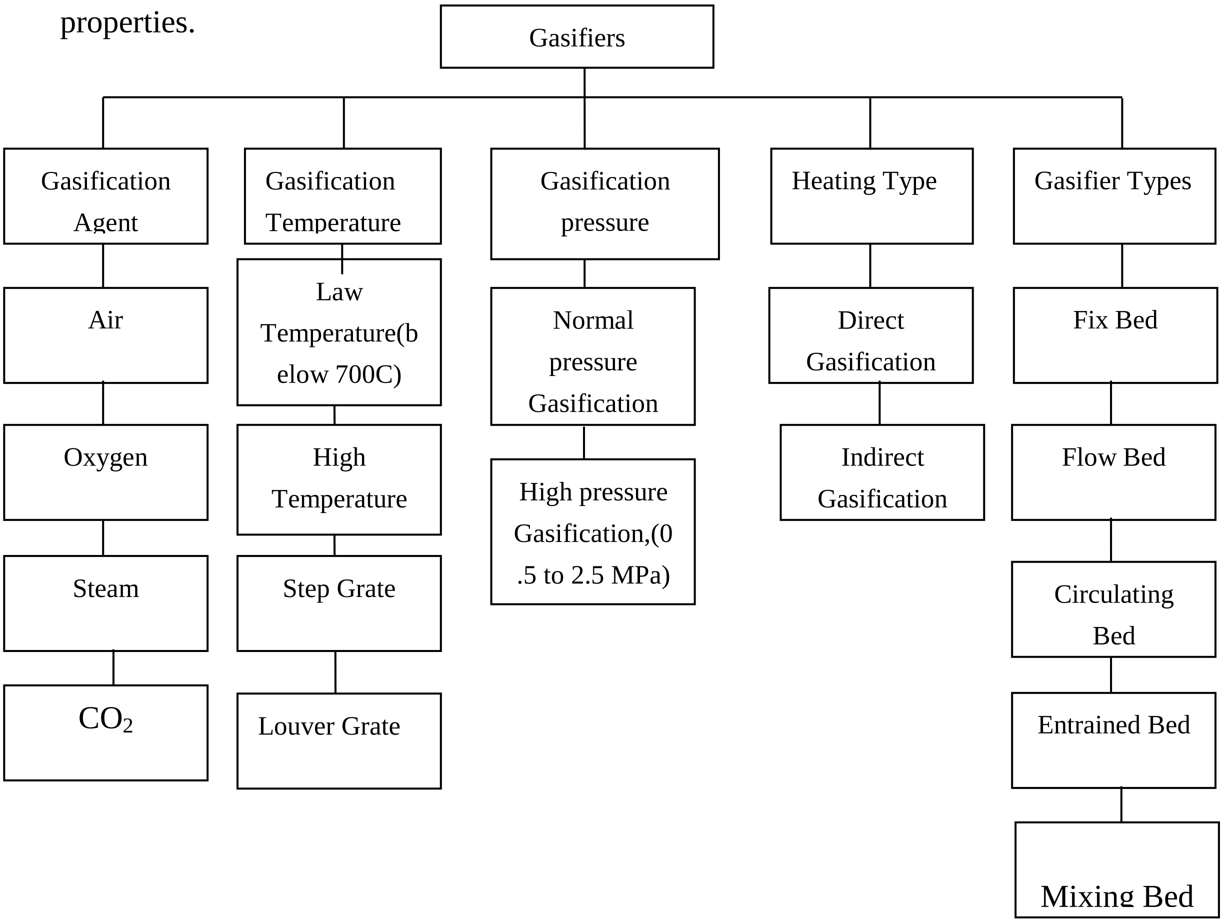


Figure 3.9: Classification of gassifierss[21]

3.5 Summary of literature Review

There are many types of solid fuel burners used in the industry and different technologies are used. Mainly the burners are classified according to the fuel type, oxidizer type, draft type, mixing type and heating type. Under the category of the solid fuel burner, coal burners and bio mass burners are dominant. Those burners are different according to the firing technology, fuel sizing and grates arrangement. The bio mass burners are also two types which are gassifiers and burners. The countries like Sri Lanka, this type of solid fuel burners are installed and it needed to study and collect data to evaluate the performance of burners in Sri Lanka. In the Chapter 04, the details will be discussed.

CHAPTER 4: BURNER SELECTION AND SOLID FUEL BURNERS USED IN SRI LANKA

4.1 Introduction

The burner design and selection is a difficult task in designing of the thermal system. Many factors have to be considered including flow dynamics of the thermal system and temperature variation inside the burner. Selection of the burner is very important to meet the best performance of the boiler. At the designing stage, the designer should have an idea about the available capacities of the burner. Selection will depend on the following factors [10].

1. Burner capacity
2. Back pressure of the furnace
3. Fuel to be used
4. Fuel flow rate
5. Capacity regulation method of the burner
6. Generation output of the boiler attached to the burner, steam or hot water.
7. Codes and standards related for the boiler and burners.

4.1.1 Type of power output of boiler

The type of output of the boiler depends on the application requirements. Some industries require hot water and some require steam. The requirement will decide the operating capacity, operation pattern, temperature and the pressure of the boiler. It will also decide the specifications of the burner. Hot water is used for heating of industrial spaces such as tea drying, food drying, and rubber drying. The temperature range of a hot water boiler is from 82.2 °C to 104.4 °C at the pressure range of 30 psi (2.07 bar) to 125 psi(8.61 bar) [11]. These types of hot water generators are low pressure applications, but steam boilers can be operated in both high pressure and low pressure applications. High pressure boilers are used in process industries at 700 psi [11]. Some industries require saturated steam. But some special industries such as power generation require superheated steam to harness the energy from the steam at higher enthalpy. According to this requirement, the burner or boiler specifications are decided at the design stage. The design pressure of the boiler is used to design the thickness of the boiler plates and the operation pressure should be lower than the design pressure. The safety valve pressure is set to a value in between the operating pressure and the design pressure.

4.1.2 Codes and standards related to boilers and burners

Standards, codes, regulations related to the safety, environment, and laborers shall comply when the boiler or burner is designed for the related application. The boiler or burner has a risk of fire or explosion due to the high pressures and high temperatures. It may affect people or property. Hence, it requires the standard practices in design and fabrication.

- American Society of Mechanical Engineers (ASME) code guides Section VIII the design procedure of the boilers and burners. It contains design guidelines, fabrication guide lines, boiler inspection, testing and non-destructive testing.
- National Electrical Code (NEC), or other insuring underwriters' requirements.
- Tested to Canadian Standards by Canadian Underwriter's Laboratories (CUL), Canadian Standards Association (CSA), the Canadian Gas Association (CGA) B149 shall comply with the Burner configuration and it shall meet the burner pressure and temperature.

- Canadian Standards Association (CSA) B140 codes shall be considered.
- The Local regulations on environmental and safety shall be complied with. The water releasing temperature for environment and acidity level of releasing water has to be met.
- The emission level of the exhaust, especially the NO_2 and SO_2 levels shall be met. The burner has a direct impact on the emission levels and it can be improved by burner tuning.
- United State Federal Emission Standards direct the exhaust emission level of the boiler and show the guide lines for emission control of boilers and burners.

4.2 Solid Fuel Burners use in Sri Lanka

There are three major types used in application areas and the fuel [1] are considered in this study. Some of them use conventional burners and others use modern burners. These are located in different areas of the country depending on the requirement of the industry and availability of fuel.

1. Power station boilers with coal fired burners.
2. Power station boiler with solid fuel (fire wood) fired burner.
3. Industrial boiler with solid fuel fired burner.(Tea Factory, Food Industry, garment & Rice Mill)

In this study the following boilers were studied as described below.

4.2.1 300MW-Power Station Boiler with coal fired burner.(Power Station Burner)

This type of burner in the boilers can be found in the Coal Power Station in Sri Lanka. The boiler steam capacity is 912 tons/hour. Maximum capacity is 1025 tons/hour. The power station is started from diesel oil burning with 12 oil burners up to 160MW. Then it gradually changes to pulverized coal with the coal burner. Normally, when it reaches 160MW oil guns are stopped proportionally to the load. At the load 160MW, the coal is fired from the heat generated by the furnace itself [14].

Manufacture Details of the 4.4.1

- Output Power:300MW
- Fuel consumption: 110 tons/hour-coal
- Oil injecting rate at starting :15tons/hour

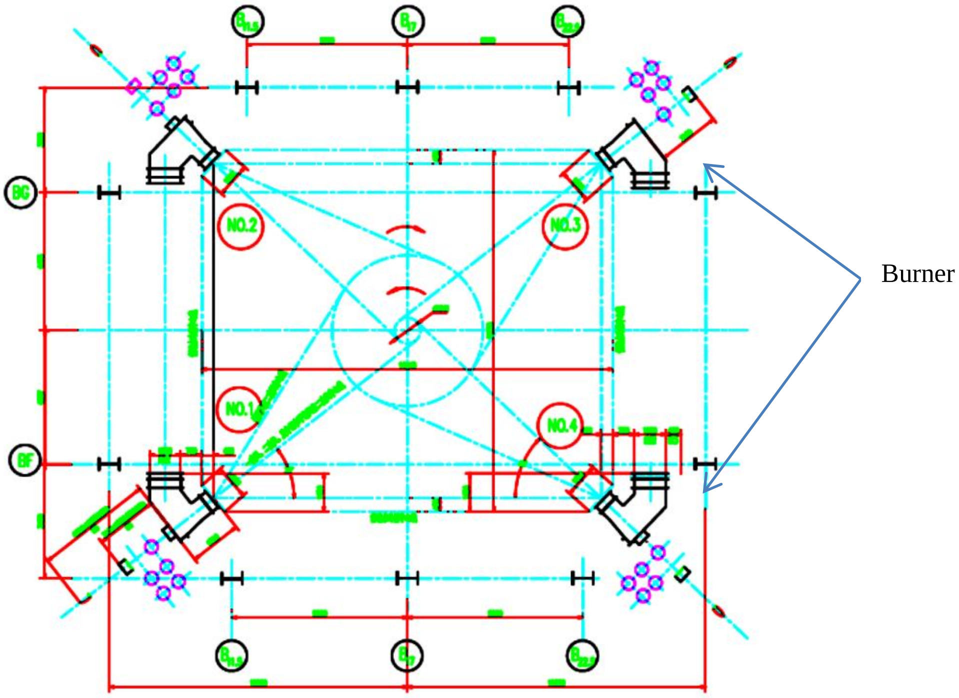


Figure 4.1: The Arrangement of the burners inside the boiler[14]

Boiler burning equipment include furnace,burner and ignition devices.The furnace is formed by furnace wall and three-dimentional space for fuel burning in it and there is a water wall around it. The bottom of the furnance is connected to a slag conveyor. The top of the furnace is flat and installed with a roof superheater. In back of the furnace, is the flue duct which is called furnace outlet. In order to improve the washing of flue to platen superheater and to fully utilize the volume of furnace, there is a furnace arch under the outlet of the furnace.

Coal powder burner is the main burning equipment of the coal-powder boiler, it's function is to let primary air which carrying coal powder and secondary air which is not carrying coal powder to spray into furnace and has a sufficient combustion. So, its performance is of great effect to the stability and economy of burning burning process. Coal powder burners can be classified as straight-flow burners and turbulent burners according to the airflow method.

In this unit, boiler is equipped with straight-flow swing burners at the four corners of the boiler. All five layers can be swung up and down with a swinging angle of ±30°. Buring mode is tangential firing. Burner spot is designed and made of anti-burnout and antiabrasion new type alloy material and its structure meets the condition in which it can be knocked-down from outside once there is maintenance. Straight-flow burner is narrow shaped and is installed on the four corners of the furnace and air flows from the four corners to form a circular shape in the centre of furnace as shown in Figure: 4.3. This method is called tangential firing.

Igniting devices are used to light coal powder when starting up the boiler. They can also keep the burning stable when the power is low or when unstable buring is caused by changed the coal amount. Ignition devices consist of oil atomizer and air register. Oil atomizer,also called oil nozzle or oil gun,is used to atomize oil into extremely fine oil droplets. Air register’s function is to send air timely to the bottom of the torch so that oil is mixed with air to form better firing conditions thus ensuring rapid and sufficient buring of oil.

The atomizer used in this unit is a simple mechanical atomizer and it consists of the splitter, the atomizing piece and the nut gland. The splitter is used to distribute the oil flow to the oil hole and guide it to the tangential slot of the atomizing pieces. Atomizing pieces' function as shown in Figure 4.4, is to guide oil from the tangential slot to the central swirl chamber to form a strong swirl and then come through the oil nozzle to form an umbrella-type oil mist and to spray it into the furnace[14].

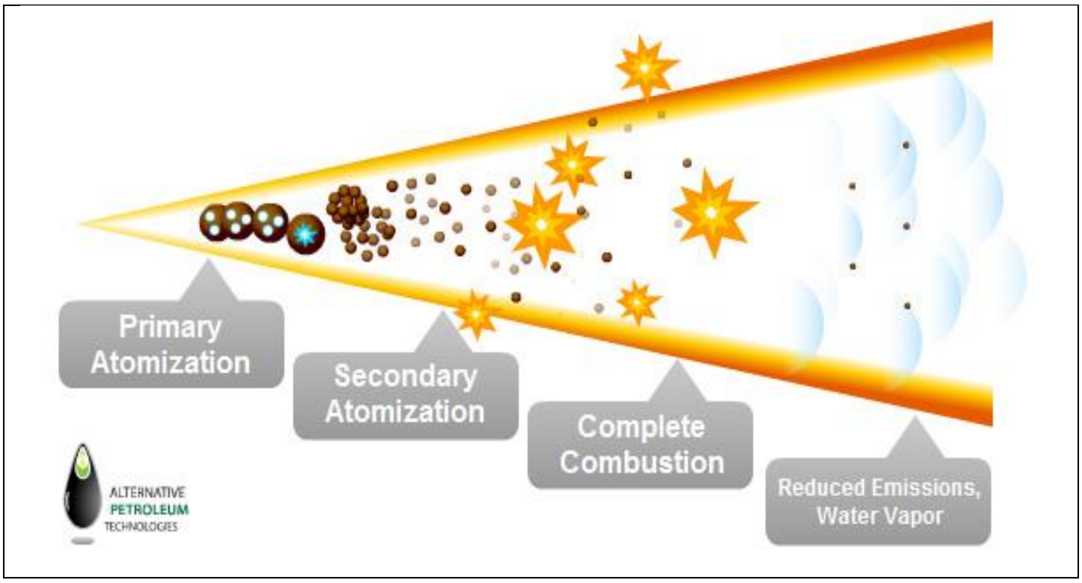


Figure 4.2: The Arrangement of the fuel atomization[13]

Basic specification of this burner equipment is shown in Annexure 02.

4.2.2 Wood Fired boiler in tea factory at Watawala

This tea factory has two types of boilers which are hot water generator and steam boiler. The boiler is used for taking steam for boiling tea leaves and hot water generator is used for generating hot air through the radiator for drying tea leaves.

Hot Water generator

This type of burner in the boilers can be found in the Carolina Tea Factory. The boiler capacity is about 574,000 kcal/h. This boiler is of fully automatic, three passes, forced circulation, smoke tube, wood fired, internal furnace and horizontally mounted type. This hot water generator consists of a shell and two set of smoke tubes. The burner is of plain grate type and consists of grate bars, in which fuel is burnt, with the help of primary air supplied through the bottom side of the grate bars by Forced Draft (FD) fan. The FD fan forces the air through the Air Pre Heater (APH) which increases temperature of air using the flue gas. This is an improvement to the efficiency of the system. Flue gases after the combustion, passes through the reversal chamber to the second pass smoke tube. Finally, flue gas escape through the third passes smoke tube to the smoke chamber. An Induced Draft (ID) fan is provided to create sufficient draft inside the furnace. The firing is done manually and required fuel is fed to the system by workers. Ash is collected at the bottom of the grate bars and this should be cleaned periodically. Using the preheating inlet air, the flue gas temperature and the outlet temperature can be reduced. Water is circulated by a circulation pump and leakage water is added to the system by the makeup water pump. This heated hot water is sent to the radiator which is used for air heating for the processing of tea leaves. FD fan is used to get the required amount of air for full combustion. The FD fan is connected to the space bellow the grate bars and then it causes the combustion. Basic specification of this burner equipment is shown in Annexure 02.

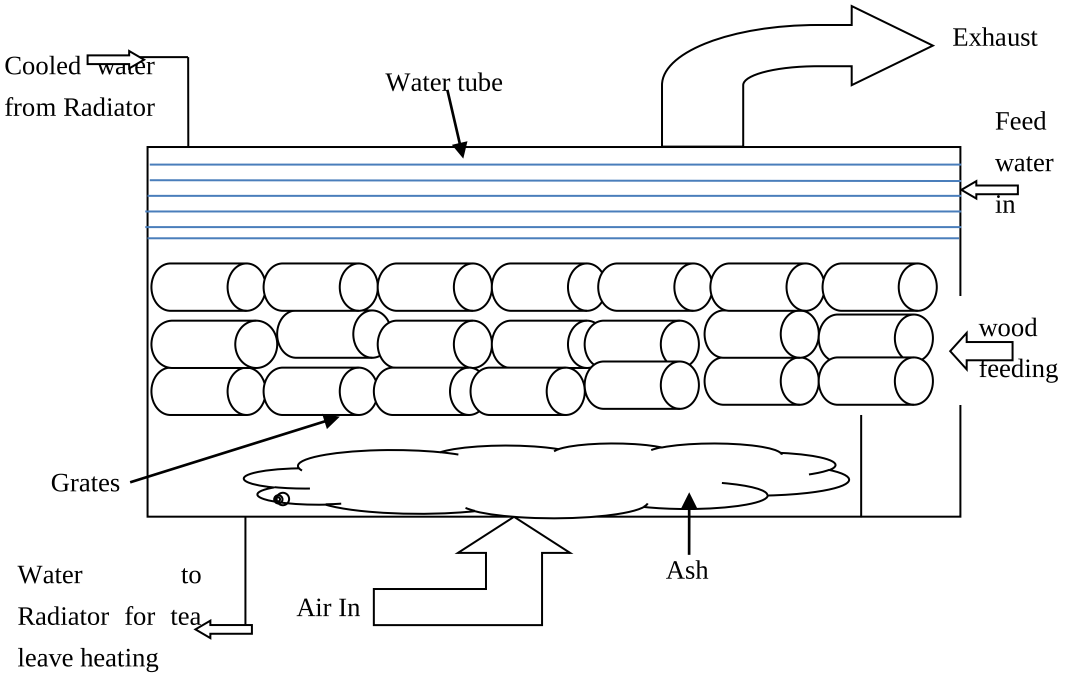


Figure 4.3: Arrangement of the Hot Water Generator

Bio mass Boiler

Capacity of the dryer is 50 ton/hour and it is vertically mounted. The main differences of the hot water generator and the boiler type dryer are the orientation and the heat transfer fluids change. In this dryer, the air is heated to the required temperature. This is the vertically mounted boiler and fuel is fed from the bottom part of the boiler as shown in Figure:4.4. The burner has fixed grate bars to keep the fire wood. The bottom part of the grate bars is used to supply air and to collect the ash which can be removed from the bottom door.

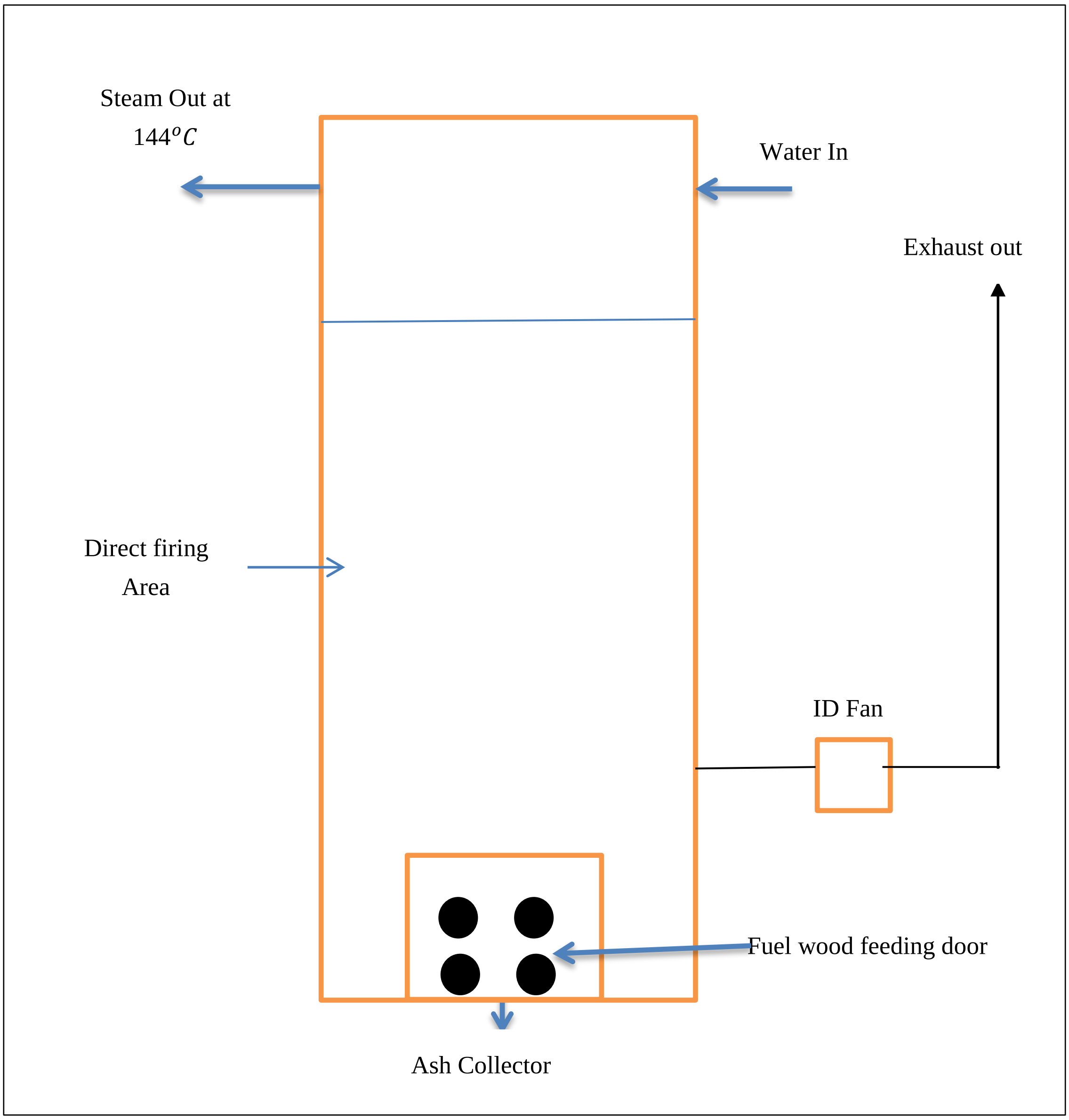


Figure 4.4: The vertically mounted boiler arrangement

Basic specification of this burner equipment is shown in Annexure 02.

These boilers use different fuel woods as given below.

- Fire wood
- Rubber (Hevea Brasiliensis)
- Gliricidia (Gliricidia Sepium)
- Epil Epil (Leucaena Leucocephala)

Sizing of logs

- Logs are cut into 0.5 inch lengths and are split into small pieces.
- Packed in to the center of the boiler

Firing method of the boiler fuel wood

- Direct firing of the boiler by normal fire
- Fuel wood is fed into the boiler at a rate of 80 kg/h

4.2.3 6MW Dendro Power Station Mahiyanganaya

This Power Station is newly constructed and under commercial operation. It has a power generation capacity of 6 MW. The Capacity of the furnace & Burner is 4,620,000 kcal/h. This plant uses mainly Gliricidia (Gliricidia Sepium) and rubber wood and remaining of saw mills. There is a sizing plant to get the desired size of above types of wood. Two types of chippers, drum chipper and disc chipper, are used to cut the wood into ½" parts. The plant has an in house storage capacity of 6000 tons which is enough for 20 days of operation. The chipped fuel is transported to the burner using a conveyer belt and is lifted to the top of the furnace by a bucket elevator. There is a temporary storage and chip is fed to the furnace according to the requirements by the automatic feeder. There is no separate burner for the ignition and initial firing is given manually to the grate fuel. These grates itself act as the burner and it continuously operates until fuel is supplied to the grates. The ash is removed continuously by four ash removers.

Basic specification of this burner equipment is shown in Annexure 02.

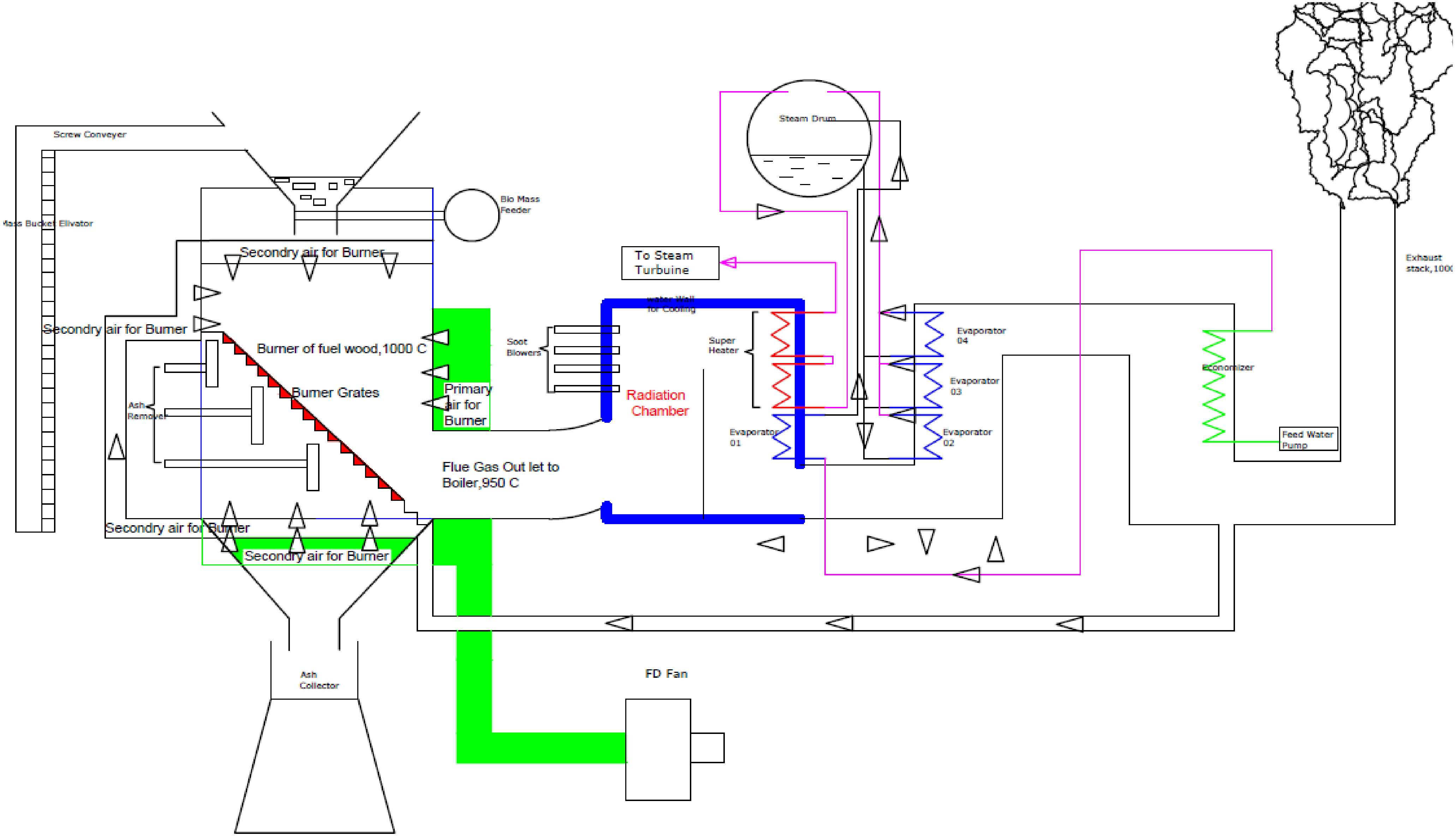


Figure 4.5: The general arrangement of the burner equipment at Mahiyanganaya

4.2.4 Sugar Factory Bagasse/Bio mass operated Boiler

This Sugar factory is located in Ampara area. It has a sugar manufacturing capacity of 2000 tons/day. This sugar factory has a boiler system to get steam for the sugar extraction process and to generate electricity for plant operation. It has a power generation capacity of 2 MW. There are two boilers and the capacity of the furnace is 420,000 kcal/h for each boiler. The steam is used by two types of steam turbines, one for power generation, with a capacity of 138 tons and the other 5 turbines for mill operation, with a capacity of 18,140 kcal/h. This plant uses Bagasse, Epil Epil and cashew wood as fuel. The furnace temperature is 900 °C. The plant produces 30% bagasse in the process. If there is enough bagasse it can be used as fuel.

There is a temporary bagasse storage at the plant and bagasse is fed to the furnace according to the requirement by a convey belt. There is no separate burner for the ignition and initial firing is given manually to the plain grate. This grate itself acts as the burner and it continuously operates until fuel is supplied to the grates. Basic specification of this burner equipment is shown in Annexure 02.

4.2.5 Tea Factory Boiler Fire wood fired burner at Welioya

This tea factory has two types of boilers namely hot water generator and steam boiler. The boiler is used to take steam for boiling tea leaves and hot water generator is used to generate hot air through the radiator for drying tea leaves.

Hot Water generator

This burner is same as described in section 4.2.2 and it uses the same arrangement of equipment. The boiler capacity is about 850,000 kcal/h. This boiler is of fully automatic, three passes, forced circulation, smoke tube, wood fired internal furnace and horizontally mounted type and it is same as shown in Figure 4.5.

Basic specification of this burner equipment is shown in Annexure 02.Fuel used in this burners are

- Fire wood
- Rubber

Firing method of the boiler fuel wood

- Direct firing of the boiler by normal fire

Bio Mass Boiler

This boiler is same as described in section 4.1.5 and it uses the same arrangement of equipment. The boiler capacity is about 800,000 kcal/h. This boiler is of fully automatic, two passes, forced circulation, smoke tube, wood fired internal furnace and horizontally mounted type. But the tubes are located separately from the burning area as shown in Figure 4.8. Basic specification of this burner equipment is shown in Annexure 02.

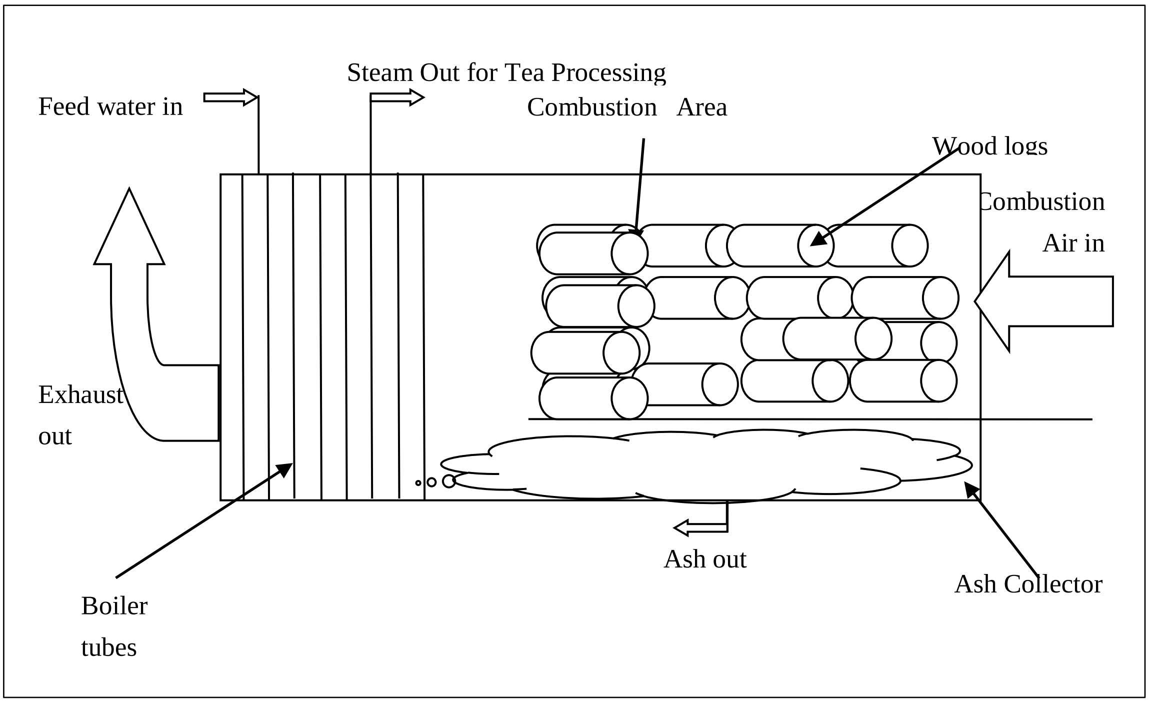


Figure 4.6: The boiler arrangement of the Tea Factory

4.2.6 Rice Mill Boiler at Ampara

This boiler is located at Ampara near the Ampara –Kandy Road. The steam is used for boiling rice. The fuel used is paddy husk and husk is fed to the burning chamber with the help of an air blower. Then the husk is fired in the burning chamber and flue gas is sent to the boiler tube chamber. Steams is generated from the boiler and sent to the rice boiling chamber. Fuel feeding can be controlled at the paddy husk feeding point according to the requirement of the rice boiler. The water is fed to the boiler using a pump.

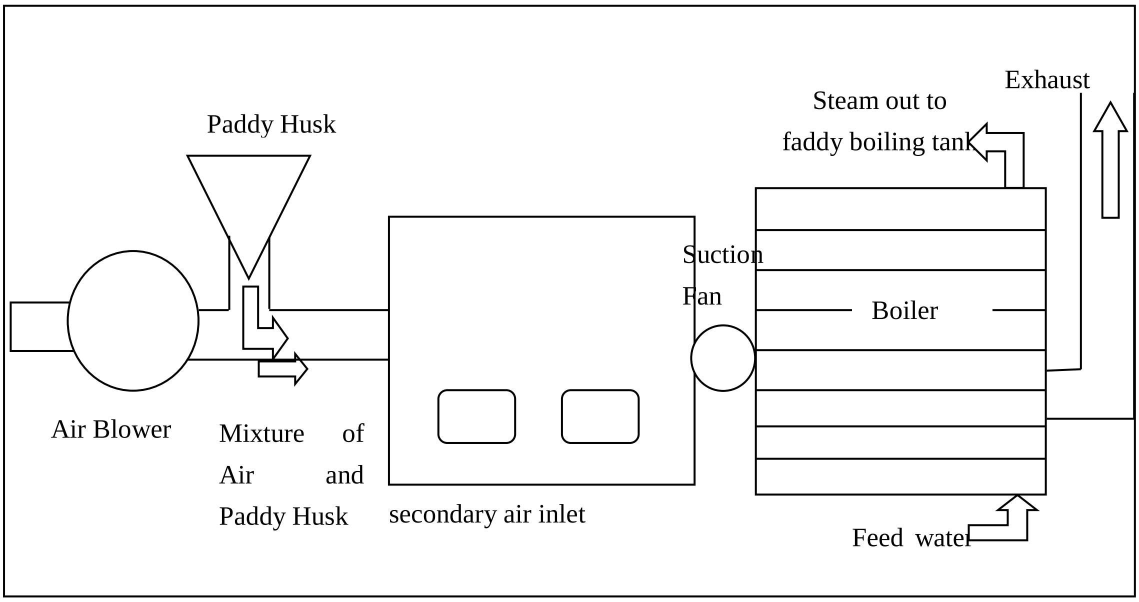


Figure 4.7: The process diagramme of the Rice mill

4.2.7 Bio Mass Boiler at Ranala in Beverages Company

This plant is located at Ranala area. It is a beverages manufacturing plant and uses steam in many stages of the process. There is a bio mass boiler to generate steam. Many types of fire wood can be used such as rubber and cashew wood. The capacity of the boiler is 5 tons/hour. This plant is installed to reduce the operation of the furnace oil boiler with the hope of reducing the operation cost. Basic specification of this burner equipment is shown in Annexure 02.

This plant is newly installed and it operates full time throughout the day. But the moisture level of the fuel wood is very high due to the rainy condition and unavailability of fire wood and timber. Hence it is necessary to keep a bigger storage than what is being used now.

4.2.8 Coal Boiler at Awissawella in Textile factory.

This factory is located in the Awissawella free trade zone and the technical details are given in the table. Basic specifications of this burner equipment are shown in Annexure 02. Steam generated in this boiler is used for dying and washing of cloths. Coal is fed to the boiler after crushing into smaller particles to increase the burning area. Basic specification of this burner equipment is shown in Annexure 02

4.2.9 Coal Boiler at Pannala in Textile factory.

This factory is located at Pannala and the technical details are given in the table. The boiler is used to generate steam for dying and washing of cloths. This boiler is a modern boiler which has been installed recently at this textile factory. Basic specification of this burner equipment is shown in Annexure 02.

4.2.10 Bio Mass Boiler at Ratmalana in Textile factory.

This textile factory is located in Ratmalana and the technical details are given in the table. Steam generated in this boiler is used for dying and washing of cloths.

A basic specification of this burner is shown in Annexure 02. A set of Boilers data used for the indirect method is shown in Annexure 03

4.3 Results (Data Collection)

Data of solid fuel burners used in Sri Lanka are to be collected in different industries and the performances has to be calculated. Using the calculated results, the improvements have to be proposed and solid fuel burners performances in Sri Lanka will be compared with world scenario.

76 boilers were studied to gather data for the performance evaluation. However, due to various reasons, only 19 owners granted permission for the study. For the calculation of the direct method, there is data for 12 boilers and for the indirect method, there is data for 9 boilers. Many of the industries were not willing to provide the data. Most of them do not have the required data and not measured at all. Some industries are not willing to expose their names, details, efficiency values due to organization’s policies and hidden factors. Accordingly, the following table shows a summary of the boilers used for this study.

Table 4.2: The summary of the collected details for performance evaluation

Industries	Number of Boilers that search for data	Data Available from the Efficiency Measurements	Number of Received data for Thesis
Beverage Industry	08	1	1
Power Stations	12	5	4
Garment Factories	28	4	3
Sugar Industries	03	1	1
Tea factories	11	5	4
Food Industries	08	5	3
Other industries	06	03	3
Total	76	24	19
Percentage/(%)		31.5%	25%

CHAPTER 5: PERFORMANCE EVALUATION OF BURNERS

5.1 Introduction

The energy Efficiency testing helps to find out how far the boiler efficiency drifts away from the best efficiency point. The purpose of the measurement of efficiency is to find out the best efficiency of the boiler or the burner. Any observed abnormal deviations could be investigated to pinpoint the problematic area for necessary corrective actions. Hence it is necessary to find out the current efficiency for performance evaluation, which is a pre requirement for energy conservation in industry [15 & 14].Some of the conventional industries are not concern about the efficiency and value of the saving the energy by improving the efficiency. The performances evaluation is part of the routine maintenance work in industrialized countries such as Japan, Germany, Canada, USA etc [14]. Mainly the performance evaluation will be done in three stages which are at the commissioning time, major routine maintenance time and energy audits [15].

5.2 Operational Factors Affecting to Boiler Performance

Various factors affecting the boiler performance are listed below. These factors are identified during operation of burners and maintenance activities, performances evaluation and design stage.

- Periodical cleaning of boilers

The maintenance of the boiler is very important for performances of the boiler. The heat transferring surface shall be kept without ash, dust or tar. The efficiency of the boiler is reduced when the cleanliness of the boiler reduces.

- Periodical soot blowing

The shoot blowing is to be done to remove the ash and particles deposited on boiler tubes and this is done during the operation to improve the heat transfer efficiency.

- Proper water treatment process

The water treatment is very important to protect boiler tube from particle depositing (Fouling), damaging boiler tube from chemical reactions.

- Draft control

The draft controlling means that the temperature of the exhaust gas shall be kept optimum to keep the efficiency in high level. If the exhaust temperature is low will be result in condensation and CO formation. If the exhaust temperature is too high will be result in losing of thermal energy

- Excess air control

If the Excess air amount is increased the efficiency will be reduced due to the heat loss through the excess air

- Percentage loading of boiler

The percentage of the loading shall be kept in design level and if it reduces the efficiency will reduced

- Steam generation pressure and temperature

The stream pressure and temperature shall be kept in design level and those vary from the design level, the efficiency will be changed and stream quality will be reduced which used for the process.

- Boiler insulation

If the insulation is damaged the loss of heat increases and efficiency will drop.

- Quality of fuel

If the quality of the fuel reduces such as high debris, particles and less carbon content, the efficiency will reduces drastically.

5.3 Performance Evaluation

These factors are based on the theoretical background. The following one of the two criteria has to check for performance evaluation. At the performance evaluation stage, many parameters have to be found out for these criteria values. The method of the evaluation criteria is complex and difficult. Modern consideration in burner is environmental protection by emission. Actually for the performance criteria shall be included the emission level also. Because, those emission is one of the harmful substance release to the environment from burner due to poor operation of burner. Hence, if the burner is efficient the emission level should also be less. But in many reference it is not included [20]. The burner or boiler thermal efficiency is depend on input heat to output heat ratio as shown in equation 5.1,

1. Burner Thermal Efficiency, η $= \frac{100 \text{ x } (\text{ Output Heat})}{(\text{Input Heat})}$ (5.1)

$$= \frac{100 \text{ x } (\text{Heat in steam output}))}{(\text{Heat inlet fuel})} \quad (5.2)$$

The efficiency of the burner can be expressed as evaporation ratio and it is the ration between quantities of stream generation by boiler to quantity of the fuel consumed by the boiler to generate the stream quantity generated. The evaporation ratio is the steam to fuel relationship to compare at the operation condition to check weather is there an any variation of the evaporation ratio. This is an instantaneous value and it related to the burner efficiency at that moment. But the burner efficiency is the detailed analysis of the system. That is the reason to ignoring the evaporation ration here.

2. Evaporation Ratio $= \frac{\text{Quantity of steam generation}}{\text{Quantity of fuel consumption}}$ (5.3)

This study concentrates only on the efficiency.

5.4 Standard used for efficiency calculation

- British standards, BS845: 1987

For this standard, the equipment should be operated in full load or constant load. The British Standard BS845: 1987 describes the methods and conditions under which a boiler should be tested to determine its efficiency using indirect method. The burner is kept at constant load condition for one hour and the next hour is used to take measurements. The efficiency of the boiler is quoted as the percentage of useful heat available, expressed as a percentage of the total energy potentially available by burning the fuel. This is expressed on the basis of gross calorific value (GCV) [15].

- ASME Standard: PTC-4-1 Power Test Code for Steam Generating Units

This consists of two parts which are as follows.

1. Part One: Direct method (also called as Input - output method)
2. Part Two: Indirect method (also called as Heat loss method)

- **IS 8753: Indian Standard for Boiler Efficiency Testing**

Most standards for computation of boiler efficiency, including IS 8753 and BS845 are designed for spot measurement of boiler efficiency.

According to these standards efficiency can be determined by following two methods.

1) **The Direct Method:** Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.
2) **The Indirect Method:** Where the efficiency is the difference between the losses and the energy input. [15]

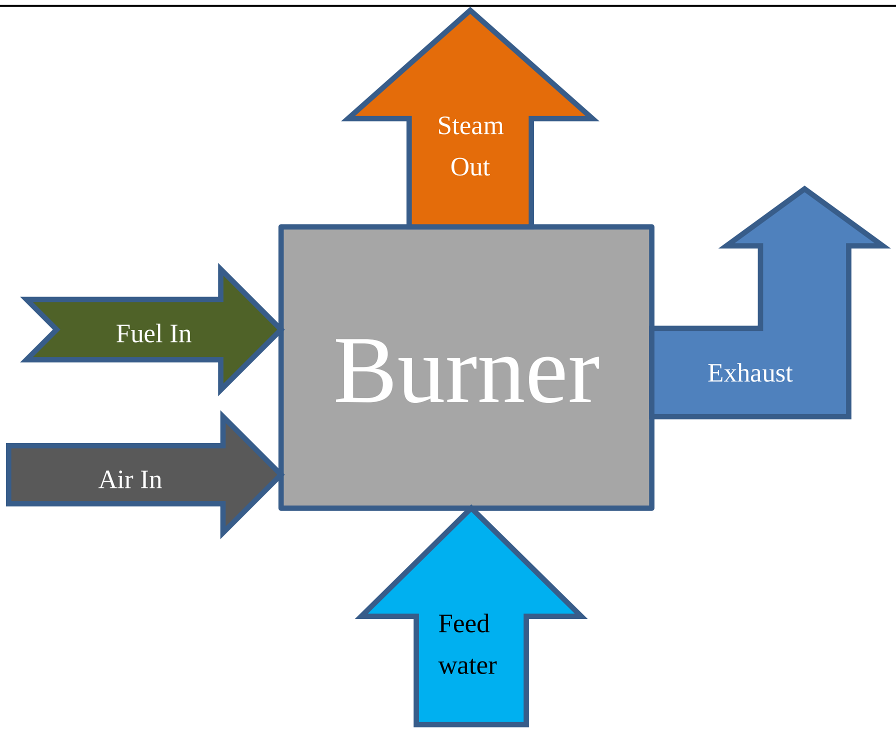
5.5 The Direct Method Testing

The input heat from fuel and output heat from steam are used for this calculation method. The energy flow diagramme is shown in Figure 5.1.

$$\text{Boiler or burner thermal efficiency} = \frac{\mathbf{100\ x\ (\ Output\ Heat)}}{(\mathbf{Input\ Heat})} \tag{5.4}$$

In this calculation, all losses from burner are not used. The following equation can be derived using the equation 5.4. The heat output is energy comes as steam and heat input is the energy released from fuel burning as shown in equation 5.5

$$\text{Boiler or burner efficiency} = \frac{\text{Steam Flow rate x (Steam enthalpy} - \text{Feed water enthalpy)}}{\text{(Fuel rate x GCV)}} \tag{5.5}$$



$$\text{Efficiency} = \frac{\text{Effective enegrgy out put from steam}}{\text{Energy Input to the Burner}}$$
$$= \frac{\text{Steam flow rate(Steam enthalpy} - \text{Feed water enthalpy)}}{\text{Fuel Feed rate x Gross Calorific Value}}$$

Figure 5.1: Burner Heat flow diagramme for direct method

5.5.1 Measurements Required for Direct Method Testing

- **Heat input**

In the calculation of the heat input it is necessary to know the calorific value and mass flow rate of fuel in the system.

The mass flow rate measurement of fuel is very difficult in solid fuel state, a bulky machine is needed to measure flow rate of fuel.If the fuel flow measurement is measured, the accuracy is very less, but in the direct method it had to do. The results are not reliable as indirect method due to this accuracy. As an instantaneous rough measurement this value can be used to have rough idea of the efficiency. The samples of coal or solid fuel has to be sent to the testing lab to analyze the calorific value.

- **Heat Output**

Heat output can be measured using a steam flow meter. This flow meter should be of orifice type. The alternative method which can be used for small boilers is to measure feed water, by previously calibrating the feed tank and noting down the levels of water during the beginning and end of the trial. Special attention should be taken not to pump water during this period. Heat addition for conversion of feed water at inlet temperature to steam, is considered for heat output.

In case of intermittent blow down of boiler, blow down should be avoided during the trial period. In case of boilers with continuous blow down, the heat loss due to blow down should be calculated and added to the heat in steam.

- **Test Data and Calculation**

Water consumption and coal consumption were measured in a coal-fired boiler at hourly intervals. Weighed quantities of coal were fed to the boiler during the trial period. Simultaneously water level difference was noted to calculate steam generation during the trial period. Blow down was avoided during the test. The measured data is given below.

- **Heat output data**

Calculation

The following equation 5.6 is the same equation 5.5,

$$\textit{Boiler}\ \text{Efficiency}\ (\eta) = \frac{\mathrm{Q\ x\ (H-h)\ x\ 100}}{\mathrm{q\ x\ GCV}} \tag{5.6}$$

Where, **Q** = Quantity of steam generated per hour (kg/hr)

q = Quantity of fuel used per hour (kg/hr)

GCV = Gross calorific value of the fuel (kCal/kg)

H = Enthalpy of steam (kCal/kg)

h = Enthalpy of feed water (kCal/kg)

5.6 The Indirect Method of Testing

The approach of this method to calculate efficiency is not straight forward and it is a method of calculating the loss to reach to efficiency. This is called indirect method.

5.6.1 Method of test

In this method, losses of the boiler are used to calculate the efficiency. The energy flow diagramme is shown in Figure 5.2.

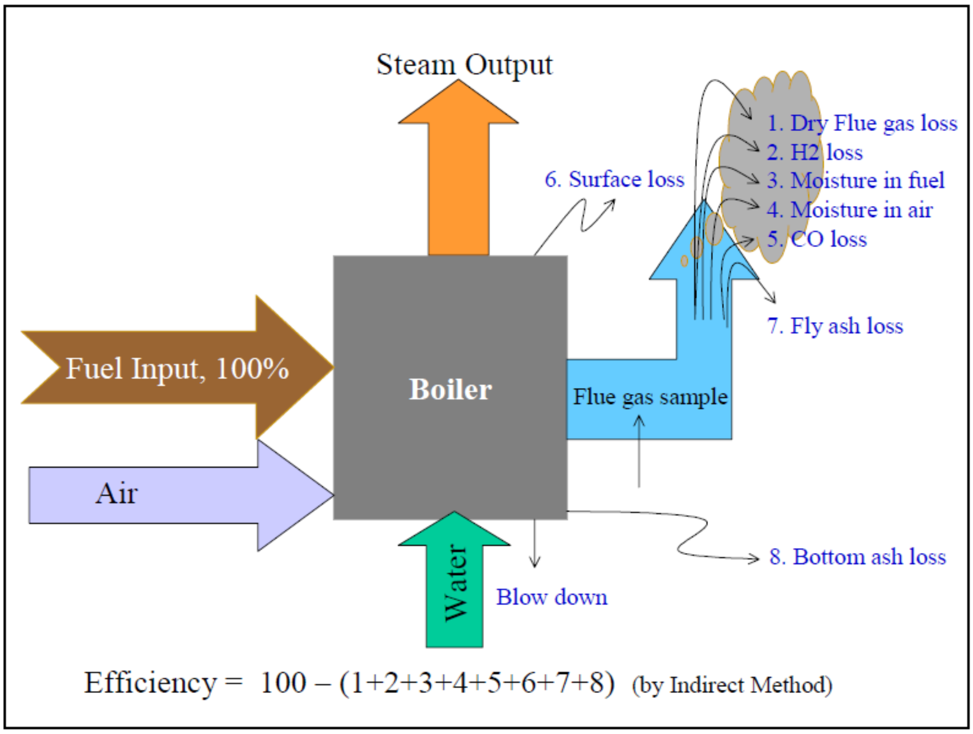


Figure 5.2: Burner Heat flow diagramme for indirect method

L1- Loss due to dry flue gas (sensible heat)

L2- Loss due to hydrogen in fuel (H_2)

L3- Loss due to moisture in fuel (H_2O)

L4- Loss due to moisture in air (H_2O)

L5- Loss due to carbon monoxide (CO) – what about other emissions

The other emissions such as CO_2 ,NO_2 , SO_2 etc are not contribute to the energy losses by absorbing the generated energy from fuel burning, but CO formation will absorbed the energy.

L6- Loss due to surface radiation, convection and other are unaccounted.

The following losses are applicable to solid fuel fired boiler in addition to above

L7- Unburnt losses in fly ash (Carbon)

L8- Unburnt losses in bottom ash (Carbon)

Boiler Efficiency by indirect method = 100 – (L1+L2+L3+L4+L5+L6+L7+L8) (5.7)

5.6.2 Measurements Required for Performance Assessment Testing

The following parameters need to be measured, as applicable for the computation of boiler efficiency and performance using the equipment shown in table 01.

a) Flue gas analysis

1. Percentage of CO_2 or O_2 in flue gas
2. Percentage of CO in flue gas
3. Temperature of flue gas

b) Flow meter measurement for

1. Steam
2. Feed water
3. Condensate water
4. Combustion air

c) Temperature measurements for

1. Flue gas
2. Steam
3. Makeup water
4. Condensate return
5. Combustion air
6. Fuel
7. Boiler feed water

d) Pressure measurements for

1. Steam
2. Fuel
3. Combustion air, both primary and secondary
4. Draft

e) Water condition

1. Total dissolved solids (TDS)
2. pH
3. Blow down rate and quantity

Table 5.1:Typical Instruments used for Boiler Performance Assessment.

Instrument	**Type**	**Measurements**
Flue gas analyzer	Portable or fixed	% CO_2 , O_2 and CO
Temperature indicator	Thermocouple, liquid in glass	Fuel temperature, flue gas temperature, combustion air temperature, boiler surface temperature, steam temperature
Draft gauge	Manometer, differential pressure	Amount of draft used or available
TDS meter	Conductivity	Boiler water TDS, feed water TDS,

The indirect method is described in the ASME Standard PTC-4-1 Power Test Code for Steam Generating Units, and this calculation requires a lot of data. Such large numbers of data are not available in burners. But, there is no facility to measure it in most places and some industries don’t like to expose the data even they have it due to the various reasons. But in the reference [24], it shows the simplified method to calculate the performance using flue gas data. These two methods are used in this calculation according to the data availability and it is described in next chapter. Direct method is also described. In the next chapter, calculation relevant to the present study is presented.

CHAPTER 6: PERFOMANCE CALCULATION

6.1 Introduction

The boiler and burner performance evaluation are done in different method. In this chapter, two methods are used to evaluation performances which are direct method and indirect method [7]. The Indirect method divided into two methods which are according to the ASME standards and simplified method for indirect method using reference 24. The performances calculations are done according to the standards ASME Standard: PTC-4-1 Power Test Code for Steam Generating Units. The equation that used to calculate the performances are extract from the mentioned standards. The reference has indicated each equation.

6.2 Calculation of the Boiler Thermal Efficiency by direct method

6.2.1 Tea Factory Boiler Fire wood fired burner at Watawala

The data are taken from the Annexure 02 of table 01

Specification of Boiler

Steam Generation Capacity(kg/hr) Q	12000.00
Quantity of fuel (kg/hr) q	275.00
GCV/(kCal/kg) at 31% moisture level	4511.32
Enthalpy of Steam(kCal/kJ) H	182.12
Enthalpy of feed water(kCal/kJ) h	100.16

Enthalpy values are taken from steam tables.

Input heat from fuel and output heat from steam are used,

Assume that the moisture content of the fuel to be zero for this calculation, because the moisture content of the fuel has to be checked using the fuel analysis. Those burners, they have not tested for the fuel composition. The blow down has to be zero for this calculation

$$\text{Boiler thermal efficiency} = \frac{100 \text{ x Heat Out put}}{\text{Heat Input}} \qquad (6.1)$$

It can derive following equation**,**

Burner thermal efficiency =

$$\frac{\text{Steam Flow rate x (Steam enthalpy} - \text{Feed water enthalpy)x100}}{\text{(Fuel rate x GCV)}}$$

$$= \frac{12000\text{x}(182.12 - 100.16)\text{x}100}{(275\text{x}4511.32)}$$

= **79.28%**

The other burner performances can be calculated using the above equation and results are shown in Table 03;

Table 6.1: Efficiency calculation of the boiler burner using the Direct Method

Parameter	Tea Factory at Watawala		Bio Mass Power Station 1	Sugar Factory	Tea factory at Welioya		Beverage company at Ranala	Textile Factory Boiler at Avissawella	Textile Factory Boiler at Pannala	Textile Factory Ratmalana	Coal Power station 1
	hot water Generator	Boiler			Boiler	Hot water generator					
Steam Generation Capacity(kg/hr) Q	12000.00	3100.00	54000.00	25000.00	16000.00	10000.00	18000	26000.00	18000.00	16000.00	960000.00
Quantity of fuel(kg/hr) q	275.00	700.00	11000.00	8000.00	3000.00	2000.00	5000.00	5000.00	2400.00	3800.00	114000.00
GCV/(kCal/kg)	4511.32	3200.00	4745.00	4503.82	4742.46	4742.46	3200.00	6453.00	6453.00	3585.00	6300.00
Enthalpy of Steam(kCal/kJ) H	182.12	642.50	993.33	788.88	710.85	704.30	652.76	1048.00	652.76	652.76	811.50
Enthalpy of feed water(kCal/kJ) h	92.30	92.30	117.40	113.22	92.30	92.30	109.04	113.22	113.22	117.40	104.86
Thermal Efficiency Of the boiler (%)	86.88	76.14	90.62	46.88	69.56	64.52	61.17	75.33	62.71	62.88	94.45

Table 6.2: Efficiency calculation of the boiler burner using the Direct Method which use the details for Indirect Method

Parameter	Coal Boiler 1	Coal Boiler 2	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	Fire Wood Boiler
Steam Generation Capacity(kg/hr) Q	240	3500	14500	50000	24000	22500	120000	1450
Quantity of fuel(kg/hr) q	35.71	500	4000	11500	4000	4000	20000	216
GCV/(kCal/kg)	5400	5254.6	3164	3078	4500	4500	6400	4421
Enthalpy of Steam(kCal/kJ) H	724.17	708.68	789.19	676.86	708.40	724.17	737.86	689.65
Enthalpy of feed water(kCal/kJ) h	109.04	109.04	100.67	113.22	104.86	104.86	109.04	144.50
Efficiency Of the boiler (%)	76.56	79.88	78.88	79.62	80.47	77.41	58.95	82.78

6.3 Calculation of the Coal Power station boiler thermal efficiency by indirect method using ASME standard

For this calculation, much more details are necessary to find out the boiler efficiency accurately. Hence, this calculation was done for the Coal Power station only. In this method, losses of the boiler were used to find out the efficiency. The calculation is done step by step as follows according to the ASME Standard: PTC-4-1.

1.Saturation pressure of water vapor at Tdb,Ps, WvTdb

This equation is from 5.11-3 equation of reference 20 and the values for the constant are given in same chapter from 32F to 140F range

Co = 0.019257

C1 = 1.29E-03

C2 = 1.21E-05

C3 = 4.53E-07

C4 = 6.84E-11

C5 = 2.20E-11

Saturation pressure of water vapor at Tdb,

$$\text{Ps WvTdb} = \mathrm{Co} + \mathrm{C1TdbF} + \mathrm{C2TdbF2} + \mathrm{C3TdbF3} + \mathrm{C4TdbF4} + \mathrm{C5TdbF5} \qquad (6.2)$$

Saturation pressure of water vapor at Tdb,Ps

$$\mathrm{WvTdb} = \mathrm{Co} + \mathrm{C1TdbF} + \mathrm{C2TdbF2} + \mathrm{C3TdbF3} + \mathrm{C4TdbF4} + \mathrm{C5TdbF5}$$

= 0.58 Psi

= 3.98 kPa

2. Partial pressure of water vapor in air, PpWvA

Partial pressure of water vapor in air, PpWvA $= 0.01\mathrm{RhmxPsWvTdb}$ [20](6.3)

= 0.01x87.6x3.98

= 3.49 kPa

3. Mass Fraction of Moisture in dry air

Fraction of Moisture in dry air, MFrWDA $= \frac{0.622\mathrm{PpWvA}}{(\mathrm{Pa}-\mathrm{PpWvA})}$ [20] (6.4)

$= \frac{0.622\mathrm{x}3.49}{(101.48-3.49)}$

= 0.022 kg/kg of dry air

4. Mass Fraction of Moisture in wet air, MFrWA

Mass Fraction of Moisture in wet air, MFrWA $= \frac{\mathrm{MFrWDA}}{(1+\mathrm{MFrWDA})}$ [20](6.5)

$= \frac{0.022}{(1+0.022)}$

= 0.0217 kg/kg of dry air

4. Primary Air rate, Xpa

Primary Air rate, Xpa $= \frac{\mathrm{MFW1}}{(\mathrm{MFW1}+\mathrm{MFW2})}$[20] (6.6)

$= \frac{287020}{(287020+782996)}$

= 0.268

5. Secondary Air rate

Secondary Air rate, Xsa $= \dfrac{\mathrm{MFW1}}{(\mathrm{MFW1} + \mathrm{MFW2})}$ [20] (6.7)

$= \dfrac{782996}{(287020+782996)}$

$= 0.732$

Calculation of losses and Efficiencies of burners

6. Enthalpy of Wet Air at TFg

Air temperature entering to boiler, TMnAEn = 36 ℃

Enthalpy of Wet Air at TFg, HATFg =(1-MFrWA)HaDg+MFrWAxHWvg [20](6.8)

= (1-0.0217) x101.12+0.0217x188.88

= 103.02 kJ/kg

7. Enthalpy of Wet Air at TMnAEn

Air temperature entering to the boiler, TMnAEn = 36 ℃

Enthalpy of Wet Air at TMnAEn, HAEn =(1-MFrWA)HaDa+MFrWA*Hwva [20] (6.9)

= (1-0.0217) x11.05+0.0217x20.475

= 11.254 kJ/kg

7. Unburned carbon in residue, MpToCRs

Unburned carbon in residue, MpToCRs $= \dfrac{\Sigma MpRsz(fa,ba) x MpToCRsz(fa,ba)}{100}$

(6.10)

$$= \frac{90x5.98+10x8.56}{100}$$

= 6.238 mass%

8. Total mass of residue per mass fuel, MFrRs

Total mass of residue per mass fuel, MFrRs $= \frac{MpAsF}{(100-MpToCRs)}$ (6.11)

$$= \frac{11}{100-6.238}$$

= 0.117 kg/kg fuel

9. Unburned carbon in fuel, MpUbC

Unburned carbon in fuel, MpUbC $= MpToCRs$ x MFrRs (6.12)

= 6.24x0.1173

= 0.732 kg/kg fuel

10. Carbon Burned in fuel, MpCb

Carbon Burned in fuel, MpCb $= MpCF - MpUbC$ (6.13)

= 61.32-0.732

= 60.59 kg/kg fuel

11. Carbon burnout,MpCbo $= \frac{100MpCb}{MpCF}$ (6.14)

$$= \frac{100x60.58}{61.32}$$

= 98.81 kg/kg fuel

12. Mass flow rate of Fly as, MpRsf

Mass flow rate of Fly as, MpRsf $= \frac{MpRsfa\, xMFrRs}{100\, HHVF}$ (6.15)

$= \frac{90x0.1173}{100x25485}$

$=$ 4.14x10^{-6} kg/kJ

13. Mass flow rate of Fly as, MpRsf

Mass flow rate of Fly as, MpRsf $= \frac{MpRsfa\, xMFrRs}{100\, HHVF}$ (6.16)

$= \frac{90x0.1173}{100x25485}$

$=$ 2.83 kg/kJ

14. Mass flow rate of bottom ash, MpRsb

Mass flow rate of bottom ash, MpRsb $= \frac{MpRsba\, xMFrRs}{100\, HHVF}$ [20](6.17)

$= \frac{10x0.1173}{100x25485}$

$=$ 4.60x10^{-07} kg/kJ

15. Theoretical Air, MFrThA

Theoretical Air,MFrThA = $0.1151MpCF$ +0.3430MpH2F +0.0431MSF-0.043MpO2F (6.18)

$= 0.1151MpCF + 0.3430\text{x}5.73$

$+ 0.0431\text{x}084 - 0.043\text{x}16.54$

= <u>8.35 kg/kg of fuel</u>

16. Typical value of theoretical air for fuel, ideal, MqThAf

Typical value of theoretical air for fuel, MqThAf = $\frac{MFrThA}{HHVF}$ [20](6.20)

= $\frac{8.35}{25485}$

= <u>$3.27644\text{x}10^{-4}$ kg/kJ</u>

17. Mass of Theoretical air corrected, MFrThACr

Mass of Theoretical air corrected, MFrThACr $= 0.1151MpC\text{b} + 0.3430\text{MpH2F}$

$+ 0.0431\text{MSF} - 0.043\text{MpO2}$ [20](6.21)

=

$.1151x60.78 + 0.3430\text{x}5.73$

$+ 0.0431\text{x}084 - 0.043\text{x}16.54$

= <u>8.29 kg/ kJ of fuel</u>

18. Theoretical air corrected, MqThACr

Theoretical air corrected, MqThACr = $\frac{\text{MFrThaCr}}{HHVF}$ [20](6.22)

$$= \frac{8.29}{25485}$$

= $\underline{3.25\text{x}10^{-4}\text{ kg/kg of fuel}}$

19. Moles of Theoretical air required corrected, MoThACr

Moles of Theoretical air required , MoThACr $= \frac{\text{MFrThaCr}}{28.963}$ [20] (6.23)

$$= \frac{8.29}{28.963}$$

= $\underline{0.29\text{ kg/kg of fuel}}$

20. Moles of dry product from fuel combustion, MoDPc

Moles of dry product from fuel combustion, MoDPc = $\frac{\text{MpCb}}{1201}+\frac{\text{Mp SF}}{3206.4}+\frac{\text{M}pN2F}{2801.3}$

[20] (6.24)

$$= \frac{60.78}{1201}+\frac{0.87}{3206.4}+\frac{1.25}{2801.3}$$

= $\underline{0.05\text{ kg/kg of fuel}}$

21. Moles of wet product from fuel combustion, MoWPc

Moles of wet product fuel combustion, MoWPc = MoDPc+$\frac{\text{Mp}H2F}{201.6}+\frac{\text{M}pWF}{1801.5}$

[20](6.25)

$$= 0.51+\frac{5.73}{201.6}+\frac{8.10}{1801.5}$$

= $\underline{0.543\text{ kg/kg of fuel}}$

22. Moles of Moisture in air,MoWA

Moles of Moisture in air,MoWA = $1.608 \mathrm{MFrWA}$ [20] (6.26)

$= 1.608x0.0216$

= 0.030 moles

23. Excess Air at AH inlet,XpAe

The Following equation is obtained from equation 5.9-15 of Chapter 5 from reference 20

Excess Air at AH inlet, XpA =

$$\frac{100VpO2e[MoWPc+MoThACr(0.7905+MoWA)]}{MoThACr[20.95-VpO2e(1+MoWA)]}.$$

[20] (6.27)

$$= \frac{100x3.57[0.88+0.2861(0.7905+0.03)]}{0.2861[20.95-3.57(1+0.03)]}$$

= 56.33 kg/kg of fuel

24. Excess Air at AH outlet,XpA

Excess Air at AH outlet, XpA =

$$\frac{100VpO2[MoWPc+MoThACr(0.7905+MoWA)]}{MoThACr[20.95-VpO2(1+MoWA)]}$$

(6.28)

$$= \frac{100x5.1[0.88+0.2861(0.7905+0.03)]}{0.2861[20.95-5.1(1+0.03)]}$$

= 88.60 %

25. Moles wet gas per mass fuel at AH inlet, MoFge

Moles wet gas per mass fuel at AH inlet, MoFge = $MoWPc +$

$$MoThACr[0.7905 + MOWA + \frac{XpAe(1+MoWA)}{100}] \qquad [20](6.29)$$

$$= \quad 0.88 + 0.2861[0.7905 + 0.03 + \frac{56.33(1+0.03)}{100}]$$

= <u>0.95%</u>

26. Moles wet gas per mass fuel at AH outlet, MoFg

Moles wet gas per mass fuel at AH outlet, MoFg

$$= \; MoWPc + MoThACr[0.7905 + \; MOWA + \frac{XpA(1+MoWA)}{100}] \qquad (6.30)$$

$$= \quad 0.88 + 0.2861[0.7905 + 0.03 + \frac{88.6(1+0.03)}{100}]$$

= <u>1.04%</u>

27. Mass of dry air at AH inlet, MqDAe

Mass of dry air at AH inlet, MqDAe = $MqThACr(1 + 0.01XpAe)$ [20](6.31)

= $0.000325(1 + 0.01x56.33)$

= <u>$5.08x10^{-4}$ %</u>

28. Mass of dry air at AH outlet, MqDA

Mass of dry air at AH outlet, MqDA = $MqThACr(1 + 0.01XpA)$ [20](6.32)

$= 0.000325(1 + 0.01x88.6)$

$= \underline{6.13\text{x}10^{-4}\%}$

29. Mass of wet air at AH inlet, MqAe

Mass of wet air at AH inlet, MqAe $= MqDAe(1 + MFrWDA)$

[20](6.33)

$= 0.000508(1 + 0.022)$

$= \underline{5.20\text{x}10^{-4}\%}$

30. Mass of wet air at AH outlet, MqA

Mass of wet air at AH outlet, MqA $= MqDA(1 + MFrWDA)$

[20](6.34)

$= 0.000613(1 + 0.022)$

$= \underline{6.27\text{x}10^{-4}\%}$

31. Wet gas from fuel, MqFgF

Wet gas from fuel, MqFgF $= \frac{(100 - MpAsF - MpUbC)}{100HHVF}$

[20](6.35)

$= \frac{(100 - 11 - 0.7320)}{100X26377}$

$= \underline{3.3\text{x}10^{-5}\%}$

32. Moisture from H2O in fuel, MqWF

Moisture from H2O in fuel, MqWF $= \frac{MpWF}{100HHVF}$ [20] (6.36)

$$= \frac{12}{100X26377}$$

= $\underline{3x10^{-6}\%}$

33. Moisture from hydrogen in the fuel,MqWH2F

Moisture from hydrogen in the fuel,MqWH2F $= \frac{8.937MpH2F}{100HHVF}$ [20](6.37)

$$= \frac{5.73}{100X26377}$$

= $\underline{2x10^{-6}\ \%}$

34. Moisture in air at AH inlet,MqWAe

Moisture in air at AH inlet,MqWAe = MFrWDA MqDAe [20](6.38)

= 0.022x0.000508

=0.022x0.000508%

= $\underline{1.12x10^{-5}\%}$

35. Moisture in air at AH outlet,MqWA

Moisture in air at AH outlet,MqWA = MFrWDA MqDA [20](6.39)

= 0.022x0.000613

= 0.000014%

= $\underline{1.35x10^{-5}\%}$

36. Total Moisture in flue gas at AH inlet, MqWFge

Total Moisture in flue gas at AH inlet, MqWFge = MqWF+MqWH2F +MqWAe [20](6.40)

= 0.000003+0.000002+0.000011

= $\underline{1.6\text{x}10^{-5}\%}$

37. Total Moisture in flue gas at AH outlet, MqWFg

Total Moisture in flue gas at AH outlet, MqWFg = MqWF+MqWH2F+MqWA [20] (6.41)

= 0.000003+0.000002+0.000014

= $\underline{1.9\text{x}10\text{-}5\%}$

38. Total Wet flue gas weight at AH inlet, WqFge

Total Wet flue gas weight at AH inlet, WqFge = MqDAe+MqWAe+MqFgF [20] (6.42)

= 0.000508+0.000011+0.000033

= $\underline{5.52\text{x}10^{-4}\%}$

39. Total Wet flue gas weight at AH outlet, MqFg

Total Wet flue gas weight at AH outlet,MqFg = MqDA+MqWA+MqFgF [20] (6.43)

= 0.000319+0.000014+0.000033

= $\underline{6.6\text{x}10^{-4}\%}$

40. Air heater(AH) leakage rate,A1

Air heater(AH) leakage rate,A1 $= \frac{(MqFg - MqFge)}{MqFge\ x100}$[20] (6.44)

$= \frac{(0.000019 - MqFge)}{MqFge\ x100}$

= <u>0.001925 %</u>

41. Dry flue gas weight at AH inlet, MqDFge

Dry flue gas weight at AH inlet, MqDFge = MqFge-MqWFge [20](6.45)

= 0.000553-0.000017

= <u>$9.4x10^{-9}$%</u>

42. Dry flue gas weight at AH outlet,MqDFge

Dry flue gas weight at AH outlet,MqDFge = MqFg-MqWFg [20](6.46)

= 0.000660-0.000019

= <u>$6.41x10^{-4}$%</u>

43. Mean Specific heat of hot air

= 36℃

Mean Specific heat of hot air, MnCpA $= \frac{(\mathrm{HATFg} - \mathrm{HAEn})}{(\mathrm{TFgK} - \mathrm{TMnAEnK})}$

[20](6.47)

$$=\frac{(103.022-11.254)}{(394.49-309.15)}$$

= <u>1.027 kJ/kg</u>

44. Mean Specific heat of wet Flue Gas

Mean Specific heat of wet Flue Gas is taken from ASME PTC4,5.19.12 section, Fig:5-19-3 of ref 20

= 0.241 btu/lbm.F

= 1.00905 kJ/kg.K

45. Corrected flue gas temperature

Corrected flue gas temperature $=\left(\frac{MqFg}{FqFge}-1\right)($TFg-TMnAEn) (6.48)

$$= 125.34+\frac{1.075}{1.00905}\left(\frac{0.43}{0.39}-1\right)$$

x(125.34-36)

= <u>134.668 K</u>

46. Enthalpy of dry flue gas

Enthalpy of dry flue gas, HDFg $= \mathrm{Co} + \mathrm{C1TK} + \mathrm{C2TK2} + \mathrm{C3TK3} + \mathrm{C4TK4} + \mathrm{C5TK5}$ (6.49)

Where, TK-Dry flue gas temperature in K, Co-$C5$ are Coefficient for dry flue gas temperature from 250K to 1000K from reference 20

Co = -1.23E+02

C1 = 4.07E-01

C2 = 5.80E-01
C3 = 6.33E-08
C4 = -2.92E-11
C5 = 2.49E-15

Enthalpy of dry flue gas, HDFg = 46.98 Btu/lbm

= 106.99 kJ/kg

6.3.1 Loss Calculation of the burner

1. Dry Flue Gas Loss

Dry Flue Gas Loss, QpLDFg = 100MqDFgexHDFg [20](6.50)

= **4.41** kJ

2. Loss Due to the water in fuel

Enthalpy of Water vapour at TFgF

Enthalpy of Water vapour at TFgF, HSt = $0.4329TFgF+3.958E\text{-}5TFgF^2$ $+1062.2$ [20]

[Equation 5.19-6 of section 15.19.5 ref 20] (6.51)

$= 0.4329 \times 273.992 + 3.958E^{-5} \times 273.992^2 + 1062.2$

= 1183.782 btu/blm

= 2753.49 kJ/kg

Enthalpy of Water at Trad

Enthalpy of Water at Trad , HWRe = $TradF - 32$ [Equation 5.19-7 of section 15.19.5 ref 20] (6.52)

= 77-32 = 45F

= **45.000** btu/blm

= **104.67** kJ/kg

Loss due to the water in fuel,

Loss due to the water in fuel, QpLWF = 100MqWF*(HSt-HWRe)

[20](6.52)

Loss due to the unburnt carbon in Residue,QpLUbC $= \frac{33700\text{MpUbC}}{\text{HHVF}}$ [20] (6.53)

= 100x5.52E^{-06}x

(2753.478-104.67)

= **<u>1.46 kJ</u>**

3. Loss Due to the water from combustion of H2 In fuel

Loss Due to the water from combustion of H2 In fuel,

QpLH2F = 100MqWH2F(HSt-HWRe)

[20] (6.54)

= 100x52.01E^{-05}x

(2753.478-104.67)

= **<u>5.324 kJ</u>**

4. Loss Due to the moisture in air

Enthalpy of Water vapour at TFg ,Tc = 2TFgF-77

[Graph 5.19-2 from reference [20] (6.56) where Tc= Mean specific temperature

Tc = 2x273.992-77 = 470.98 F

Cp value at the Tc=470.98 F is takan from Graph 5.19-2 from reference 20

Cp = 0.456 btu/lbm

Enthalpy of Water vapour at TFg, HVVRs = $\mathrm{Cp}(\mathrm{T}-77)$

[section 5.19.12 ref 20](6.57)

= 0.456x(273.992-77)

= **89.828** Btu/lbm

= **208.9407468** kJ/kg

Loss Due to the moisture in air,

Loss Due to the moist air QpLWA = 100MFrWDAxMqDAe xHVVRs [20](6.58)

= 100x0.022x4.02E^{-04}x208.940

= **0.185** kJ

5. Loss due to the unburnt carbon in Residue

Loss due to the unburnt carbon in Residue QpLUbC = $\frac{33700\mathrm{MpUbC}}{\mathrm{HHVF}}$ [20](6.59)

$$= \frac{33700\mathrm{x}0.54}{25485}$$

= **0.690** kJ

6. Loss due to the surface radiation & convection

Loss due to the surface radiation & convection, QpLSrc = this value is taken from design report [14]

= **0.210** kJ

7. Loss Due to the unaccounted factors

Loss Due to the unaccounted factors QpLUm = This value is taken from design report [14]

= **0.300** kJ

8. Sum of Losses

Sum of Losses, QpL = $\mathrm{QpLDFg} + \mathrm{QpLUbC} + \mathrm{QpLH2F} + \mathrm{QpLWA} + \mathrm{QpLUbC} + \mathrm{QpLSrc} + \mathrm{QpLUm}$ [20] (6.60)

= 4.408+1.462+5.324+0.185+ 0.690+0.21+0.30

= **12.579** kJ

9. Efficiency of Boiler HHVF Base

Efficiency of Boiler HHVF Base, EFH = $100 - \mathrm{QpL}$ [20] (6.61)

= 100-12.579

= **87.421 %**

10. Efficiency of Boiler LHVF Base

Efficiency of Boiler LHVF Base, EFL $= \frac{\mathrm{EFHxHHVF}}{\mathrm{LHVF}}$ [20](6.62)

$$= \frac{87.421 \mathrm{x} 26377}{24099}$$

= **<u>92.449 %</u>**

The stages of the calculation are shown in the table 4 step by step as follows.

Table 6.3: Loss Calculation and Efficiency of Coal Power station 1 using the Indirect Method

Item	Parameter	Notation	Basic Equation	Value	Unit
Design Data					
	Reference Air Temperature	Trad		25	C
	C	MpCF		65	mass %
	H	MpH2F		3.8	mass %
	N	MpN2F		1.5	mass %
	O	MpO2F		6.2	mass %
	S	MpSF		0.5	mass %
	Moisture	MpWF		12	mass %
	Fixed Carbon	MpFc		49.5	mass %
	Volatile matter	MpVm		27	mass %
	Ash	MpAshF		11	mass %
	Lower heating Value	LHVF		25216	kJ/kg
	Higher Heating Value	HHVF		26377	kJ/kg
Analysis data of coal					
	C	MpCF		61.32	mass %
	H	MpH2F		5.73	mass %
	N	MpN2F		1.25	mass %
	O	MpO2F		16.54	mass %
	S	MpSF		0.87	mass %
	Moisture	MpWF		8.1	mass %

Item	Parameter	Notation	Basic Equation	Value	Unit
				24099	mass %
	Lower heating Value	LHVF		24099	kJ/kg
	Higher Heating Value	HHVF		25485	kJ/kg
Atmospheric parameters					
	Barometric pressure	Pa		101.48	kPa
	Dry bulb temperature	Tdb		28.89	C
	Dry bulb temperature	TdbF		84	F
	Wet bulb temperature	Twb		27.17	C
	Relative humidity	Rhm		87.6	%
	saturation pressure of water vapor at Tdb	Ps WvTdb		3.98	kPa
	partial pressure of water vapor in air	PpWvA	0.01RhmxPsWvTdb	3.49	kPa
	Mass Fraction of Moisture in dry air	MFrWDA	0.622PpWvA/(Pa-PpWvA)	0.022	kg/kg of dry air
	Mass Fraction of Moisture in wet air	MFrWA	MFrWDA/(1+MFrWDA)	0.0216	kg/kg of dry air
Air and Flue gas Data					
	Primary Air Temperature at Ah inlet	TAEnP		46.91	C
	Secondary Air temperature at AH inlet	TAEnS		32	C
	primary Air Flow	MFW1		287020	kg/h
	Secondary Air flow	MFW2		782996	kg/h
	Primary Air rate	Xpa	MFW1/(MFW1+MFW2)	0.27	
	Secondary Air Rate	Xsa	MFW2/(MFW1+MFW2)	0.73	

	Parameter	Notation	Basic Equation	Value	Unit
	Flue Gas temperature at AH inlet	TFg		125.34	C
	O2 Content in flue gas at AH inlet	VpO2e		3.57	Vol % wet base
	O2 Content in flue gas at AH inlet	VpO2		5.1	Vol % wet base
Residue data					
	Unburnt total carbon in fly ash	MpToCRsfa		5.98	mass%
	Unburned total Carbon in bottom ash	MpToCRsba		8.56	mass%
	Mass fraction of fly ash	MpRsfa		90	mass%
	Mass fraction of bottom ash	MpRsba		10	mass%
	Unburned carbon in residue	MpToCRs		6.24	mass%
	Total mass of residue per mass fuel	MFrRs		0.09	kg/kg fuel
	Unburned carbon in fuel	MpUbC		0.54	mass%
	Carbon Burned in fuel	MpCb		60.78	mass%
	Carbon burnout	MpCbo		99.12	%
	Mass flow rate of Fly ash	MqRsf		3.05E-06	kJ/kg
	Mass flow rate of bottom ash	MqRsb		3.39E-07	kJ/kg
Combustion air Properties					
	Theoretical air ideal	MFrThA		8.35	kg/kg fuel
	Typical value of theoretical air for fuel, ideal	MqThAf		3.28E-04	kg/kJ
	Mass of Theoretical air corrected	MqThACr		8.29	kg/kg fuel

Item	Parameter	Notation	Basic Equation	Value	Unit
	Moles of theoretical Air Required(Corrected)	MoThACr		0.29	kmoles/kg fuel
	Moles of dry product from fuel combustion	MoDPc		0.051	kmoles/kg fuel
	Moles of wet product from fuel combustion	MoWPc		0.088	kmoles/kg fuel
	Moles of Moisture in air	MoWA		0.03	kmoles/mole dry air
	Excess Air at AH inlet	XpAe		23.4	%
	Excess Air at AH outlet	XpA		36.81	%
	Moles wet gas per mass fuel at AH inlet	MoFge		0.39	kmoles/kg fuel
	Moles wet gas per mass fuel at AH outlet	MoFg		0.43	kmoles/kg fuel
	Mass of dry air at AH inlet	MqDAe		4.02E-04	kJ/kg
	Mass of dry air at AH outlet	MqDA		4.45E-02	kJ/kg
	Mass of wet air at AH inlet	MqAe		4.11E-04	kJ/kg
	Mass of wet air at AH outlet	MqA		4.55E-04	kJ/kg
Flue gas Products					
	Wet Gas from fuel	MqFgF		3.59E-05	kJ/kg
	Moisture from H2O in Fuel	MqWF		5.52E-06	kJ/kg
	Moisture from hydrogen in the fuel	MqWH2F		2.01E-05	kJ/kg
	Moisture in air at AH inlet	MqWAe		8.89E-06	kJ/kg
	Moisture in air at AH outlet	MqWA		9.85E-06	kJ/kg
	Total Moisture in flue gas at AH inlet	MqWFge		3.45E-05	kJ/kg

	Parameter	Notation	Basic Equation	Value	Unit
	Total Moisture in flue gas at AH outlet	MqWFg		3.55E-05	kJ/kg
	Total Wet flue gas weight at AH outlet	WqFge		4.46E-04	kJ/kg
	Total Wet flue gas weight at AH inlet	WqFge		4.91E-04	kJ/kg
	Air heater(AH) leakage rate	A1		9.99E+00	%
	Dry flue gas weight at AH inlet	MqDFge		4.12E-04	kJ/kg
	Dry flue gas weight at AH outlet	MqDFg		4.56E-04	

Calculation of losses and Efficiency of the boiler

		parameter	Symbol	Basic Equation	Calculation	Value	**Unit**
1	***Dry Gas loss calculation***						
		Flue gas temperature at AH out let	TFgk	273.15+Tk		394.49	K
		Flue gas temperature at AH out let	TFgF	1.8TFg+32		257.61	F
		Enthalpy of the dry air at TFg	HADg	$Co+C1TFgk+C2TFgk^2+C3TFgk^3+C4TFgk^4+C5TFgk^5$		101.12	KJ/Kg
		Air temperature entering to the boiler	TMnAEnK	273.15+TMnAEnK		309.15	K

Item		parameter	Symbol	Basic Equation	Calculation	Value	Unit
		Air temperature entering to the boiler	TMnAEnF	1.8TMnAEnF+32		96.8	F
		Enthalpy of the Dry Aur at TMnAEn	HADa			11.05	KJ/Kg
		Enthalpy of the Water vapor at TFgF	HWvg			188.88	KJ/Kg
		Enthalpy of the Water vapor at TMnAEnF	Hwva			20.47	KJ/Kg
		Enthalpy of Wet Air at TFg	HATFg	(1-MFrWA)HaDg+MFrWA*HVVvg		103.12	
		Enthalpy of Wet Air at TMnAEn	HAEn	(1-MFrWA)HaDa+MFrWA*Hwva		11.25	
		Mean Specific heat of hot air	MnCpA	(HATFg-HAEn)/TFgK-TMnAEnK)		1.0283	KJ/Kg K
		Mean Specific heat of wet Flue Gas	MnCpFg	ASME PTC4,5.19.12 curve		1.009	KJ/Kg K
		Corrected flue gas temperature	TFgc		273.99	134.44	C
		Temperature of Flue Gas AH outlet	TFgF	1.8TFgc+32	407.59	273.992	F
		Temperature of Flue Gas AH outlet	TFgK	273.15+TFgc		407.59	K
		Enthalpy of dry flue gas	HDFg			109.3	KJ/Kg
		Dry Flue Gas Loss	**QpLDFg**	**100MqDFge*HDFg**	4.50E+00	**4.503**	%

2	***Loss Due to the water from fuel***						
		Enthalpy of Water vapour at TFgF	HSt			2753.52	KJ/Kg
		Reference Air Temperature	TradF	1.8Trad+32		77	F
		Enthalpy of Water at Trad	HWRe	TradF+32		104.67	KJ/Kg

Item		Parameter	Symbol	Basic Equation	Calculation	Value	Unit
		Loss due to the water in fuel	**QpLWF**	**100MqWF*(HSt-HWRe)**	1.46E+00	**1.462**	%
3	***Loss Due to the water from combustion of H2 In fuel***						
		Loss Due to the water from combustion of H2 In fuel	**QpLH2F**	**100MqWF(HSt-HWRe)**	5.32	**5.324**	%
4	***Loss Due to the moisture in air***						
		Enthalpy of Water Vapor at TFg	HVVRs			206.21	KJ/Kg
		Loss Due to the moist air	**QpLWA**	**100MFrWDA*MqDAe *HVVRs**	0.18	**0.183**	%

Item		Parameter	Symbol	Basic Equation	Calculation	Value	Unit
5	***Loss due to the unburnt carbon in Residue***						
		Loss due to the unburnt carbon in Residue	QpLUbC	**33700*MpUbC/HHVF**	0.71	**0.714**	%
6	***Loss due to the surface radiation & convection***						
	Loss due to the surface radiation & convection		QpLSrc	Designed Value		**0.21**	%
7	***Loss Due to the unaccounted factors***						
	Loss Due to the unaccounted factors		QpLUm	Designed Value		**0.3**	%
8	***Sum Of Losses***		QpL			12.69	%
9	***Thermal Efficiency of Boiler HHVF Base***		**EFH**	**100-QpL**	**87.30**	**87.3**	%
10	***Efficiency of Boiler LHVF Base***		**EFL**	**EFHxHHVF/LHVF**	**92.32**	**92.23**	%

6.4 Calulation of the other solid fuel burner efficencies by Indirect method using reference 24

These burner efficency calculation is a simplied calculation comparied to the section 6.2 coal burner calculation.There are many assumption to calculate the burner efficency as describe below.The reference for this calculationis is reference [24]

The following Calculation is done for the data set of the Coal Burner 1 Table 02 of Annex 02.

The compositions of the fuel for the 100kg of fuel are calculated using the atomic weight of the components.

Table 6.4: The compositions of the fuel for the 100kg of fuel

Composition of the fuel/(%)	percentage/%	Weight for 100kg of fuel	Moles for 100kg of fuel
C	65	60.00	5.00
H	3.8	3.80	0.32
N	1.5	1.50	0.13
O	6.2	6.20	0.52
S	0.5	0.50	0.04

1. Calculation of the energy Input to the Burner

Average Fuel Consumption Rate = 35.71 kg/h

Gross Calorific Value of Coal = 43 MJ/kg

Energy Input to the Boiler = GCV x Fuel Consumption rate (6.63)

= 43x35.71 MJ

= <u>1443.57 MJ</u>

2. Calculation of Theoretical Air Ratio

The balance equation of fuel burning is as follows.

$$CH_xO_yS_z \ + \ (1+\frac{(x-2y}{4}+z)\ (O_2 + 3.7\ N_2 \longrightarrow CO2 \ + \frac{x}{2}\ H_2O + 3.76(1+\frac{(x-2y}{4}+z)\ N_2 + zSO_2$$

From above equation, theoretical Air requirement is defined as follows

Theoretical Air Requirement, TA

$$= \frac{\{\left(1+\frac{x-2y}{4}+z\right)(137.28)\}}{(12+x+16y+32z)} \qquad [24](6.64)$$

$$= \frac{\{\left(1+\frac{0.702-2x0.072}{4}+0.003\right)(137.28)\}}{(12+0.702+16x0.072+32x0.003)}$$

= 9.55 kg of air/kg of fuel

3. Calculation of the Percentage of Excess Air Supplied

Percentage of excess air supplied, EA

$$= \frac{(O_2x100}{(21-O_2})TA \qquad (6.65)$$

$$= \frac{(8.8x100}{(21-8.8})X9.55$$

= 72.37 %

4. Calculation of the actual mass of Air Supplied

Actual mass of Air Supplied ,AAS

$$= (1+\frac{EA}{100})\ TA \qquad [24] \quad (6.66)$$

$$= (1+\frac{72.37}{100})x\ 9.55$$

= 16.46 kg of air/kg of fuel

6.4.1 Calculation of the losses of the burner

i. Percentage heat loss due to dry flue gas

Dry Flue gas loss $= \frac{mC_p(T_f - Ta)100}{GCV\ of\ Fuel}$ [24](6.67)

Where Cp- Specific Heat of Flue Gas , 0.23 Kcal/kg°C [24] and Assume that flue gas Cp value not changed to different flue gases in different temperatures

M –mass of CO_2 +Mass of SO_2 +Mass of N_2 + mass of O_2

T_f – Flue Gas Temperature ,°C

T_a – Ambient Temperature ,°C

Mass of the CO2 +SO2+N2+O2 in flue Gas, **m** $= \frac{.65x44}{12} + \frac{.005X64}{32} + 0.015 + \frac{(8.8)x23}{100}$

m = <u>16.47 kg/kg of fuel</u>

Dry Flue gas loss $= \frac{16.47x0.23x(140-35)100}{5400}$

= **<u>9.0 %</u>**

ii. Percentage heat loss due to evaporation of water formed due to H2 in fuel

Evaporation of water formed due to H2 in fuel $= \frac{[9 \text{ x H2 } \{584 + \text{Cp } (\text{Tf} - \text{Ta})\} * 100]}{\text{GCVfuel}}$

[24](6.68)

Where,

Cp = specific heat of superheated steam, 0.45 kCal/kg°C [24]

Assume that the specific heat of the superheated steam is same for all boilers this calculation

H2 = Percentage of H2 in 1 kg of fuel

GCV = Gross Calorific Value of Fuel,(kCal/kg)

Tf = Flue Gas Temperature, °C

Ta = Ambient Temperature, °C

Evaporation of water formed due to H2 in fuel $= \frac{[9 \text{ x } 3.8 \{584+.45\ (140-35)\}*100]}{5400}$

$= \underline{4.0\ \%}$

iii. Percentage heat loss due to evaporation of moisture present in fuel

Percentage heat loss due to moisture present in fuel

$$= \frac{[M\{584+ Cp\ (Tf-Ta)\} \text{ x } 100]}{GCVfuel}$$

[24](6.69)

Where

M = percent moisture in 1kg of fuel

Cp = specific heat of superheated steam ,0.45 kCal/kg°C [24]

GCV = Gross Calorific Value of Fuel,(kCal/kg)

Tf = Flue Gas Temperature, °C

Ta = Ambient Temperature, °C

Assume that the specific heat of the superheated steam is same for all boilers this calculation

Percentage heat loss due to moisture present in fuel

$$= \frac{[7\{584+ .45\ (140-35)\} \text{ x } 100]}{5400}$$

$= \underline{0.82\ \%}$

iv. Percentage heat loss due to moisture present in air

Percentage heat loss due to moisture present in air

$$= \frac{AAS\ Humidity\ Factor\ Cp\ (Tf - Ta)}{GCV\ of\ Fuel} 100$$

(6.70)

Where,

AAS = Actual mass of Air supplied, kg of air/kg of fuel

Cp = specific heat of superheated steam ,0.45 kCal/kg°C [24]

GCV = Gross Calorific Value of Fuel,(kCal/kg)

Tf = Flue Gas Temperature, °C

Ta = Ambient Temperature, °C

Assume that relative humidity of the intake air is 50 % ,

Humidity Factor(HF), kg of water/kg of dry air – 0.014 kg of water/kg of dry air at the RH 50% from the ref [26] or psychometric chart

Percentage heat loss due to moisture present in air

$$= \frac{16.46x0.014\ \ x0.45\ (140-35)}{5400} 100$$

= <u>0 %</u>

If the HF or RH change much this loss values is zero. There is no much impact this loss to total losses.

v. Percentage heat loss due to unburnt fuel in fly ash

According to the reference [25], normal fly ash amount is 30% and bottom ash amount is 3%. In this data set the bottom ash amount and fly ash amount per kg of fuel is not measured and that valued are assumed as above mentioned amounts. The calorific value of fly ash is to be taken as 2% of the GCV of Fuel and the calorific value of bottom ash are to be taken as 4% of the GCV of Fuel according to the reference [26] data

fly ash amount of 1kg of coal = 0.3 kg

GCV of fly ash = 5400x2%

= 105.09 kCal/kg

Percentage heat loss

$$\text{unburnt fuel in fly as} = \frac{\text{Total ash collected kg of fuel burnt xGCV of fly ashx 100}}{\text{GCV fuel}} \tag{6.71}$$

$$= \frac{0.3\ \text{x}105.09\text{x}\ 100}{5400}$$

= <u>0.01%</u>

vi. Percentage heat loss due to unburnt fuel in bottom ash

bottom ash amount of 1kg of coal = 0.03 kg

GCV of the bottom ash = 5400x4%

= 210.18 kCal/kg

Percentage heat loss unburnt

$$\text{fuel in bottom ash} = \frac{\text{Total ash collected kg of fuel burnt xGCV of Bottm ashx 100}}{\text{GCV fuel}} \tag{6.72}$$

$$= \frac{0.03\ \text{x}210.18\text{x}\ 100}{5400}$$

= <u>0%</u>

vii. Percentage heat loss due to radiation

Percentage heat loss due to radiation and unaccounted losses It is estimated that radiation, unburnt CO losses and others are to be 2% of total energy[24].

ix. Calculating the blow down losses

Percentage Loss due to the blow down = $\frac{Sf}{(Sb-sf)}$ (6.73)

Where

S_f – TDS level of Feed water in ppm-106 ppm

S_f – TDS level water inside the boiler in ppm-1019 ppm

Percentage Loss due to the blow down = $\frac{106}{(1019-106)}$

= 0%

Total Losses = 9%+ 4.0% + 0.82 + 0 + 0.01%+0 + 2%

Total Losses = **15.83 %**

Percentage thermal efficiency = (100- Total losses) (6.74)

= 100-15.83

= **87.2%**

Table 6.5: Calculated losses and total efficiecy of the indirect method

	Parameter	Coal Boiler 1	Coal Boiler 2	Bio Mass power station 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	coconut husk Boiler New 1	Coconut husk Boiler 2	Coal Boiler 3	Fire Wood Boiler
	Year Of Installation	1985	1994	2014	2014	2010	2014	2005	2007	2013
1	Percentage heat loss due to dry flue gas	9	11.08	12.50	18.24	17.69	3.68	5.91	4.04	11.56
2	Percentage heat loss of evaporation of water formed due to H_2 in fuel	4.00	4.45	7.41	9.32	7.79	7.39	7.87	3.41	10.79
3	Percentage heat loss due to evaporation of moisture present in fuel	0.82	1.95	6.02	2.37	2.70	1.37	1.46	0.68	4.99
4	Percentage heat loss due to moisture present in air	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Percentage heat loss due to unburnt fuel in fly ash	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.03
6	Percentage heat loss due to unburnt fuel in bottom ash	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04
7	Percentage Unburned Fuel Loss	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Percentage heat loss due to radiation & others	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Total Losses		15.83	**19.47**	**27.94**	**31.93**	**30.18**	**14.43**	**17.24**	**10.12**	**29.34**
Percentage Efficiency		**84.17**	**80.53**	**72.06**	**68.07**	**69.82**	**85.57**	**82.76**	**89.88**	**70.66**

CHAPTER 07:RESULTS & DISCUSSION

7.1 Introduction

The improvement of the boiler is progressing drastically all over the world due to improvements in energy efficiency. They have used much complicated operating system such as SCADA and steam generation systems such as ultra-critical steam generations. The Significant parameters of the burner efficiency have to be addressed to reduce the loss in every possible way. In a country like Sri Lanka, many of the industries are not concerned about efficiency based improvement. It is bad practice of the energy conservation perspectives as a fuel exporting country.

7.2 Results and Discussion of the Coal Power station 1 Burner Indirect Method using ASME Standard PTC-4

Calculation is done based on the ASME standards PTC-4. The parameters are changed and it observed the variations in efficiency which is plotted as below.

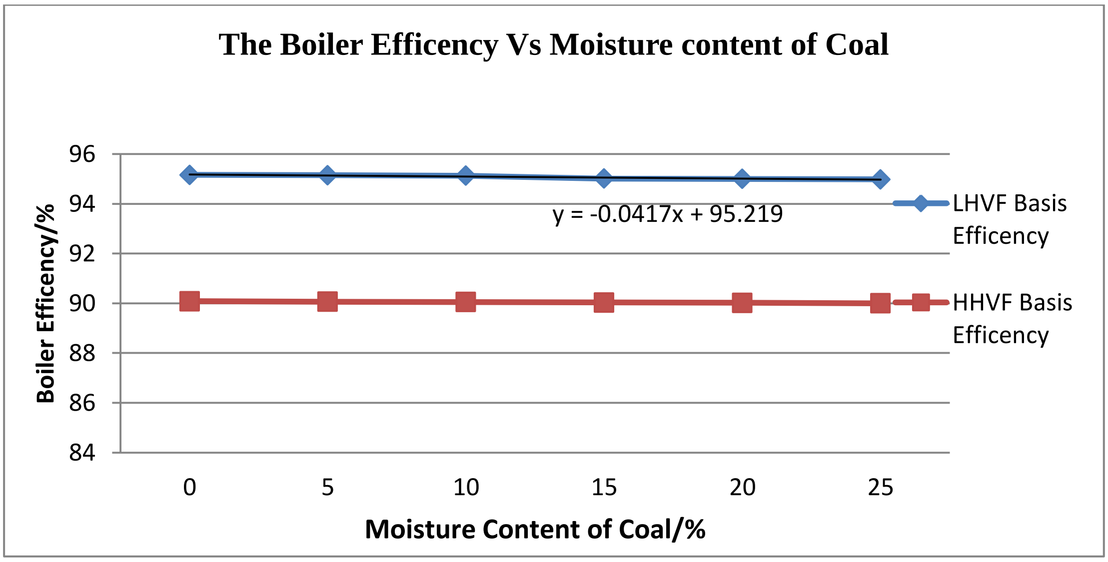


Figure 7.1: The Boiler effiency Vs Moisture Content of coal in Coal Power Station 1

In the Figure 7.1, the moisture content of the fuel is varied and it checks the efficiency values. This result gives the guide line to variation of moisture content.

Figure 7.1 show that the moisture content will not have much impact on efficiency. Actually, coal contains 6-10% moisture, which is not much compared to bio mass. But in the actual conditions, the GCV will be changed according to the carbon content. Hence, the actual variation much more than this value.

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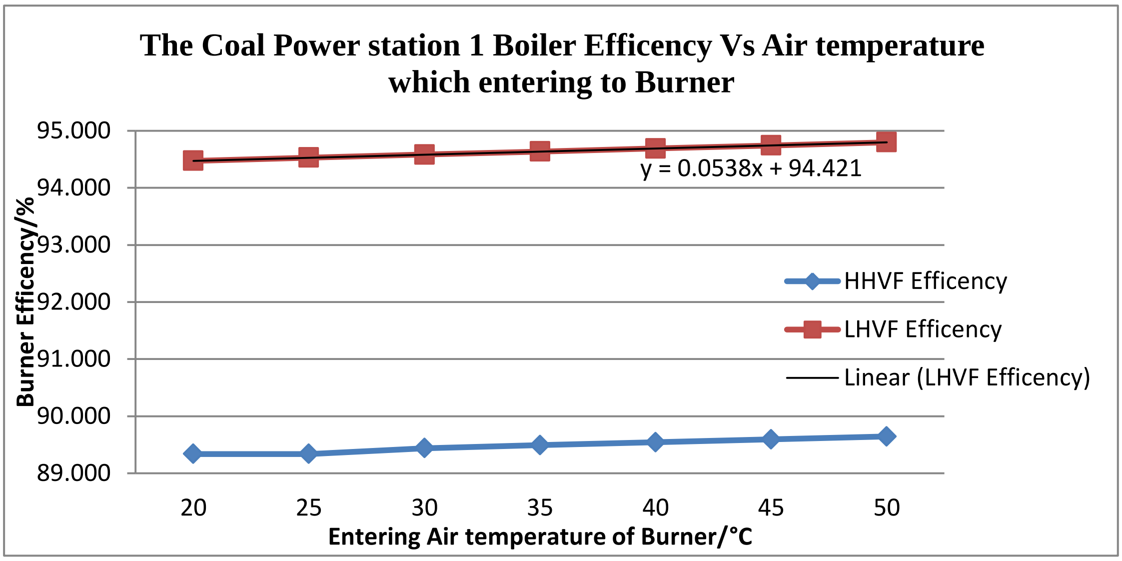


Figure 7.2 : Coal Power Station 1Boiler effiency Vs air temperature entering to burner

The entering air temperature is varied by keeping the other parameters constant to get the variation of the efficiency. This variation is much important because many locations the inlet air temperature is neglected. The efficiency will change by 0.05% change when the temperature of air of air increases by 1°C according to the Figure 7.2.

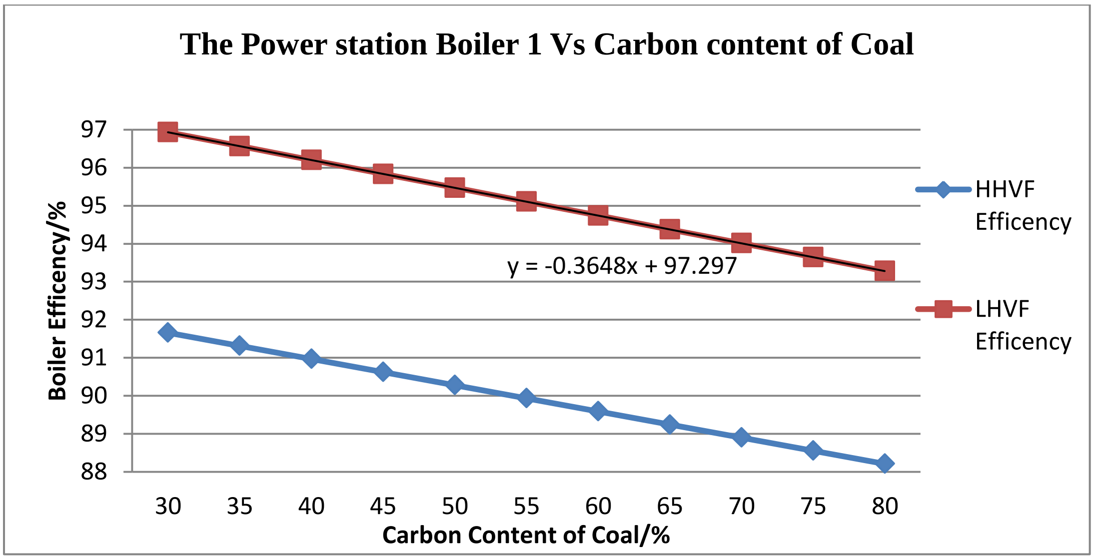


Figure 7.3 : The Coal Power Station 1 Boiler effiency Vs Carbon content of coal

The corbon contenent of the fuel is chaged by keeping the other parameters constant to get the actual variation of efficiency. The efficiency shall be incresed when the carbon content is increased. Figure 7.3 show that the carbon content will have much impact on efficiency under the constant GCV of the fuel. But at the actual condition, the GCV will be change according to the carbon content varied. Hence, actual variation is much higher than these results. The efficiency variation for 1% change in carbon content is 0.36 %.

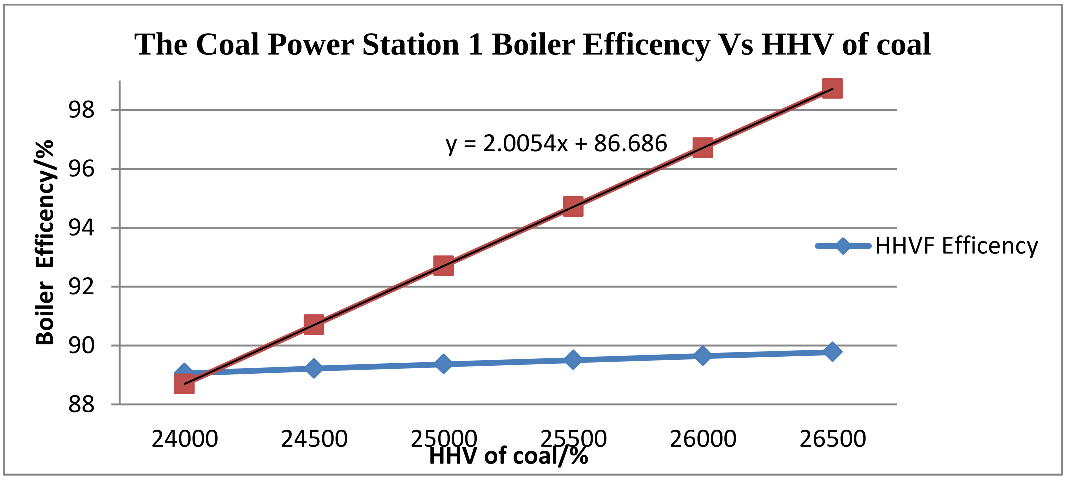


Figure 7.4 : The Coal Power Station 1 Boiler effiency Vs HHV of coal

The following graph shows that the variation of the efficiency with HHV of the fuel by keeping all other parameters constant. When HHV increases efficiency of HHVF is showing small change but LHVF efficiency shows the higher variation due to the selection of HHV or LHV. Figure 7.4 shows that when the GCV is increased the efficiency is increased drastically. For 500 kCal, there is a 2% increase in efficiency. Actually, this scenario happened when the carbon content of the fuel increases as shown in Figure 7.3.

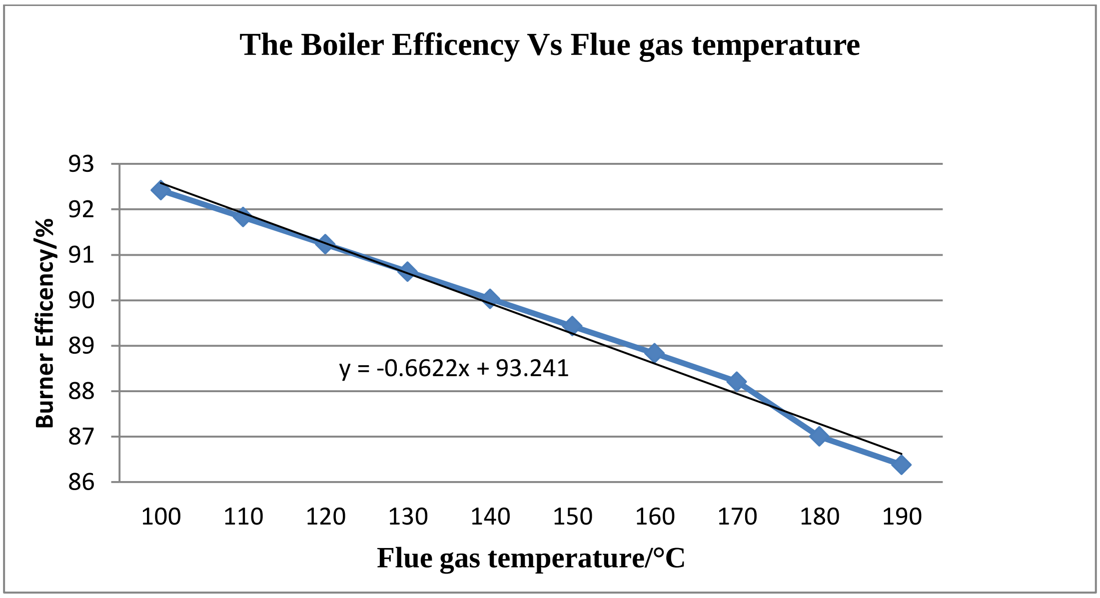
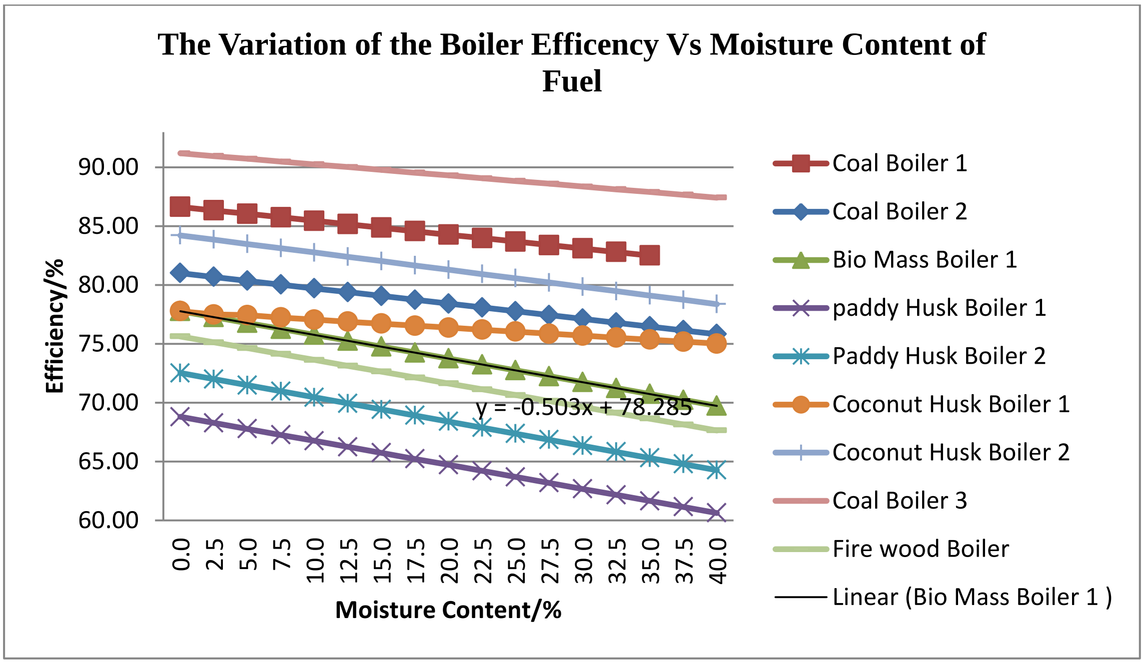


Figure 7.5 : The Coal Power station 1 Boiler effiency Vs Flue gas temperature

As a norm, expert in the boiler believes that the efficiency will be drop when the flue gas temperature is increased. Because when flue gas temperature increased the heat loss in increased though the flue gas. The graph 7.5 shows slight variation of efficiency with flue gas temperature increasing. At the practical situation, it has to be control flue gas temperature between middle ranges to avoid adverse effect such as condensation on chimney, loss in efficiency. Figure 7.5 shows the variation efficiency vs flus gas temperature and it has a significant impact on efficiency which is 0.66% variation for 1°C.

7.3 Results and Discussion of other solid fuel boiler efficencies by Indirect method using reference 24

The calculation is done in section 6.4 and parameters chenge are done to identified the significant parameter that effecting to the burner efficiency. The results are discussed case by case as describe below.



7.6 : The Variation of the Boiler Efficency Vs Moisture Content of Fuel

The moisture content of the fuel changes to see the variation of efficiency. The other parameters are kept constant. The moisture content of the fuel increases the efficiency decreases 0.5 % for decrease in moisture content 2.5 % according the Figure 7.6. This is a significant variation to efficiency.

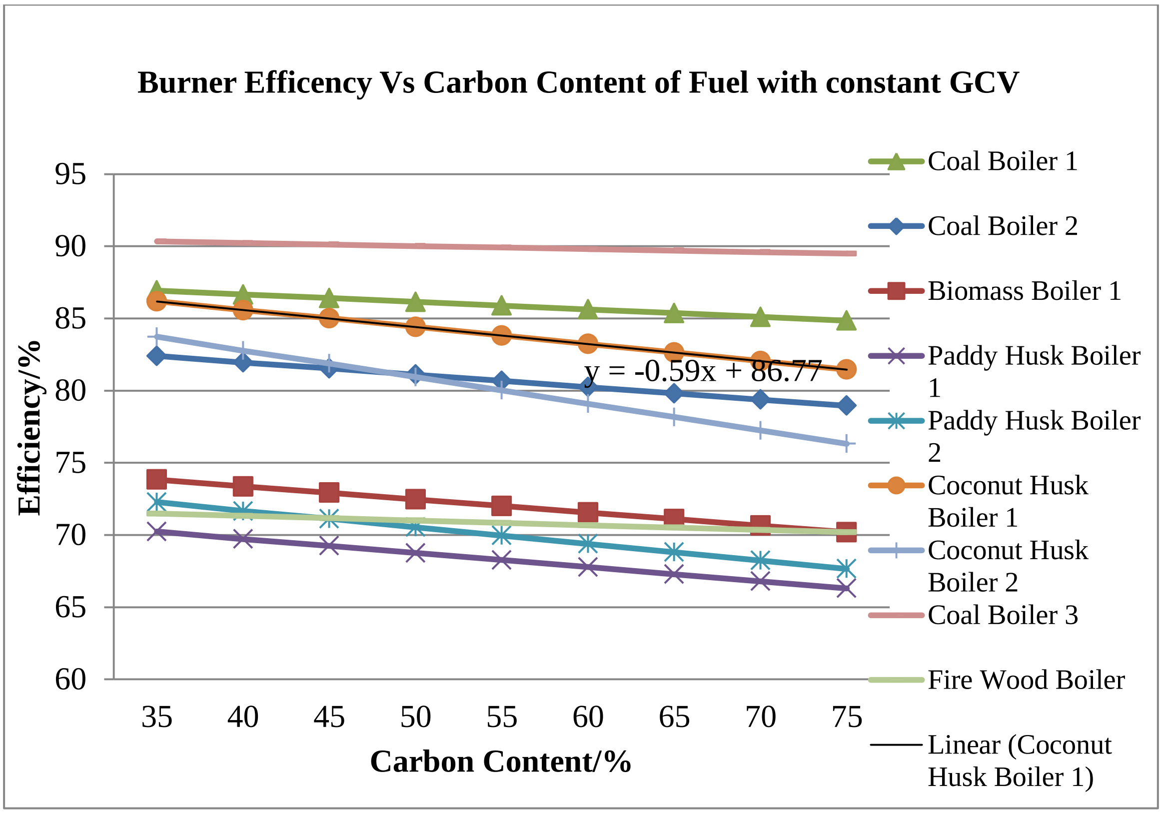


Figure 7.7 : Boiler Efficency Vs Carbon Content of Fuel with constant GCV

In the Figure 6.1, the moisture content of the fuel is varied and it checks the efficiency values. This result gives the guide line to variation of moisture content.

Figure 7.7 show that the moisture content will not have much impact on efficiency. At the actual condition, the GCV will be change according to the carbon content varied. Here, the GCV and other all parameters kept constant to analyze. The Figure 7.7 shows the 0.59 % efficiency variation for a 1% variation of carbon content at constant GCV. This is a parameter with a heavy impact with constant GCV. The coal power station 1, under indirect method does not show this much of a variation with constant GCV. Normally, GCV of the fuel changes when the carbon content is changed, and then the variation to efficiency will be much more.

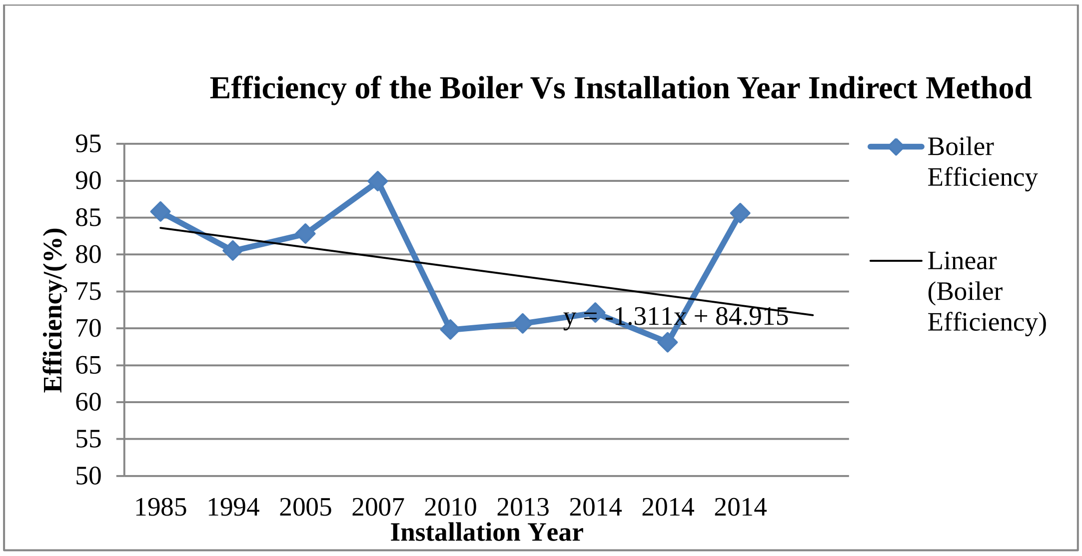


Figure 7.8 : Thermal Efficiency of the Boiler Vs Installation Year Indirect Method

These boilers are installed in different years and sometimes, there may be variation of the efficiency with installation year. It very difficult to identified the clear variation according to the Figure 7.8.

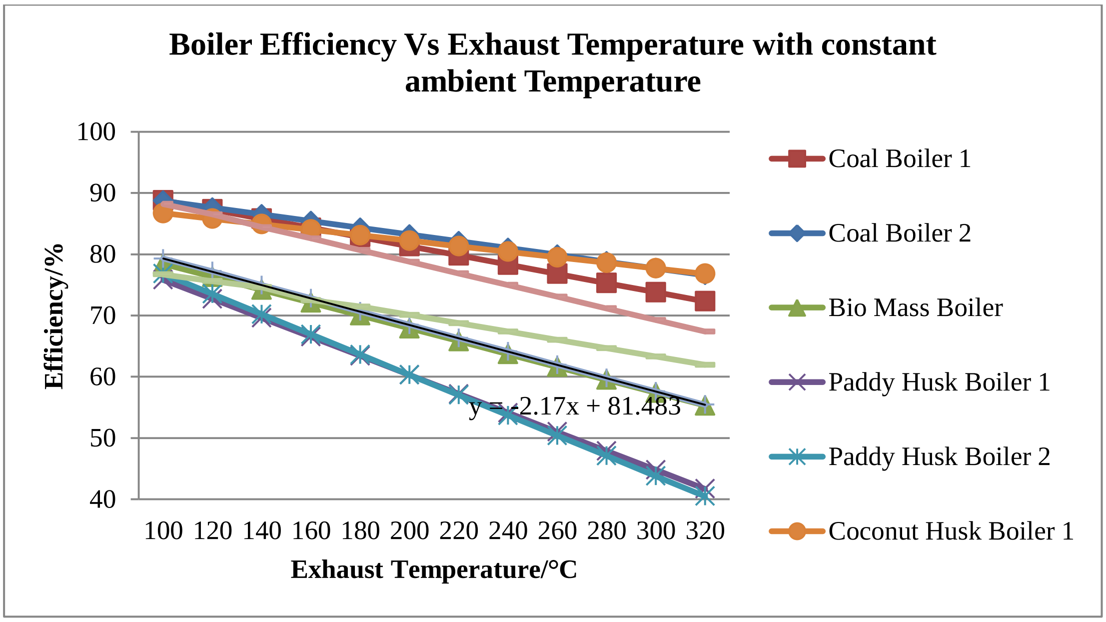


Figure 7.9 : Boiler Efficiency Vs Flue gas Temperature with constant ambient Temperature

The efficiency will be drop when the flue gas temperature is increased. Because when flue gas temperature increased the heat loss in increased though the flue gas. The graph 7.9 shows slight variation of efficiency with flue gas temperature increasing. At the practical situation, it has to be control flue gas temperature between middle ranges to avoid adverse effect such as condensation on chimney, loss in efficiency. A maximum amount of 2.17% in efficiency reduces for 1°C increase in exhaust temperature and this is a very significant variation. This is also the location improvement is applicable.

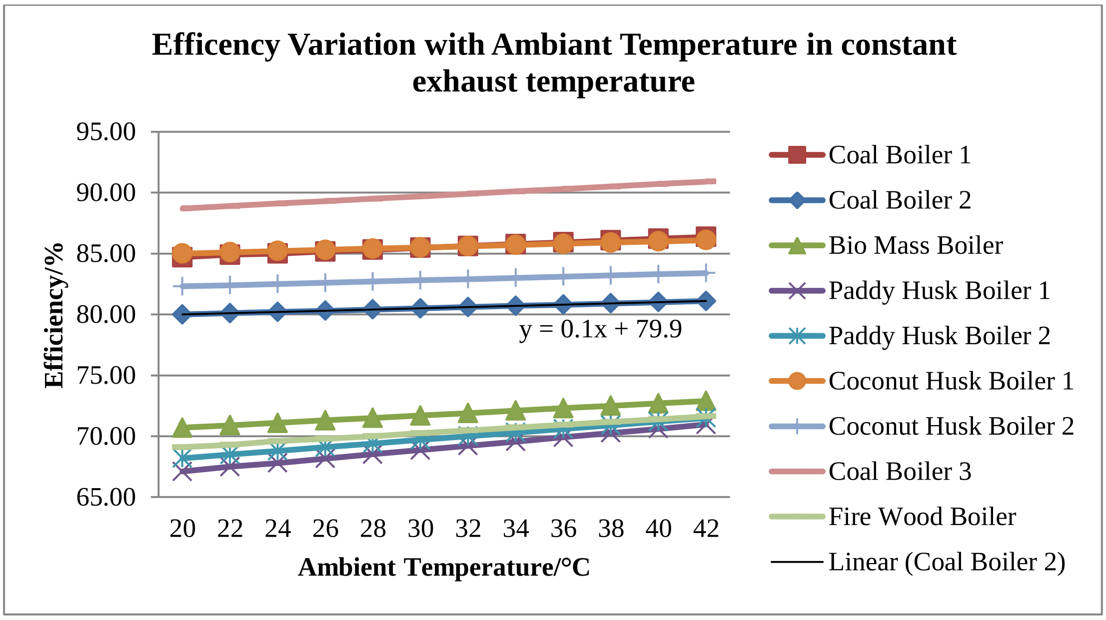


Figure 7.10 : Boiler Efficency Variation with Ambiant Temperature in constant exhaust temperature

The ambient air temperature is varied by keeping the other parameters constant to get the variation of the efficiency. This variation is much important because many locations the ambient air temperature is neglected as important factor. The efficiency variation of 0.1% with 1°C ambient temperature in constant exhaust temperature is shown in Figure 7.10. This variation is very important in the improvement of the boiler process as described in this chapter.

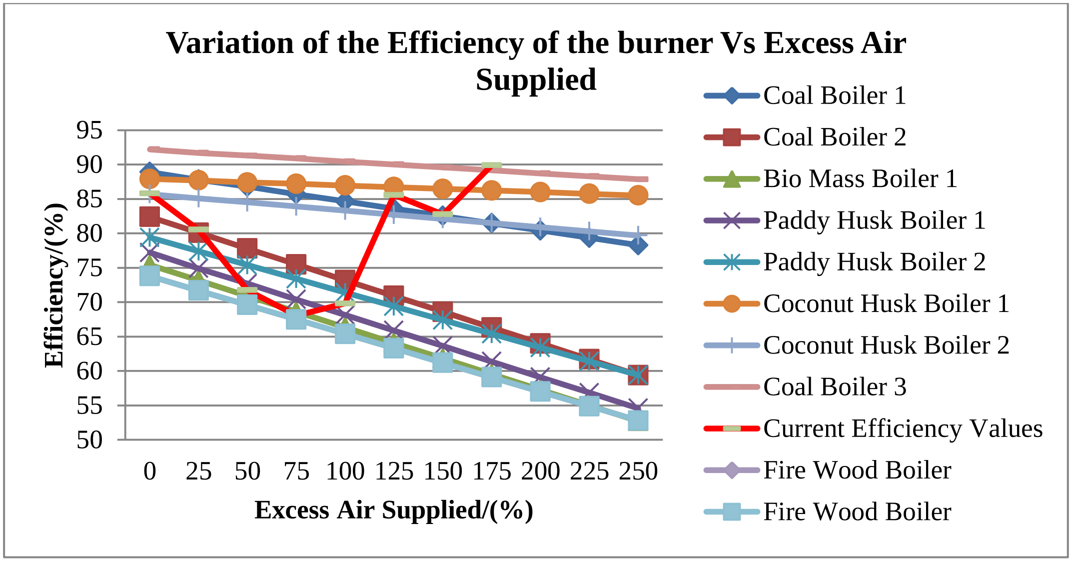


Figure 7.11 : Variation Efficiency Vs Excess Air Supplied

The Excess air percentage is varied by keeping the other parameters constant to get the variation of the efficiency. This variation is much important to keep the efficiency. The Figure 7.11 shows the efficiency variation with excess air supplied and 0.6% to 2.26% of efficiency reduction is there for a 1% increase in excess air supplied. There shall be efficiency drop, when the excess air amount increases due to heat loss through excess air. This is also a significant change to consider in the improvement process.

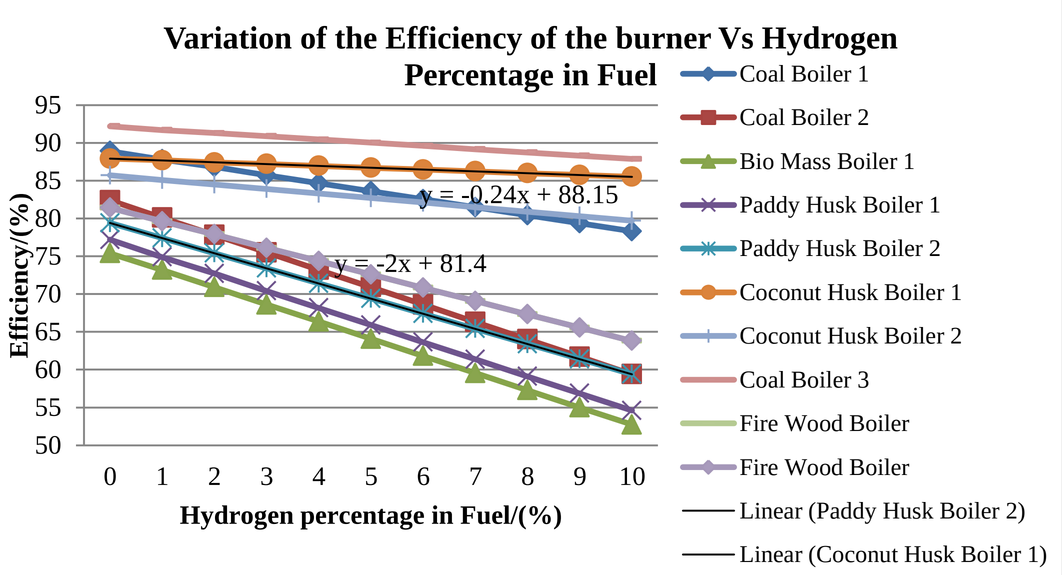


Figure 7.12 : Variation of the Efficiency Vs Hydrogen Percentage in Fuel

The Hydrogen percentage in fuel is varied by keeping the other parameters constant to get the variation of the efficiency. Normally, when Hydrogen percentage is changed, calorific value of fuel is also changed. But, at these conditions, other all parameters are kept constant. The change in hydrogen percentage variation will result in 0.24% -2% efficiency changes for a 1% hydrogen percentage as shown in Figure 7.12. In the site conditions, It is not practical to improve using this parameter.

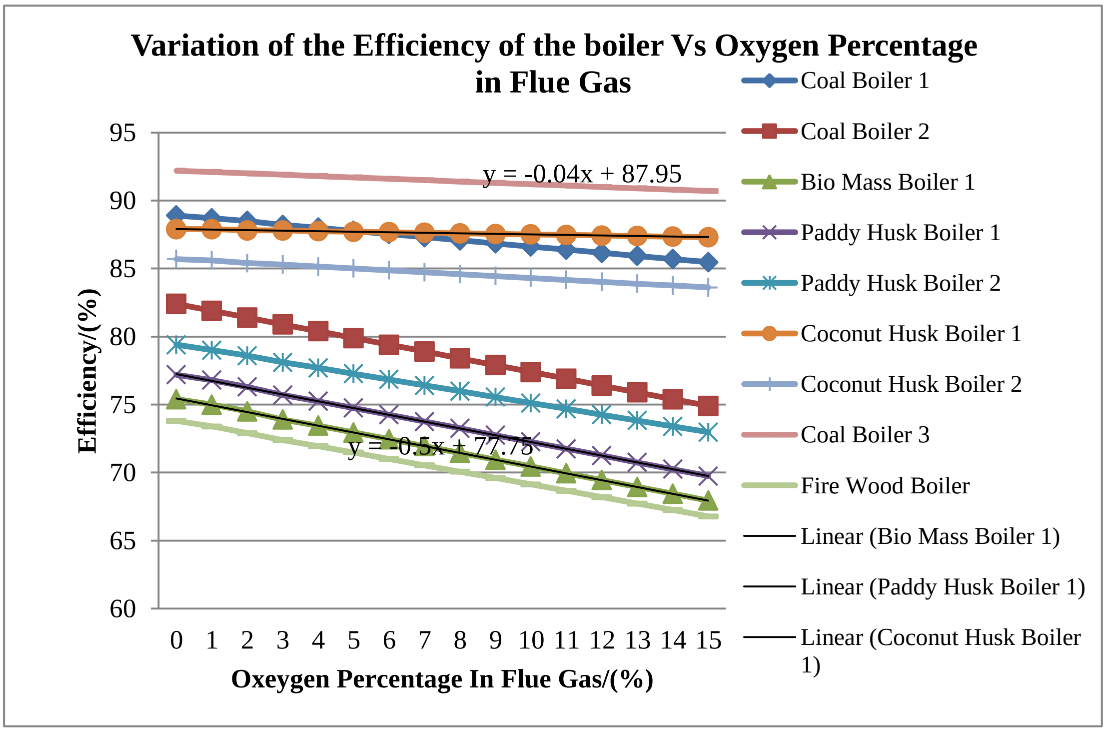


Figure 7.13 : Variation of the Efficiency of the boiler Vs Oxygen Percentage in Flue Gas

The Hydrogen percentage in fuel is varied by keeping the other parameters constant to get the variation of the efficiency. Normally, when Hydrogen percentage is changed, calorific value of fuel is also changed. According to the Figure 7.13, the efficiency drop for an increment of 1% oxygen in flue gas will be about 0.24 %-

2.26 % .This is also a significant variation to consider when improving the process. From Figure 7.9 to Figure 7.13 and Figure 7.7 shows same variation pattern of efficiency as two groups of boilers. Low efficiency group is consisting of coal boiler 2, biomass boiler 1, faddy husk boiler 1 and faddy husk boiler 2. High efficiency group is consisting of coal boiler 1, coal boiler 3, coconut husk boiler 1 and coconut husk boiler 2. The reason for the law efficiency group is the high flue gas loss compared to the other boiler and loss due to the moisture present in fuel from table 06.

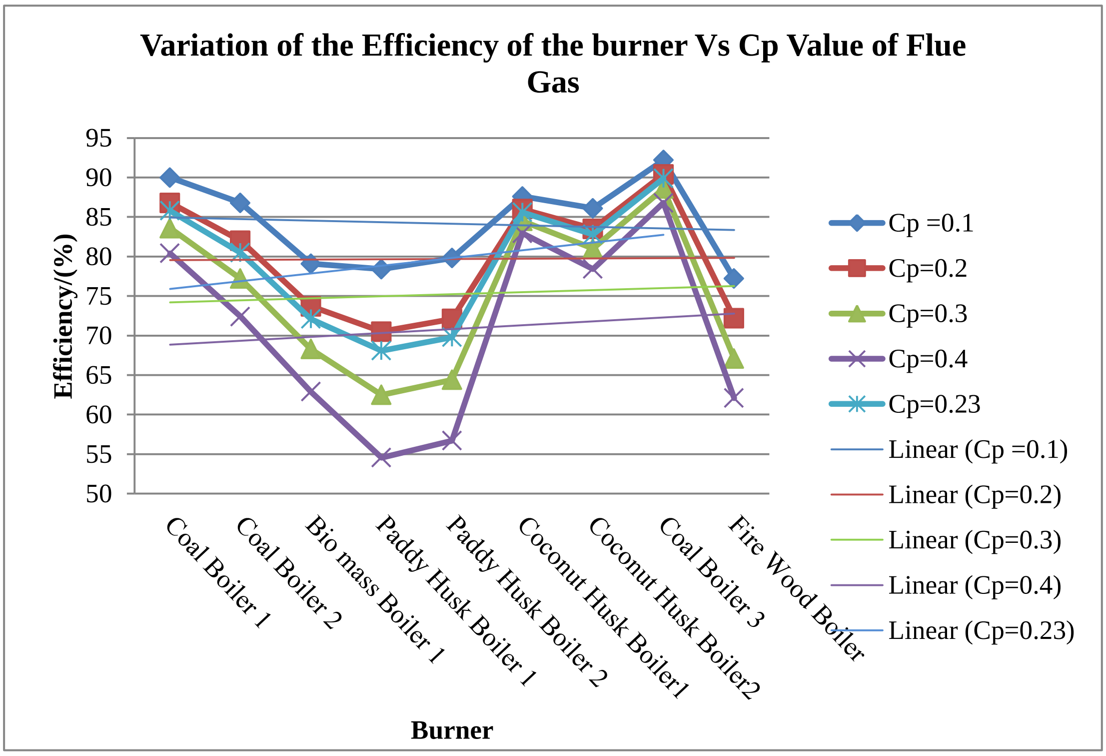


Figure 7.14 : Variation of the Efficiency of the boiler Vs Cp Value of Flue Gas

The Figure 7.14 can be used for checking the reliability of the assumptions made to the calculation of efficiency for the Cp value of flue gas. At calculation, the Cp Value is assumed as 0.23 kJ/kg.K. The maximum variation of efficiency shown by paddy husk boiler 1 is from 78.4% to 54.7% when the specific heat capacity, Cp changes from 0.1 to 0.4 kJ/kg.K. This is a higher impact on the results if Cp of the flue gas deviates from assumed values.

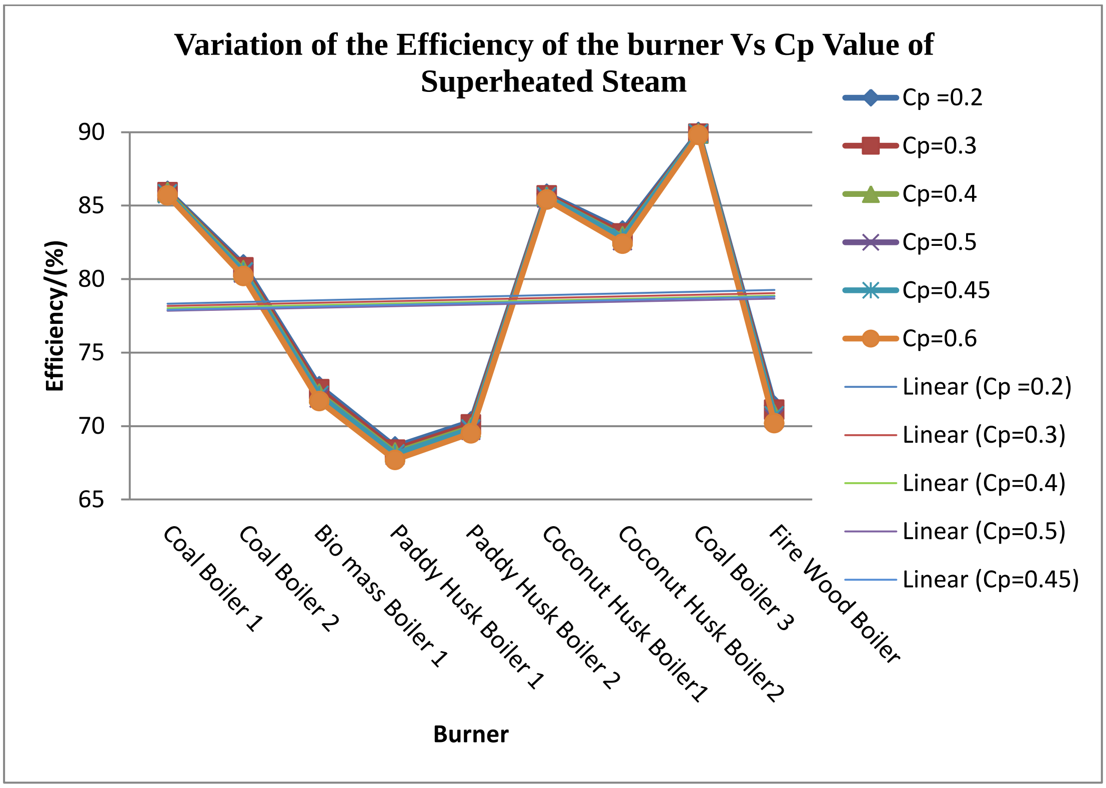


Figure 7.15 : Variation of the Efficiency of the boiler Vs Cp Value of Superheated Steam

The Figure 7.15 can be used for checking the reliability of the assumption made to the calculation of efficiency for the Cp value of superheated steam. At calculation, the Cp Value of superheated steam is assumed as 0.45 kJ/kgK**.** The maximum efficiency change is 1% for bio mass boiler 1 when Cp changes 0.2 to 0.6 kJ/kg.K. This parameter does not impact the results.

7.4 Comparison Direct method results and Indirect method results

The result of the direct method shows only the efficiency values and it is not represent which location is having the problem. This method gives an idea of the efficiency only. It is a simple calculation and these parameters are difficult to find out at the site conditions. If the accuracy of that parameter is less, the efficiency values are not reliable. There are some assumptions and it can’t do any analysis due to the availability of the less parameter to check whether there is any significant impact by the assumptions.

The indirect method used for calculation of efficiency of coal burner at power station. This calculation is comprehensive calculation and it reflects the all losses separately to the analyzer to decide what type of improvement shall be take placed.

Table 7.1: Comparison of direct method results and indirect method results

Boiler Name	Direct Method Thermal Efficiency/(%)	Indirect Method Thermal Efficiency/(%)
Coal Power Station 1	94.45	87.30
Bio mass Power Station 1	90.62	72.06
Coal Boiler 1	76.56	85.82
Coal Boiler 2	79.88	80.53
Paddy Husk Boiler 1	78.88	68.07
Paddy Husk Boiler 2	79.62	69.82
Coconut Husk Boiler 1	80.47	85.57
Coconut Husk Boiler 2	77.41	82.76
Coal Boiler 3	58.95	89.88
Fire Wood Boiler	82.78	70.70

According to the above table 07 and Figure 7.16, shows that the indirect method results are different the direct methods results. Because, the indirect method is the much descriptive results compared to the direct method and direct method is rough estimation only. The reason to this variation is the accuracy of the reading which may be less such as fuel flow rate, temperatures of product, etc. The value of the indirect and direct method efficiencies shall be same.

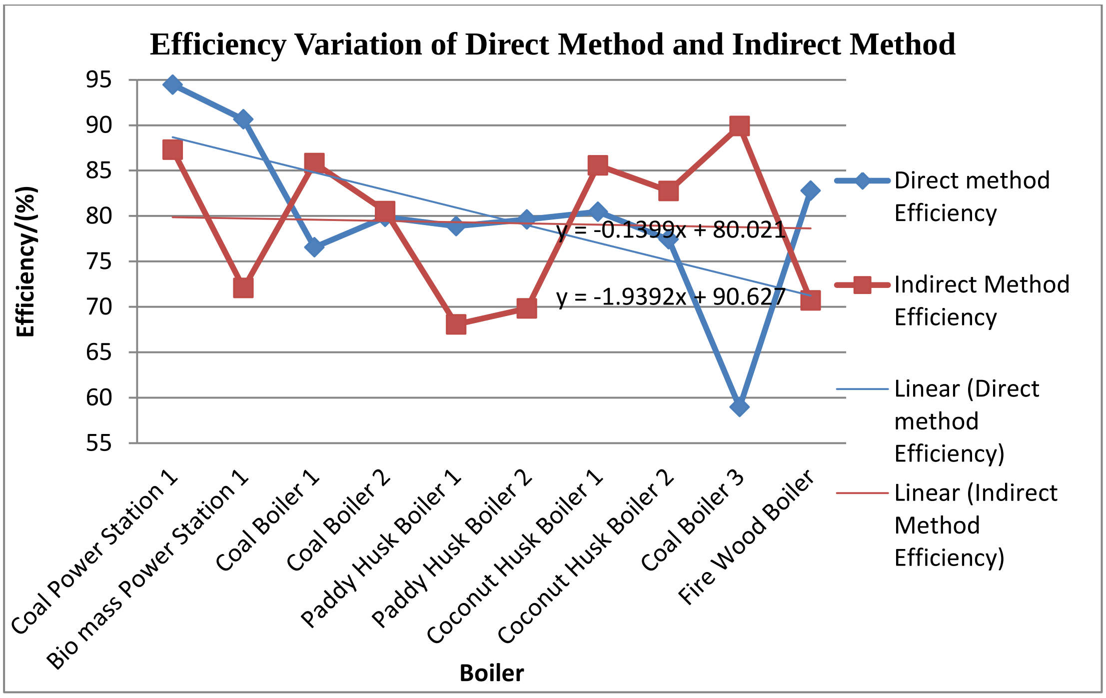


Figure 7.16 : Efficiency Variation of Direct Method and Indirect Method

7.5 Identification of significant parameter

The effcency of the boilers are calculated in both methods and it shows the deviation of two values as shown in Table 07. The variations of the efficiency of boiler are shown in Figure 7.16. The direct method efficiency variation and indirect method efficiency variation are identified in graph 7.16

The indirect method is proven as the more accurate method than the indirect method.Specially, the fuel feeding rate is difficult to measure in site conditions and complicated instrument is required to measure it. The fuel feed rate effect the results highly according to the calcualtion. This is because of inaccurate data used without considering the losses in the direct method. But, in indirect method, many data with high accuracy is used to calculate the efficency. Indirect method calculation use every loss that occurs from burner to get the final efficency. Normally, the indirect method is used to calculated the burner efficency and it is more accuate than the direct method. Direct method is an ajusted rough value to be reffered by plant operators. The direct method requires the less numbers of equipment and less numbers of parameters. It doesn’t give the idea to operator as to why the efficiency is lower. The main advantage of the indirect method is that it is giving the reason to the low efficiency.

7.6 Improvements for the Boilers

1. Effect of moisture content of the solid fuel

When the moisture content of coal increses the efficency of the burner decreses according to the the Figure and it is due to the absorbing of the heat by moisture. Hence, this graph shows that the moisture level will effect the performance of the solid fuel burner. The graph 7.1 shows a smaller variation but actually it may be higher than the value shown, because, this calculation is done by taking different graph values from reference 20 for the same moisture levels.

In the indirect method, the calculation is much more complex, but factors that effect the efficency can be modelled as shown in this chapter, Figure 7.1 to 7.6. This will help the plant management to decide what type of modification is required and requirement of the maintenance activities carreid out. The Effect of the moisture content of the fuel is 0.041-0.5% in efficiency drop per 1% increment in the moisture content. This is the clear guide line to improve the moisture content of the fuel. One option is to use a part of the exhaust flue gas to heat the fuel by sending them under the fuel stock to remove the moisture in fuel. The other option is to sent the flue gas through the radiator to heat air which in turn can be used to dry the moisturized fuel. Actually , the flue gas heat is wasted and it can be used for the above proposed method to improve the efficiency of the process.

2. Ambiant temperature

The burner efficency increses when the air temperature which feed to the buner, increses. According to the Figure 7.2 & 7.9, the efficiency gain is 0.1- 0.05 % for 1°C increment in ambient temperature. The mass flow rate of air will be inceased. When temperature of air goes up and efficency will also go up. It means that day time and dry season, burner effcency will be higher than other times. There are two options which are to mix the small amount of exhaust gas with inlet air or radiater can be used to heat the inlet air. The mixing of the exhaust gas should be done very carefully because it will effect the oxygen percentage of the inlet air. The exact amount of the exhaust gas has to be find out.

3. Carbon content of the fuel

Carbon content of the fuel is an identical property for the selected fuel. But the Figures 7.3 & 7.7 showing the importace of the carbon content of the fuel to the efficiency. It is recommended to select the proper fuel for the boiler that it is designed. As described in the section 7.7, when the carbon content of the fuel increases the GCV is also incresed. At the analysis stage, it is assumed the GCV is constant, that is why the efficiency reduces when the carbon content is increased.

4. Exhaust Temperature

The variation of the efficiency vs flue gas temperature is shown in Figures 7.5 & 7.9. The figure 7.5 shows that efficiency drop for a 1°C increment in flue gas is 0.66% and Figure 7.9 shows a 0.9 - 2.17 % variation for 1°C increment in flue gas. As an assumption, the ambient temperature is kept constant to analyse the variation. Flue gas temperature is the very significant parameter and It has high potential to improve the process. The flue gas can be used to heat the boiler feed water, heat the inlet air, remove the moisture in the fuel. The feed water heating is currenlty used by modern boiler system and some of the old boilers can be modified to heat feed water. The seperate boiler tubes can be used for this purpose accoring to the modified design. The other two method were explained above.

5. Excess Air Supplied to the Boiler

According to the Figure 7.11, the efficiency will drop by 0.6% - 2.26% for 25% in excess air supply. When, the excess air amount is inceased the heat loss will also be incresed due to the absorbtion of the heat generated at boiler by excess air. The present efficiency points are marked on the Figure 7.11 and it shows the efficiecy reduction with the increse of the excess air supply. The effciency drop is also significant and the excess air quantity should be controlled as per the design conditions. This can be done by controlling the forced draft fan. The flow can be controlled according the load conditions using the Variable Speed Drivers to change excess air amount in to the boiler. But it should be made sure that the oxygen amount sufficient for the burning of fuel.

6. The oxygen Percentage in Flue Gas

The high oxygen content in the flue gas gives the indication of amount of excess air supplied and it will increse the efficiency drop of 0.24%-2.26 % for a 1% increment in oxygen as shown Figure 7.13. The oxygen quantity can be controlled by the excess air control method itself.

7.7 The important variation in analysis

Figure 7.8 shows the variation of efficiency vs installation year, but the results can not be explain how it happened. This may be due to available fuel having high moisture content and as a results it decreses the efficiency.Actually, modern boiler shall have high efficiency values.

There are two majour assumptions for Cp value of Flue gas and superheated steam. The effect of the assumption is discussed as shown in the Figures 7.14 &7.15. According to the results, the Specific Heat Capacity of the flue gas has large impact on the efficiency but Cp value of superheated steam has no effect on the efficiency compaired to the Cp of flue gas.

According to the Figures 7.1 to 7.16, the coal burner efficiencies are loacted in the high efficiency range due to the low moisture content and paddy husk boiler located in lower efficiency range. Middle efficiency range is allocated to coconut husk burners. This shows the moisture content as the majour factor when compairing the result.

7.8 Other improvemets based on observations

The problems that are specific to individual boilers are listed below

- *Tea Factoryat Watawala*

Wet timber logs such as cashew and rubber are used. The sizes are 0.75m in length and 0.2m in diameter. It is much lager than the specified dimentions. In addition to that the moisture content of the logs is too high. Ash removing of the boiler is not done periodically. Feeding of bio mass to the boiler is not done in a consisitent and regular manner. The reason for this is lack of quaity controlling and monitoring of the boiler operation such as air to fuel ratio. The periodical maintenance is done by the agent of the boiler and it is done properly.

- *Tea Factory at Welioya*

Wet timber logs such as cashew and rubber are used. The moisture content of the logs is too high.The ash removing of the boiler is not done periodically. The feeding of bio mass to the boiler is not done in a consisitent and regular manner. The reason for this is lack of quaity controlling and monitoring of the boiler operation. The periodical maintenance is done by the agent of the boiler and it is done properly.

7.3 Suger Factory

This is a prime example for a place where low efficency is maintained due to very old boiler equipment. The reason for this is that the plant is reopened after a long absence of operation. This boiler was very old but it is used for variety of purposes such as power generation, machinary operation and suger extracting. The boiler can be oprated using bio mass and baggase which is the residue of the sugar production. In many places it can be seen that there are heat losses due to leaking and insulation damages. Many of the boiler tubes are damged and plugged and the boiler is not operating in it’s full capacity. Wet timber logs such as cashew, and Epil-Epil are used. The moisture content of the logs is too high. Properly dried timber can be arranged in the planning of the production and boiler operation. Drying of timber can be done easily by using the ample amount of sunlight which is present in this area and by the excess steam. The other biomass which is used for this burner is baggase and it also contains a high moisture content. Drying methods such as sunlight drying or heating by steam is recommended. The boiler maintenance is also an isuue for this plant due to high expences for spares, but enough time is available for the maintenance during the off season of suger cane. Spare parts and technology is not available due to the old age of machines and unavailability of documents. The exsisting stream tubines and boilers are heavily worn and are out of order. The repairing technology is very primitive and poor compaired to the available technology.

Steam drum water level controlling is not avalable and it is achived by the boiler operator manually. But, the automatic steam drum water level controlling is recomemded to improve the efficiency of the boiler. There are very old in-efficient induced draft and force draft fans which may cause improper air to fuel ratio.

Ash controlling is a very important factor in proper boiler operation, but the Higurana burner is consists of a basic ash collector which has to remove the ash manually as a bottom ash collecting and ash collecting mechanism is not available.

The boiler bufles are damaged heavily and it has to be repaired. At the boiler tubes, the shoot blowing action has reduced due to the leakages of steam from shoot blowers. Shoot blowers are fixed only for the two ends of the boiler tubes. A shoot blower at the middle of the tubes is recommended to improve the efficency of the burner.

The fire bricks are out of the required order which means that there can be pattern of the brick layer to insulate the boiler walls and some of them are damaged.

An automatic blow down system is recommended to the burner to reduce the unessary heat loss. The super heater is having severe problems because of tube bending due to the lack of steam adjument controlling to the superheater. Hence, the heat is stagnated on the superheater tube and they are deformed.

- *Bio mass power station 1.*

This is a newly installed and sophisticated burner and boiler system. It is working at it’s maximum performance. It is operated using a modern operation system called SCADA(Sequential Controlling and Data Aquirsition). The controlling part of the burner is good, but the biomass quality is not as. Because, biomass contains high moisture content even when a 20 days indoor stock is available. Different types of low calorific value biomass are fed into the burner during the times when the biomass collection is law.

- *Bio mass boiler in Beverages company at Ranala*

This is a newly installed boiler which runs on bio mass and there are no any low eficency issues, operation-wise. But, timber with high moisture content is used without controlling the moisture level. Sizes of the timber also has to be maintained to the specified level. Feeding of the bio mass shall be maintained according to the requirement.

7.6 Rice mills at Ampara

This rice mills also has many locations where heat loss is present and it affects the burner efficency.

Paddy husk feeding blower can not be changed acording to the load conditions at the working time and automatic feeding controller is recommended to improve the efficency.

From burner to boiler there are small gaps which may cause heavy heat loss from the system. Burner ash removing is very difficult with heat and it has to be done manually. The burner and the boiler are installed seperately which causes energy loss when flue gas moves from burner to boiler.

Feed water flow and steam drum water level have to be changed manually and it may cause abnormal conditions in steam geneation.

The boiler and pipes are not insulated to prevent heat loss to the environrment and its beter to have a proper insulation layer to prevent it.

The common bad practices and shortcomings that were observed in the above burners and hot water generators that may cause a reduction of performances are as follows.

- Wet fuel wood which consist about 45% moisture level, is used.
- The separation is done by the grate which is a very inefficient method.
- Tar and the smoke on the inner boiler wall.
- The boiler is not cleaned regularly when wet fuel wood is used.
- Insulation of the stream piping and hot water piping is heavily damaged.
- Boiler outer insulation is also heavily damaged.
- The water treatment unit that feed the boiler is not functioning well and it will lead to fouling inside the boiler tubes.
- The water treatment unit should be back washed for proper injection of the chemicals such as NaCl.
- Boiler routine maintenance is not carried out according to the schedule.

7.9 Comparison of the efficiency of boiler with moisture content in Sri Lanka and other countries in world

The variation of the efficiency of the boiler with moisture content of some foreign countries is shown in reference 27.

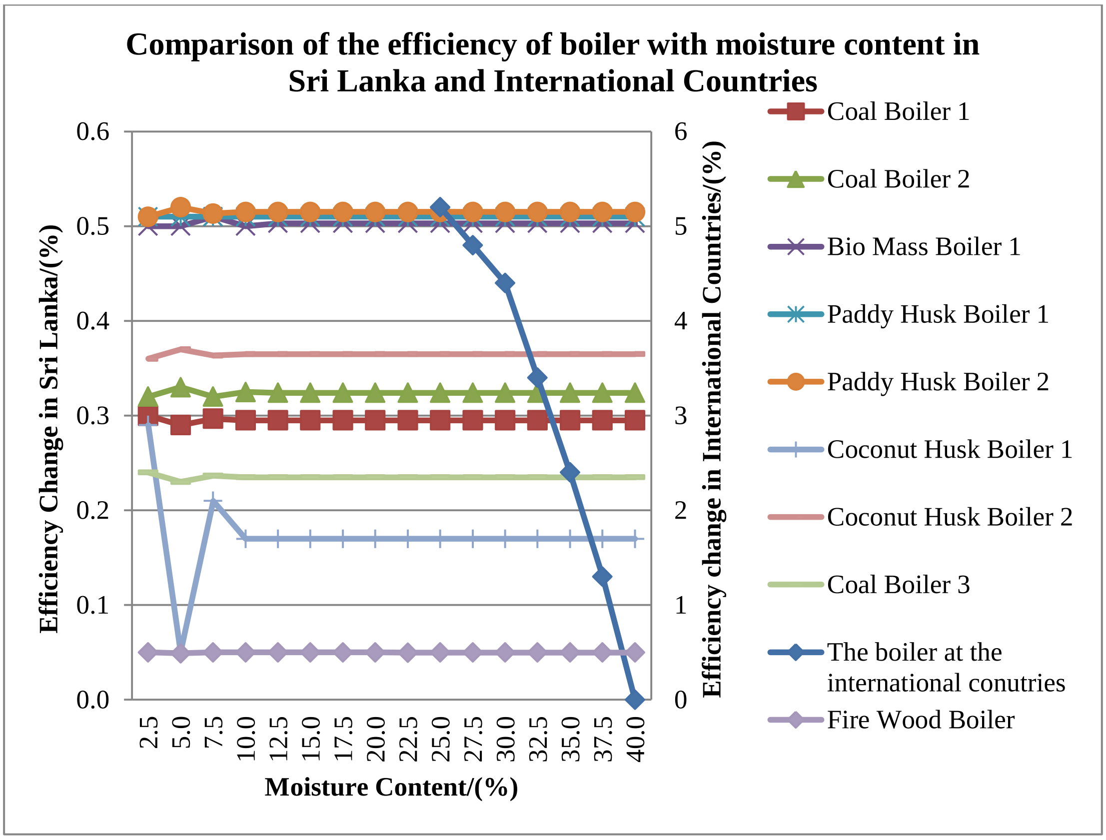


Figure 7.17 : Comparison of the efficiency of boiler with moisture content in Sri Lanka and world senario

The calculated efficiency of burners in Sri Lanka is also shown in Figure 7.17. Burners and boilers in other countries show more variations of efficiency with moisture content compared to the Sri Lanka. The variation of the efficiency of the burner with HHV of international countries is shown in reference 28.

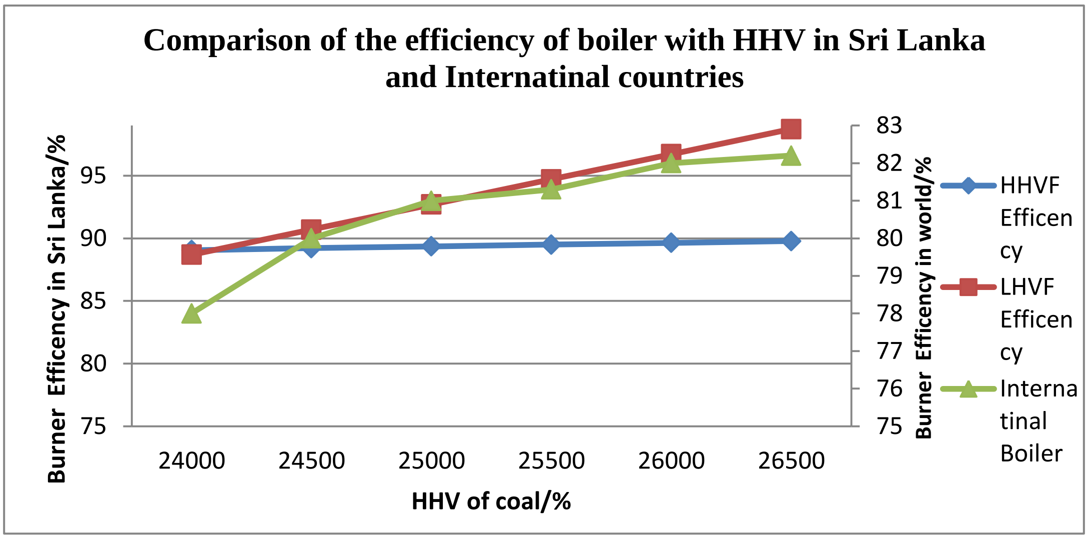


Figure 7.18 : Comparison of the efficiency of boiler with HHV in Sri Lanka and international countries

The Coal power Station 1 shows a much higher of efficiency with HHV compared to the Other Countries as shown in Figure 7.18. The coal power station 1 has a modern boiler which has advanced control of burning and the high efficiency is due to this situation.

CHAPTER 08: CONCLUTION & FUTURE WORKS

The burner purformance can be calculated using two methods; namely the direct method and the indirect method. The indirect method is fairly difficult to use as it requires considerable amount of experimental measurements to find out the performancces. But it is much more accurate compaired to the direct method. The modern burner’s performances is found out using the indirect method. The performances varied according to the moisture content of the fuel and envirnmental conditions. Normally, conventional burners perform less than the modern burners. This is because of better controlling of the firing inside the burner.The summary of the results are shaown in Table 8.1. The monogramme is developped for the industries to be used in the efficiency selection with exhaust temperature and ambient temperature as shown in Figure 8.1.

Table 8.1: Summary of the findings by Efficiency Calculation

Burner or Boiler	Efficiency calculation Method	Paratmeter that effect to efficiency	Most significant parameter	Possible improvements
Coal Power Station 1 burner	Direct Method	Can not find	-	-
	Indirect Method ASME Standards	1. The moisture content of fuel 2. Air temperature 3. Carbon Content of fuel 4. HHV of Fuel 5. Flue gas temperature	1. The moisture content of fuel 2. Air temperature 3. Flue gas temperature	1. Remove the moisture from coal 2. Heating of inlet air
Low Efficiency Boilers 1. Coal Boiler 2 2. Bio Mass power station 1 3. Paddy Husk Boiler 4. Paddy Husk Boiler	Direct Method	Can not find	-	-
	Indirect Method Reference 24	1. The moisture content of fuel 2. Air temperature	1. Moisture content of fuel	1. Remove the moisture from fuel

Burner or Boiler	Efficiency calculation Method	Paratmeter that effect to efficiency	Most significant parameter	Possible improvements
		3. Carbon Content of fuel 4. HHV of Fuel 5. Flue gas temperature 6. Excess Air Supplied 7. Oxegen percentage in flue gas	2. Air temperature 3. Flue gas temperature 4. Excess Air	2. Heating of inlet air from flue gas 3. Excess air Control
High Efficiency Boilers 1. Coal Boiler 1 2.Coconut husk Boiler New 1 3.Coconut husk Boiler 1 4. Coal Boiler 1	Direct Method	Can not find	-	-
	Indirect Method Reference 24	1. The moisture content of fuel 2. Air temperature 3. Carbon Content of fuel 4. HHV of Fuel 5. Flue gas temperature 6. Excess Air Supplied 7. Oxegen percentage in flue gas	1. Moisture content of fuel 2. Air temperature 3.Flue gas temperature 4. Excess Air	1. Remove the moisture from coal 2. Heating of inlet air 3. Excess Air Control

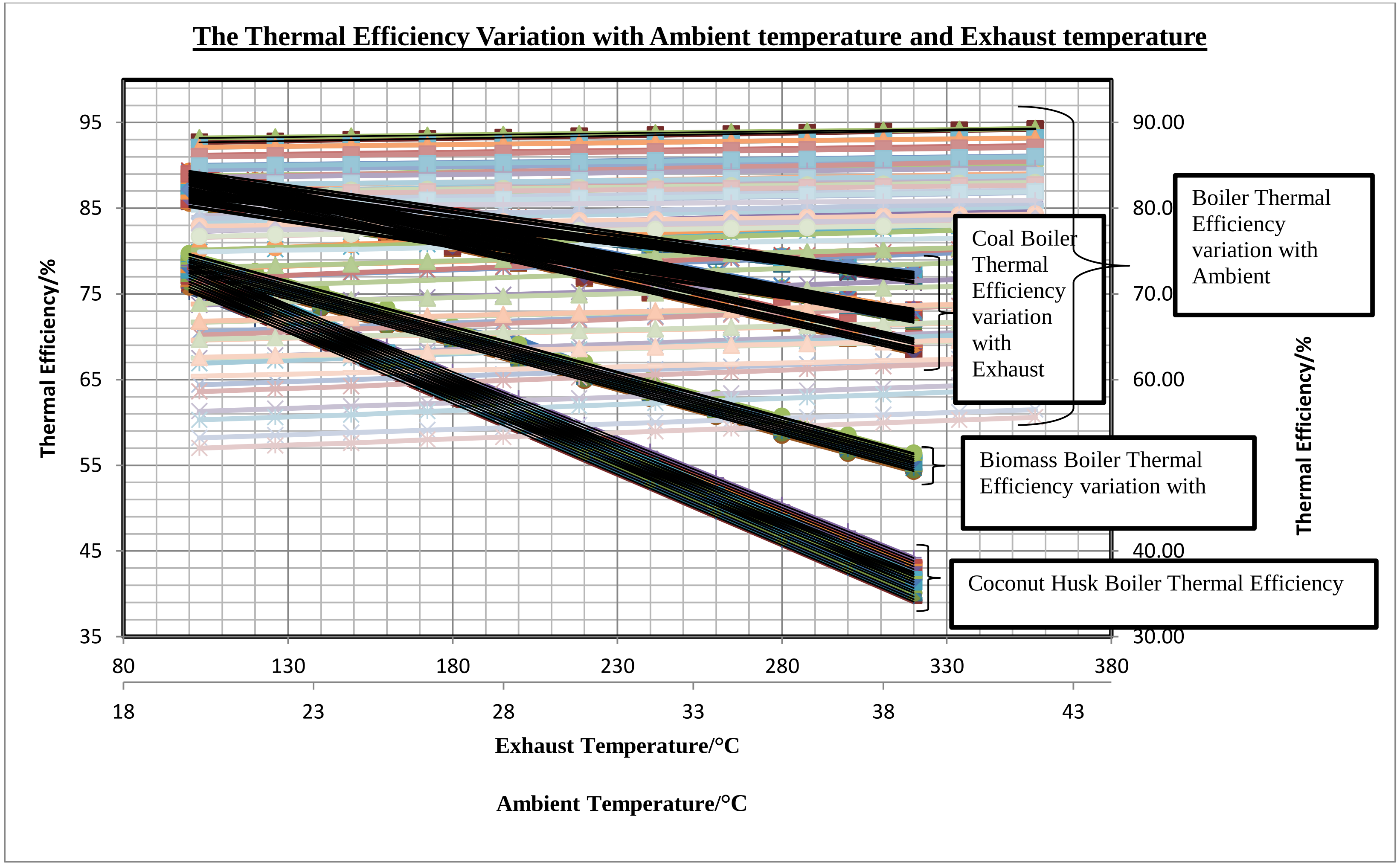


Figure 8.1 : Monogramme for the thermal efficiency vs Exhaust and Ambient temperature

For these calculations, Cp value of the flue gas is taken from literature and it has a notable effect to the final calculation as describe in chapter 07. And aslo Cp value of superheated steam is assumed and it has no significant effect to the efficiency.

According to the direct method and indirect method calculation, the indirect method gives more descriptive results compared to the direct method and direct method is a rough estimation only. Only the indirect method can be used to descriptively analyze the efficiency of the burner.

The burners and boiler in other countries, shows a much higher variations of efficiency with moisture content compared to the Sri Lanka.

The Coal Power Station 1 shows a much higher efficiency with HHV compared to the other countries.

8.1 Future works

1. To study and proposed a method to control of moisture content of the fuel using exhaust gas.The mechanism for exhaust gas extracting shall be proposed in this study and the quantity of exhaust that is sent to the fuel, shall be calculated. The heat exchanging techniques has to be developed in suaitable way such as heating platform.The storage area of the fuel can be heated up using this heating surface.The exaust gas shall not be exposed to the storage yard, because workers has to work there. The percentage of exhaust gas to be used, will have to be varied according to the moisture content and temperature of fuel. The controlling and monitoring of the fuel system has to be develop.

2. To study and propose a method for controlling of excess air by variable speed forced draft fan to improve the boiler efficiency. The minimum excess air amount has to be found out using the original design. The excess air supply has to be varied if the boiler is run at variable load condition. This system has to programmed to operate different load conditions. The air flow rate will have to be measured using air flow meter and speed of the forced draft fan

will have have to be changed until required design flow condtion established according to the current load.

3. To study and propose a method to heat the inlet air using exhaust gas to improve the efficiency of the boiler. Radiator type heat exchanging system shall be suitable for this application.The air flow rate to the boiler and required exhaust flow shall be calculated. The air flow measuring system and exhaust flow adjustment system shall have to be introduced a to controlling the exhaust flow.

4. To develop a graph to find out the Higher Heating Value for Flue Gas at different temperatures. Development of the methamatical relationship between Higher Heating Value for Flue Gas Vs temperature is nessary to model this graph.Then, the temperature is varied to get the relavent Cp values.

5. To model the variation of the burner perfomances with envirnmetal conditions. The atmospheric pressure, temperature, wind speed shall be considered in this study. The efficiency variation with envirnmental conditions has to be measured and studied to find the best operation condition for optimum operation of the unit. All perfomance variation vs envirnmental condition can be plotted and it can be used in industries to improve their plant out put.

6. To implement the perfomaces variation with maintenances work implemented and to predict the maintenance cycle. The efficiency before maintenance and after maintenance shall be found out. Then, a suitable period of the maintenance can be predicted in an economically feasible way. Using this results, reliability centerd maintenance system can be introduced to the plant to optimize the maintenance work.

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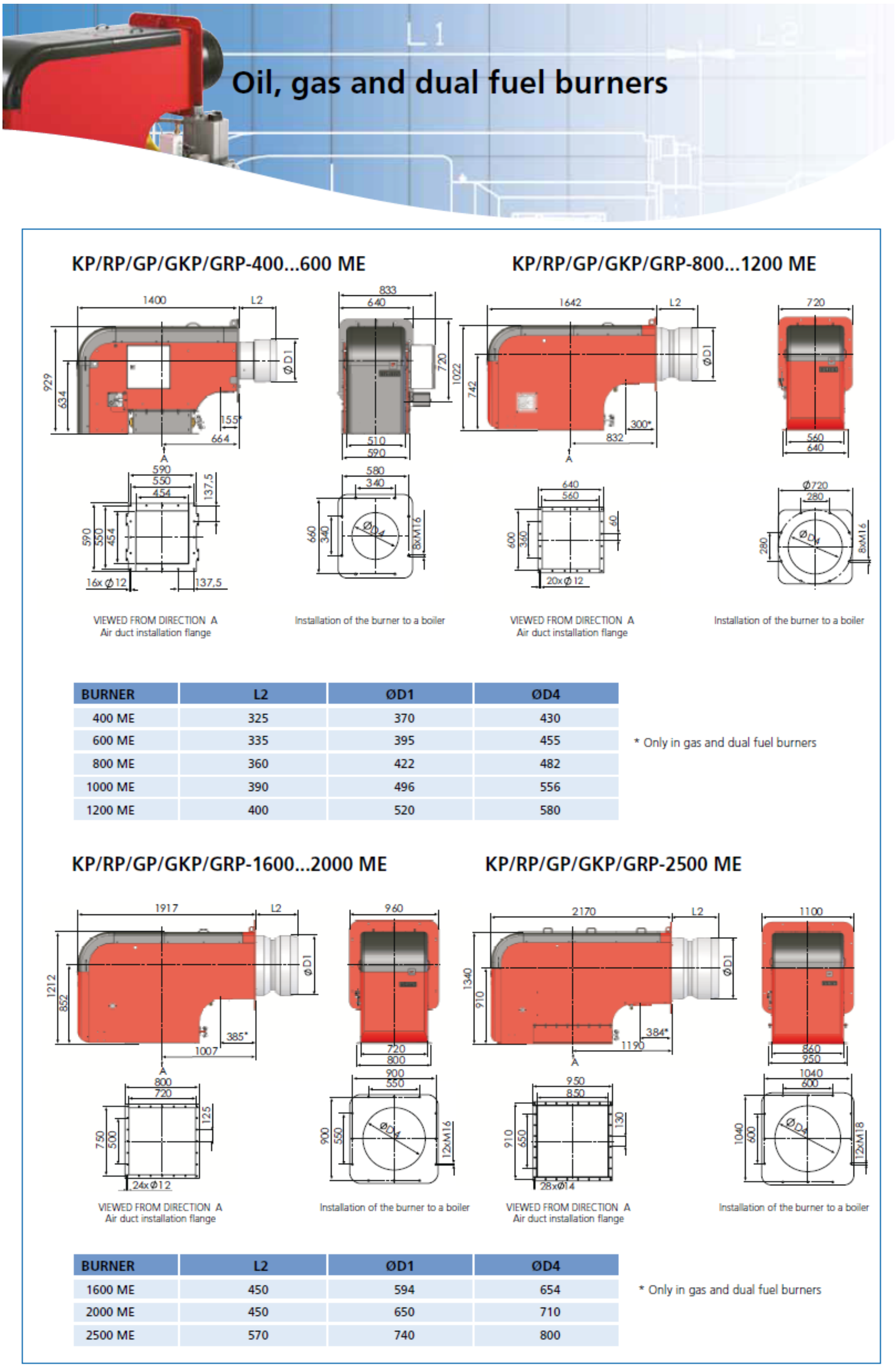
Appendix A:Burner Selection Data Sheet



Oil, gas and dual fuel burners

KP/RP/GP/GKP/GRP-400...600 ME

KP/RP/GP/GKP/GRP-800...1200 ME

VIEWED FROM DIRECTION A
Air duct installation flange

Installation of the burner to a boiler

VIEWED FROM DIRECTION A
Air duct installation flange

Installation of the burner to a boiler

BURNER	L2	ØD1	ØD4
400 ME	325	370	430
600 ME	335	395	455
800 ME	360	422	482
1000 ME	390	496	556
1200 ME	400	520	580

* Only in gas and dual fuel burners

KP/RP/GP/GKP/GRP-1600...2000 ME

KP/RP/GP/GKP/GRP-2500 ME

VIEWED FROM DIRECTION A
Air duct installation flange

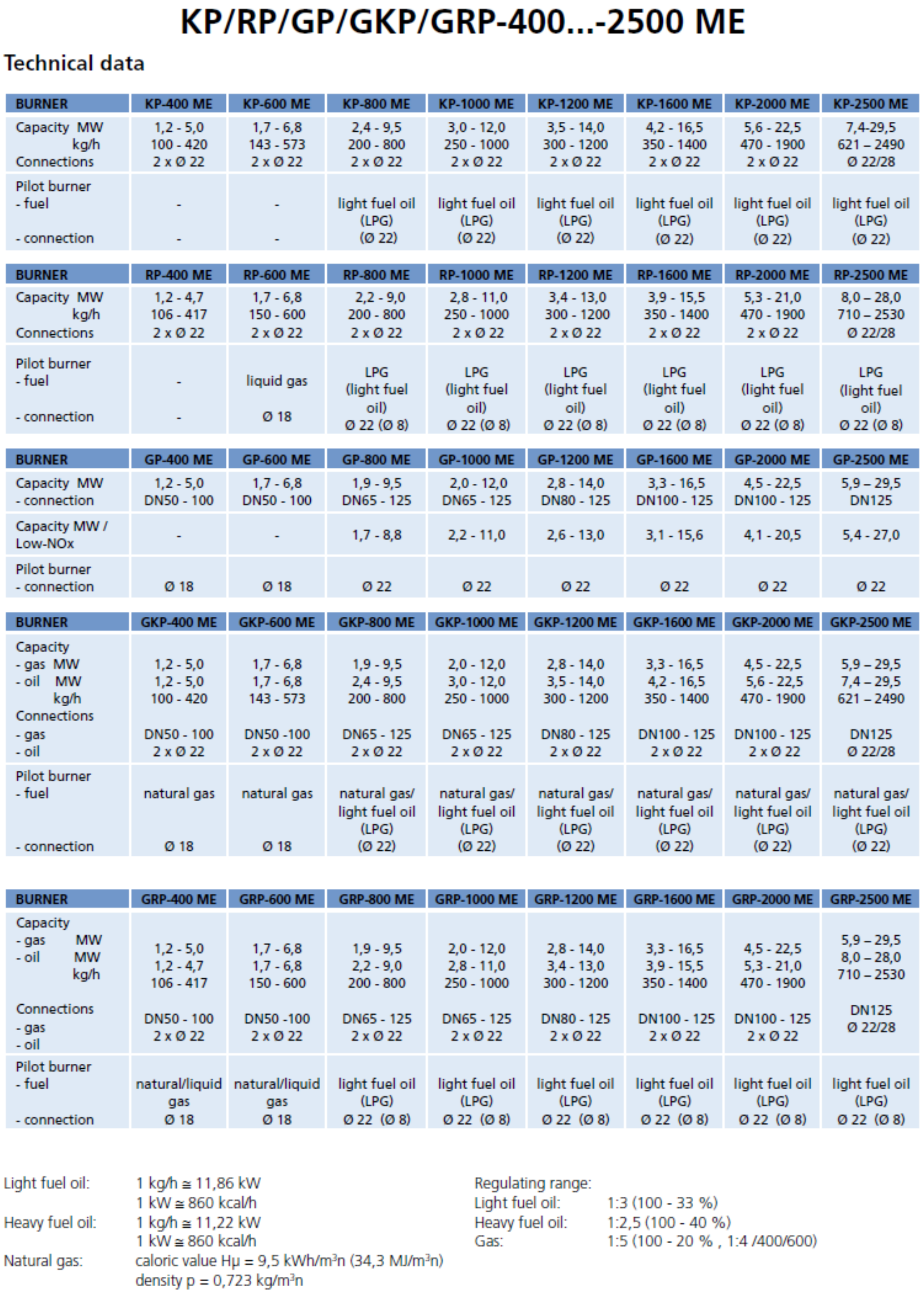
Installation of the burner to a boiler

VIEWED FROM DIRECTION A
Air duct installation flange

Installation of the burner to a boiler

BURNER	L2	ØD1	ØD4
1600 ME	450	594	654
2000 ME	450	650	710
2500 ME	570	740	800

* Only in gas and dual fuel burners



KP/RP/GP/GKP/GRP-400...-2500 ME

Technical data

BURNER	KP-400 ME	KP-600 ME	KP-800 ME	KP-1000 ME	KP-1200 ME	KP-1600 ME	KP-2000 ME	KP-2500 ME
Capacity MW	1,2 - 5,0	1,7 - 6,8	2,4 - 9,5	3,0 - 12,0	3,5 - 14,0	4,2 - 16,5	5,6 - 22,5	7,4-29,5
kg/h	100 - 420	143 - 573	200 - 800	250 - 1000	300 - 1200	350 - 1400	470 - 1900	621 – 2490
Connections	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	Ø 22/28
Pilot burner - fuel	-	-	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)
- connection	-	-	(Ø 22)	(Ø 22)	(Ø 22)	(Ø 22)	(Ø 22)	(Ø 22)

BURNER	RP-400 ME	RP-600 ME	RP-800 ME	RP-1000 ME	RP-1200 ME	RP-1600 ME	RP-2000 ME	RP-2500 ME
Capacity MW	1,2 - 4,7	1,7 - 6,8	2,2 - 9,0	2,8 - 11,0	3,4 - 13,0	3,9 - 15,5	5,3 - 21,0	8,0 – 28,0
kg/h	106 - 417	150 - 600	200 - 800	250 - 1000	300 - 1200	350 - 1400	470 - 1900	710 – 2530
Connections	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	Ø 22/28
Pilot burner - fuel	-	liquid gas	LPG (light fuel oil)	LPG (light fuel oil)	LPG (light fuel oil)	LPG (light fuel oil)	LPG (light fuel oil)	LPG (light fuel oil)
- connection	-	Ø 18	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)

BURNER	GP-400 ME	GP-600 ME	GP-800 ME	GP-1000 ME	GP-1200 ME	GP-1600 ME	GP-2000 ME	GP-2500 ME
Capacity MW	1,2 - 5,0	1,7 - 6,8	1,9 - 9,5	2,0 - 12,0	2,8 - 14,0	3,3 - 16,5	4,5 - 22,5	5,9 – 29,5
- connection	DN50 - 100	DN50 - 100	DN65 - 125	DN65 - 125	DN80 - 125	DN100 - 125	DN100 - 125	DN125
Capacity MW / Low-NOx	-	-	1,7 - 8,8	2,2 - 11,0	2,6 - 13,0	3,1 - 15,6	4,1 - 20,5	5,4 - 27,0
Pilot burner - connection	Ø 18	Ø 18	Ø 22	Ø 22	Ø 22	Ø 22	Ø 22	Ø 22

BURNER	GKP-400 ME	GKP-600 ME	GKP-800 ME	GKP-1000 ME	GKP-1200 ME	GKP-1600 ME	GKP-2000 ME	GKP-2500 ME
Capacity								
- gas MW	1,2 - 5,0	1,7 - 6,8	1,9 - 9,5	2,0 - 12,0	2,8 - 14,0	3,3 - 16,5	4,5 - 22,5	5,9 – 29,5
- oil MW	1,2 - 5,0	1,7 - 6,8	2,4 - 9,5	3,0 - 12,0	3,5 - 14,0	4,2 - 16,5	5,6 - 22,5	7,4 – 29,5
kg/h	100 - 420	143 - 573	200 - 800	250 - 1000	300 - 1200	350 - 1400	470 - 1900	621 – 2490
Connections								
- gas	DN50 - 100	DN50 -100	DN65 - 125	DN65 - 125	DN80 - 125	DN100 - 125	DN100 - 125	DN125
- oil	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	Ø 22/28
Pilot burner - fuel	natural gas	natural gas	natural gas/ light fuel oil (LPG)	natural gas/ light fuel oil (LPG)	natural gas/ light fuel oil (LPG)	natural gas/ light fuel oil (LPG)	natural gas/ light fuel oil (LPG)	natural gas/ light fuel oil (LPG)
- connection	Ø 18	Ø 18	(Ø 22)	(Ø 22)	(Ø 22)	(Ø 22)	(Ø 22)	(Ø 22)

BURNER	GRP-400 ME	GRP-600 ME	GRP-800 ME	GRP-1000 ME	GRP-1200 ME	GRP-1600 ME	GRP-2000 ME	GRP-2500 ME
Capacity								
- gas MW	1,2 - 5,0	1,7 - 6,8	1,9 - 9,5	2,0 - 12,0	2,8 - 14,0	3,3 - 16,5	4,5 - 22,5	5,9 – 29,5
- oil MW	1,2 - 4,7	1,7 - 6,8	2,2 - 9,0	2,8 - 11,0	3,4 - 13,0	3,9 - 15,5	5,3 - 21,0	8,0 – 28,0
kg/h	106 - 417	150 - 600	200 - 800	250 - 1000	300 - 1200	350 - 1400	470 - 1900	710 – 2530
Connections								
- gas	DN50 - 100	DN50 -100	DN65 - 125	DN65 - 125	DN80 - 125	DN100 - 125	DN100 - 125	DN125
- oil	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	2 x Ø 22	Ø 22/28
Pilot burner - fuel	natural/liquid gas	natural/liquid gas	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)	light fuel oil (LPG)
- connection	Ø 18	Ø 18	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)	Ø 22 (Ø 8)

Light fuel oil:	1 kg/h ≅ 11,86 kW 1 kW ≅ 860 kcal/h
Heavy fuel oil:	1 kg/h ≅ 11,22 kW 1 kW ≅ 860 kcal/h
Natural gas:	caloric value Hμ = 9,5 kWh/m^3n (34,3 MJ/m^3n) density p = 0,723 kg/m^3n

Regulating range:

Light fuel oil:	1:3 (100 - 33 %)
Heavy fuel oil:	1:2,5 (100 - 40 %)
Gas:	1:5 (100 - 20 % , 1:4 /400/600)

Appendix B :Burners Technical Data

Table 01: Collected data for Direct method efficiency calculation

Description	Units	Hot water Watawala	Bio Mass, Watawala	Mahiyanganaya	Higurana Suger	Welioya tea Hot water	Welioya tea Bio Mass	Ranala Factory	Boiler at Avissawella	Boiler At Pannala Textile Factory	Boiler At Ratmalana Textile Factory
Heat Output (MCR)	Kcal/h	600,000	850,000	4,620,000	420,000	850,000	800,000	60,000	300,000	240,000	240,000
Operating Pressure	bar	10.54	10.34	10.34	15.17	5	6	9.5 bar	35	10	10
Water Flow Rate	m3/h	35	38	26-30	55	36	6	1	26	25	25
Operating Temperature	°C	110-135	145	1000	900	270	260	270	900		
Fuel		Fuel Wood	Fuel wood	Fuel wood (Griceidia, and other)	Fuel wood Bagasse	Jungle wood(Size 18”x4”), Rubber	Jungle wood(Size 24”), Rubber	Fuel wood (Griceidia, and other)	Pulverized coal	Pulverized coal	Pulverized coal

Description	Units	Hot water Watawala	Bio Mass, Watawala	Mahiyanganaya	Higurana Suger	Welioya tea Hot water	Welioya tea Bio Mass	Ranala Factory	Boiler at Avissawella	Boiler At Pannala Textile Factory	Boiler At Ratmalana Textile Factory
Fuel calorific Value (GCV)	kcal/kg	3200	3200	7643	7643 4490	3200	3200	3200	6448.8	6448.8	6448.8
Fuel Consumption on GCV basis	Kg/hr	275	700	11,000	8,000 6000	3000	2000	5000	5000	2400	3800
Thermal Efficiency NCV	%	68%	64%	98%	About 65%	-	-	85%	85%	85%	85%
Steam Pressure	bar	-	150	62	15	5	-	8.5	35	10	10
Steam Temperature	°C	-	135-145	750-800	900		-	255	385	182	182

Description	Units	Hot water Watawala	Bio Mass, Watawala	Mahiyanganaya	Higurana Suger	Welioya tea Hot water	Welioya tea Bio Mass	Ranala Factory	Boiler at Avissawella	Boiler At Pannala Textile Factory	Boiler At Ratmalana Textile Factory
Boiler tube type		Water tube	Water tube	Water tube	Fire tube	Water tube	Water tube	Water tube	Water tube	Water tube	Water tube
Feed Water Temperature	°C	24	24	28	27	22	22	26	27	27	28
Ambient Temperature	°C	26	26	31	30	25	25	30	30	30	32

Table 02: Collected Data for the Indirect Calculations

	Parameter	Unit	Coal Boiler 1	Coal Boiler 2	Bio Mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler 1	Coconut Husk Boiler 2	Coal Boiler 3	Fire Wood Boiler 1
	Year Of Installation of Boiler		1985	1994	2014	2014	2010	2014	2005	2007	2013
	Flue Gas Analyse Data										
1	Oxegen, O_2 (%)	%	8.8	3.55	5.7	10.5	11.4	14.7	11.7	11.9	5.67
2	Excess Air (%)	%	73.0	85	37	98	127	238	130	110	150
3	Carbon Dioxide, CO_2 (%)	%	9.0	14.87	13.4	10	9.4	7.1	11.4	8.2	3300
4	Carbon Monoxide, CO (mg/m3)	mg/m^3	0	59	0.5	397	3	3375	1098	83.8	1.69
5	Sulphar Dioxide,SO2 (mg/m3)	mg/m^3	637	0	0	464	13	893	244	408	0
6	Nitrogen Dioxide, NOx (mg/m3)	mg/m^3	251	60	278	432	376	86	107	344.6	0
7	Flue Gas Temp. (C)	°C	143	45	163	150	142	100	190	81	157
8	Average Fuel Consumption Rate	Kg/hr	240	3500	25000	14500	50000	24000	22500	120000	1700
9	Gross Calorific Value of Fuel	MJ/kg	22.00	22	13.397	13.397	13.397	19.58	19.58	26.79	18.5
11	Energy Input to the Boiler	MJ	1443.57	77000	334925	194256.5	669850	469920	440550	3214800	31450
12	Cp of Flue Gas	kCal/kg	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
	Ultimate Analysis Data										
13	Carbon percentage in fuel, C	%	60.00	60.00	62.00	61.28	60.50	40.00	40.00	61.20	61.0
14	Hydrogen percentage in fuel, H	%	3.80	3.80	4.10	5.12	4.20	6.00	6.00	4.00	6.00

	Parameter	Unit	Coal Boiler 1	Coal Boiler 2	Bio Mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler 1	Coconut Husk Boiler 2	Coal Boiler 3	Fire Wood Boiler 1
15	Nitrogen percentage in fuel, N	%	1.50	1.00	2.1	0.92	1.8	0.5	0.5	1.8	2.1
16	Oxygen percentage in fuel, O	%	6.20	6.20	5.8	4.53	5.8	38	38	4.1	5.8
17	Suphar percentage in fuel, S	%	0.50	0.50	0.5	0.08	0.6	0.3	0.3	0.4	0.5
			72.00	71.50	74.50	71.93	72.90	84.80	84.80	71.50	
18	mass of the CO2 +SO2+N2+O2 in flue Gas,m		0.83	0.84	0.83	0.85	0.83	0.47	0.47	0.86	0.81
19	Percentage of H in 1 kg of fuel	%/kg of Fuel	3.80	3.80	4.10	5.12	4.20	6.00	6.00	4.00	6.00
20	Gross Calorific Value of Fuel, GCV	kCal/kg	5400.00	5254.6	3199.73948	3164	3078	4500	4500	6400	3200
21	Flue Gas Temperature, T_f	^{0}C	140.00	250.00	160.00	150.00	142.00	100.00	190.00	81.00	157
22	Ambient Temperature, Ta	^{0}C	35.00	30.00	30.00	26.00	30.00	30.00	30.00	33.00	34.5
29	Percentage moisture in kg of fuel, M	kg	7.00	15.00	30.00	11.70	13.10	10.00	10.00	7.20	25
30	C_p of the Superheated Steam	kCal/kg	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
35	**Relative Humidity**	%	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
36	**Humidity Factor**		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
43	fly ash amount of 1kg of coal	kg	0.30	0.3	0.3	0.147	0.2	0.16	0.16	0.3	1.3
44	GCV of fly ash	kCal/kg	108.00	105.09	63.99	63.28	61.56	90.00	90.00	128.00	64.00

	Parameter	Unit	Coal Boiler 1	Coal Boiler 2	Bio Mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler 1	Coconut Husk Boiler 2	Coal Boiler 3	Fire Wood Boiler 1
48	bottom ash amount of 1kg of coal	kg	0.03	0.025	0.1	0.163	0.01	0.01	0.01	0.01	1.01
49	GCV of the bottom ash	kCal/kg	216.00	210.18	127.99	126.56	123.12	180.00	180.00	256.00	128
50	Operation pressure	bar	10	10	71	44	51.4	10.34	10	13	10
51	Operating Temperature	^{0}C	290	260	288	440	275	260	290	320	240
52	Steam Generation rate	kg/hr	1440	15000	30000	14500	50000	3000	3200	18000	
53	Feed water Temperature	^{0}C	26	26		24	27	25	25	26	60

Appendix C: Calculation Data

Table 03: Boiler efficiency with moisture content

Moisture Content of fuel/(%)	Efficiency/(%)								Fire Wood Boiler
	Coal Boiler 1	Coal Boiler 2	Bio mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	
0.0	86.64	81.01	77.78	68.80	72.52	77.78	84.22	91.19	75.63
2.5	86.34	80.69	77.28	68.29	72.01	77.49	83.86	90.95	75.13
5.0	86.05	80.36	76.78	67.78	71.49	77.44	83.49	90.72	74.64
7.5	85.75	80.04	76.27	67.27	70.98	77.23	83.13	90.48	74.14
10.0	85.46	79.72	75.77	66.76	70.46	77.06	82.76	90.25	73.64
12.5	85.16	79.39	75.27	66.25	69.95	76.89	82.40	90.01	73.14
15.0	84.87	79.07	74.76	65.74	69.43	76.72	82.03	89.78	72.64
17.5	84.57	78.74	74.26	65.23	68.92	76.55	81.67	89.54	72.14
20.0	84.28	78.42	73.76	64.72	68.40	76.38	81.30	89.31	71.64
22.5	83.98	78.10	73.26	64.21	67.89	76.21	80.94	89.07	71.14
25.0	83.69	77.77	72.75	63.70	67.37	76.04	80.57	88.84	70.64
27.5	83.39	77.45	72.25	63.19	66.86	75.87	80.21	88.60	70.14
30.0	83.10	77.12	71.75	62.68	66.34	75.70	79.84	88.37	69.65
32.5	82.80	76.80	71.24	62.17	65.83	75.53	79.48	88.13	69.15
35.0	82.51	76.48	70.74	61.66	65.31	75.36	79.11	87.90	68.65
37.5	82.21	76.15	70.24	61.15	64.80	75.19	78.75	87.66	68.15
40.0	81.92	75.83	69.73	60.64	64.28	75.02	78.38	87.43	67.65

Table 04: Boiler efficiency with Carbon content

Carbon Content/(%)	Efficiency /(%)								
	Coal Boiler 1	Coal Boiler 2	Bio mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	Fire Wood Boiler
35	86.93	82.40	73.84	70.23	72.27	86.19	83.73	90.33	71.48
40	86.65	81.94	73.36	69.71	71.65	85.57	82.76	90.22	71.32
45	86.41	81.54	72.93	69.25	71.12	85.01	81.88	90.12	71.16
50	86.14	81.10	72.47	68.75	70.53	84.41	80.94	90.01	71.00
55	85.88	80.67	72.01	68.26	69.96	83.82	80.02	89.91	70.83
60	85.62	80.24	71.56	67.77	69.38	83.23	79.09	89.80	70.67
65	85.36	79.81	71.10	67.28	68.81	82.64	78.17	89.70	70.51
70	85.10	79.38	70.65	66.79	68.23	82.05	77.24	89.59	70.35
75	84.84	78.95	70.19	66.30	67.66	81.46	76.32	89.49	70.19

Table 05: Boiler efficiency with Installation year

Plant Name	Year Of Installation	EfficiencyValue/(%)
Coal Boiler 1	1985	85.8
Coal Boiler 2	1994	80.5
Coconut Husk Boiler 2	2005	82.8
Coal Boiler 3	2007	89.9
Paddy Husk Boiler 2	2010	69.8
Fire Wood Boiler	2013	70.64
Bio Mass Boiler	2014	72.1
Paddy Husk Boiler 1	2014	68.1
Coconut Husk Boiler 1	2014	85.6

Table 06: Boiler efficiency with Exhaust Temperature

Exhaust Temperature 1	Ambiant temperature	Coal Boiler 1		Coal Boiler 2		Bio mass Boiler 1		Paddy Husk Boiler 1		Paddy Husk Boiler 2		Coconut Husk Boiler1		Coconut Husk Boiler2		Coal Boiler 3		Fire Wood Boiler	
		Efficiency Ambient 1	Efficiency Exhaust 1	Efficiency Ambient 2	Efficiency Exhaust 2	Efficiency Ambient 3	Efficiency Exhaust 3	Efficiency Ambient 4	Efficiency Exhaust 4	Efficiency Ambient 5	Efficiency Exhaust 5	Efficiency Ambient 6	Efficiency Exhaust 6	Efficiency Ambient 7	Efficiency Exhaust 7	Efficiency Ambient 8	Efficiency Exhaust 8	Efficiency Exhaust 9	Efficiency Ambient 9
100	20	84.70	88.8	80.00	88.7	70.70	78.40	67.10	75.80	68.20	76.80	85.00	85.6	82.30	86.7	88.70	88.20	76.70	69.10
120	22	84.90	87.3	80.10	87.6	70.90	76.30	67.50	72.70	68.50	73.50	85.10	84.4	82.40	85.8	88.90	86.50	75.60	69.30
140	24	85.00	85.8	80.20	86.5	71.10	74.20	67.80	69.60	68.80	70.20	85.20	83.2	82.50	84.9	89.10	84.40	74.60	69.60
160	26	85.17	84.3	80.30	85.4	71.30	72.10	68.17	66.50	69.10	66.90	85.30	82	82.60	84	89.30	82.57	72.50	69.80
180	28	85.32	82.8	80.40	84.3	71.50	70.00	68.52	63.40	69.40	63.60	85.40	80.8	82.70	83.1	89.50	80.67	71.45	70.00
200	30	85.47	81.3	80.50	83.2	71.70	67.90	68.87	60.30	69.70	60.30	85.50	79.6	82.80	82.2	89.70	78.77	70.09	70.25
220	32	85.62	79.8	80.60	82.1	71.90	65.80	69.22	57.20	70.00	57.00	85.60	78.4	82.90	81.3	89.90	76.87	68.73	70.48
240	34	85.77	78.3	80.70	81	72.10	63.70	69.57	54.10	70.30	53.70	85.70	77.2	83.00	80.4	90.10	74.97	67.37	70.71
260	36	85.92	76.8	80.80	79.9	72.30	61.60	69.92	51.00	70.60	50.40	85.80	76	83.10	79.5	90.30	73.07	66.01	70.94
280	38	86.07	75.3	80.90	78.8	72.50	59.50	70.27	47.90	70.90	47.10	85.90	74.8	83.20	78.6	90.50	71.17	64.65	71.17
300	40	86.22	73.8	81.00	77.7	72.70	57.40	70.62	44.80	71.20	43.80	86.00	73.6	83.30	77.7	90.70	69.27	63.29	71.40
320	42	86.37	72.3	81.10	76.6	72.90	55.30	70.97	41.70	71.50	40.50	86.10	72.4	83.40	76.8	90.90	67.37	61.93	71.63

Table 07:Boiler efficiency with Excess Air Percentage

Excess Air Supplied Percentage/(%)	Efficiency/(%)								
	Coal Boiler 1	Coal Boiler 2	Bio mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	Fire Wood Boiler
0	88.9	82.4	75.4	77.2	79.4	87.9	85.7	92.2	73.8
25	87.8	80.1	73.2	74.9	77.4	87.7	85.1	91.7	71.7
50	86.8	77.8	70.9	72.7	75.4	87.4	84.5	91.3	69.6
75	85.7	75.5	68.6	70.4	73.4	87.2	83.9	90.9	67.5
100	84.65	73.2	66.35	68.15	71.4	86.95	83.3	90.45	65.4
125	83.59	70.9	64.08	65.89	69.4	86.71	82.7	90.02	63.3
150	82.53	68.6	61.81	63.63	67.4	86.47	82.1	89.59	61.2
175	81.47	66.3	59.54	61.37	65.4	86.23	81.5	89.16	59.1
200	80.41	64	57.27	59.11	63.4	85.99	80.9	88.73	57
225	79.35	61.7	55	56.85	61.4	85.75	80.3	88.3	54.9
250	78.29	59.4	52.73	54.59	59.4	85.51	79.7	87.87	52.8

Table 08: Boiler efficiency with Hydrogen Percentage in Fuel

Hydrogen percentage in Fuel/(%)	Efficiency/(%)								
	Coal Boiler 1	Coal Boiler 2	Bio mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	Fire Wood Boiler
0	89.90	85.50	79.60	77.60	77.80	93.10	90.90	93.30	81.4
1	88.80	83.90	77.80	75.80	75.90	91.90	89.60	92.50	79.6
2	87.70	82.70	75.90	73.90	74.00	90.60	88.20	91.60	77.9
3	86.70	81.50	74.10	72.00	72.10	89.40	86.80	90.70	76.1
4	85.60	80.10	72.25	70.15	70.20	88.15	85.45	89.85	74.35
5	84.53	78.78	70.41	68.28	68.30	86.91	84.08	88.98	72.59
6	83.46	77.46	68.57	66.41	66.40	85.67	82.71	88.11	70.83
7	82.39	76.14	66.73	64.54	64.50	84.43	81.34	87.24	69.07
8	81.32	74.82	64.89	62.67	62.60	83.19	79.97	86.37	67.31
9	80.25	73.50	63.05	60.80	60.70	81.95	78.60	85.50	65.55
10	79.18	72.18	61.21	58.93	58.80	80.71	77.23	84.63	63.79

Table 09: Boiler efficiency with Oxygen Percentage in flue gas

Oxygen Percentage in Flue Gas/(%)	Boiler Efficiency/(%)								
	Coal Boiler 1	Coal Boiler 2	Bio mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	Fire Wood Boiler
0	88.90	82.40	75.40	77.20	79.40	87.90	85.70	92.20	73.8
1	88.70	81.90	75.00	76.80	79.00	87.90	85.60	92.10	73.4
2	88.50	81.40	74.50	76.30	78.60	87.80	85.40	92.00	72.9
3	88.20	80.90	73.90	75.70	78.10	87.80	85.30	91.90	72.4
4	88.00	80.40	73.45	75.25	77.70	87.75	85.15	91.80	71.95
5	87.77	79.90	72.95	74.75	77.27	87.71	85.01	91.70	71.48
6	87.54	79.40	72.45	74.25	76.84	87.67	84.87	91.60	71.01
7	87.31	78.90	71.95	73.75	76.41	87.63	84.73	91.50	70.54
8	87.08	78.40	71.45	73.25	75.98	87.59	84.59	91.40	70.07
9	86.85	77.90	70.95	72.75	75.55	87.55	84.45	91.30	69.6
10	86.62	77.40	70.45	72.25	75.12	87.51	84.31	91.20	69.13
11	86.39	76.90	69.95	71.75	74.69	87.47	84.17	91.10	68.66
12	86.16	76.40	69.45	71.25	74.26	87.43	84.03	91.00	68.19
13	85.93	75.90	68.95	70.75	73.83	87.39	83.89	90.90	67.72
14	85.70	75.40	68.45	70.25	73.40	87.35	83.75	90.80	67.25
15	85.47	74.90	67.95	69.75	72.97	87.31	83.61	90.70	66.78

Table 10: Boiler efficiency with Cp Value of Flue gas

Cp value of Flue Gas/(%)	Efficiency/(%)								
	Coal Boiler 1	Coal Boiler 2	Bio mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	Fire Wood Boiler
0.1	90.00	86.80	79.10	78.40	79.80	87.60	86.10	92.20	77.2
0.2	86.80	82.00	73.70	70.50	72.10	86.00	83.50	90.40	72.2
0.3	83.60	77.20	68.30	62.50	64.40	84.50	81.00	88.60	67.1
0.4	80.40	72.40	62.90	54.57	56.70	82.93	78.43	86.80	62.1
0.23	85.80	80.50	72.10	68.10	69.80	85.60	82.80	89.90	70.7

Table 11: Boiler efficiency with Cp value of the superheated steam

Cp value of Flue Gas/(%)	Efficiency/(%)								
	Coal Boiler 1	Coal Boiler 2	Bio mass Boiler 1	Paddy Husk Boiler 1	Paddy Husk Boiler 2	Coconut Husk Boiler1	Coconut Husk Boiler2	Coal Boiler 3	Fire Wood Boiler
0.2	86.00	81.00	72.70	68.60	70.30	85.80	83.30	90.00	71.4
0.3	85.90	80.80	72.50	68.40	70.10	85.70	83.10	89.90	71.1
0.4	85.90	80.60	72.20	68.20	69.90	85.60	82.90	89.90	70.8
0.5	85.80	80.40	71.90	68.00	69.70	85.50	82.60	89.90	70.5
0.6	85.70	80.20	71.70	67.70	69.50	85.40	82.40	89.80	70.2
0.45	85.80	80.50	72.10	68.10	69.80	85.60	82.80	89.90	70.7