Experimental Studies of Co-gasification with Coal and Waste Wood of Downdraft Gasifier System

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Experimental Studies of Co-gasification with Coal and Waste Wood of Downdraft Gasifier System

Major Project Report

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By

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Thermal Engineering at Nirma University and has not been submitted elsewhere for a degree.
2. Due acknowledgement has been made in the text to all other material used.

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Undertaking for Originality of the Work

I, **VARIA NANDAN PRADIPKUMAR**, Roll. No. **11MMET23**, give undertaking that the Major Project entitled **“Experimental Studies of Co-gasification with Coal and Waste Wood in Downdraft Gasifier System”** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Mechanical Engineering (Thermal Engineering)** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report entitled "EXPERIMENTAL STUDIES OF CO-GASIFICATION WITH COAL AND WASTE WOOD OF DOWNDRAFT GASIFIER SYSTEM" submitted by Mr. NANDAN PRADIPKUMAR VARIA(11MMET23), towards the partial fulfillment of the requirements for the award of Degree of Master of Technology in Mechanical Engineering (Thermal Engineering) of Institute of Technology, Nirma University, Ahmadabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.The result embodied in this major project, to the best of our knowledge, has not been submitted to any other university or institution for award of any degree.

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Abbreviation

Fig = Figure
Min = Minute
dia = Diameter
[ ] = Bibliography number
m = Moisture content
m**i** = Initial weight of sample
m**f** = Final weight of sample
a = Ash content
Vm = Volatile matter
Fc = Fixed carbon
CV = Caloric Value
Q = Gas generation rate
GGR = Gas generation rate
Cd = Co-officient of discharge
A1 = Cross section area at inlet
A2 = Cross section area at throat
G = Gravitational constant
H = Height of water
ρ_w = Density of water
ρ_g = Density of producer gas
FC = Fuel consumption
W**im** = Initial weight of material
W**mt** = Weight of material topped up
W**mr** = Weight of material remaining
ttd = Total time duration
HGR = Heat generation rate
η = Gasifier Efficiency
HHV = Higher Heating Value
LHV = Lower Heating Value

Abstract

High prices of oil and natural gas are leading to an increased interest in "Energy Conservation" technologies such as biomass gasification, methanation, liquidification and solidification. Heating system based on wood, fuel, electricity, coal/lignite are common in some industries. Environmental pollution, poor process control and cost are some of the limitation of these systems. Lignite being low grad coal forms clinker when used as a fuel in boilers of thermal power stations. Gujarat has large reserves of lignite. In this work, an attempt is made to evaluate lignite as a fuel in downdraft gasier for decentralizes power generation gasifier. A 10 kWe downdraft gasifier was developed with the financial support of Department of Science and Technology (DST), Government of INDIA. This study presents the results of experiments investigation on different fuel mix (100% lignite, 90% lignite -10% wood, 85% lignite - 15% wood, 80% lignite - 20% wood, 75% lignite - 25% wood) were taken and performance of gasifier with above fuel mix was attempted. It was observed that efficiency of gasifier much dependent of wood concentration in fuel mix. It is observed that maximum efficiency of the order of 72% was obtained with 25% wood concentration. If experiments were conducted with high wood concentration in fuel mix, certainly efficiency would have increases. Since the major objective of present work is to analyze the use of lignite in downdraft gasifier. Present study and observetions give detailed estimate to eliminate the difficulties during lignite gasification in downdraft gasifier system.

Key words : Downdraft Gasifier, Co-gasification, Lignite, Waste wood, Clinker formation

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Chapter 1

Introduction

1.1 Introduction

Gasification techologies have been commercially applied for more than a century for the production of both fuels and chemicals. Currrent trends in the power generation and refinery industries support the observation that advanced stages of the technology with continue to be applied toward the synthesis of syngas, with an increasing number of applications in power generation, fuels and basic chemicals manufacturing[1].

Attractive features of technology include :

- The ability to produce a consistent product that can be used for the generation of electricity or as primary buliding blocks for manufacturers of chemicals and transportation fuels.
- The ability to process a wide range of feed stocks including coal, heavy oils, petroleum coke, heavy refinery residuals, refinery wastes, hydrocarbon contaminated soils, biomass and agricultural wastes.
- The ability to remove contaminants in the feed stock and to produce a clean syngas product.
- The ability to convert wastes or low-value products to higher value products.
- The ability to minimize the amount of solid waste requiring landfill disposal. Solid by-products have a market value can be used as fuel or construction material and are non-hazardous.

1.2 Gasification

Gasification is a process for converting carbonaceous materials to a combustiable or synthetic gas (e.g., H_2, CO,CO_2, CH_4). In general, gasification involves the reaction of carbon with air, oxygen, steam, carbon dioxide, or a mixture of these gases at 1,300 °F or higher to produce a gaseous product that can be used to provide electric power and heat or as a raw material for the synthesis of chemicals, liquid fuels, or other gaseous fuels such as hydrogen[1].

Once a carbonaceous solid or liquid material is converted ot a gaseous state, undesirable substances such as sulfur compounds and ash may be removed from the gas. In contrast to combustion processes, which work with excess air, gasification processes operate as substoichiometric conditions with the oxygen supply controlled (generally 35 percent of the amount of O_2 theoretically required for complete combustion or less) such that both heat and a new gaseous fuel are produced as the feed material is consumed.

Some gasification processes also use indirect heating, avoiding combustion of the feed material in the gasification reactor and avoiding the dilution of the product gas with nitrogen and excess CO_2.

when a carbonaceous material is heated, either directly or indirectly, under gasification conditions, it is first pyrolyzed. During pyrolysis light volatile hydrocarbons, rich in hydrogen, are evolved and tars, phenols and hydrocarbon gases are released. During pyrolysis the feeedstock is thermally decomposed to yield solid carbon and a gas product stream that has higher hydrogen content than the original carbonaceous feed material.

1.3 Types of Gasification

In a gasification process the feedstock is hydrogenated. This means hydrogen is added to the system directly or indirectly or the feedstock is pyrolyzed to remove carbon to produce a product with a higher hydrogen-to-carbon ration than the feedstock. these processes may be carried out separately or simultaneously. The more hydrogen that is added or the more carbon removed, the lower the overall efficiency of the synthetic gas production process. In an indirect hydrogenation process, steam is used as hydrogen source and hydrogen is produced within the gasification reactor.

An indirect hydrogenation process that is still under development is catalytic gasification. In this process, a catalyst accelerates the gasification reactions, resulting in the formation of hydrogen and CO, at relatively low temperatures. This process also promotes catalytic formation of methane at the same low temperature within the same reactor. Catalyst deactivation and costs have been a major impendiment to the commercialization of the process.

In a direct hydrogenation process feedstock is exposed to hydrogen at high pressures to produce a gas with higher methane content than indirect hydrogenation processes.

Indirect hydrogenation processes are also known as air or oxygen blown gasification, depending on whether air or oxygen is used as the oxidant source. If heat is also provided indirectly, air or oxygen is ont used to combust some of the feedstock in the gasifier. This results in as increase in the reactor temperature to the desired gasification reaction temperatures, which is a process referred to as steam reforming. Direct hydrogenation processes are called hydro-gasification[1].

1.4 Stoichiometries and Thermodynamics

As feedstock proceeds through a gasification reactor or gasifier; the following physical, chemical, and thermal processes may occur sequentially or simultaneously, depending on the reactor design and the feedstock material[1].

1.4.1 Drying

As the feedstock is heated and its temperature increases, water i the first constituent to evolve.

$$\text{Moist feedstock} + \text{Heat} \rightarrow \text{Dry feedstock} + H_2O$$

1.4.2 Devolatilizaton

As the temperature of the dry feedstock increases, pyrolysis takes place and the feedstock is converted to char.

$$\text{Dry feedstock} + \text{Heat} \rightarrow \text{Char} + \text{Volatiles}$$

Depending on the origin of the feedstock, the volatiles may include H_2O, H_2, N_2, O_2, CO_2, CO, CH_4, H_2S, NH_3, C_2H_6. Char is the residual solids consisting of organic and inorganic materials, After pyrolysis, the char has a higher concentration of carbon than the dry feedstock.

1.4.3 Gasification

Gasification is the result of chemical reactions between carbon in the char and steam, carbon dioxide, and hydrogen in the gasifier vessel as well as chemical reactions between the resulting gases. Gasification reactions can be reqresented by :

$$C + H_2O + \text{Heat} \rightarrow CO + H_2$$

$$C + 2H_2O + \text{Heat} \rightarrow CO2 + 2H_2$$

$$C + CO_2 + \text{Heat} \rightarrow 2CO$$

$$C + 2H_2 \rightarrow CH4 + \text{Heat}$$

$$CO + 2H_2 \rightarrow CH4 + \text{Heat}$$

$$CO + 3H_2 + \text{Heat} \rightarrow CH4 + H2O$$

$$CO + H_2O + \text{Heat} \rightarrow H_2 + CO_2$$

Depending on the gasification process conditions, the remaining char may or may not have a significant amount of organic content or heating value.

1.4.4 Combustion

The themal energy that derives gasification reactions must be provided directly, by combusting some of the char or dry feedstock and in some cases the volatiles within the gasifie, or indirectly, by combusting some of the feedstock, char, or clean syngas separately and transferring the required heat to the gasifier. The following chemical and thermal reactions may take place when char or dry feedstock is burned.

$$C + O_2 \rightarrow CO_2 + \text{Heat}$$

$$C + \tfrac{1}{2}O_2 \rightarrow CO + \text{Heat}$$

$$\mathrm{H2} + \frac{1}{2}O_2 \rightarrow H_2O + \mathrm{Heat}$$

$$\mathrm{Char} + \mathrm{Heat} \rightarrow \mathrm{Slag}$$

$$\mathrm{Slag} \rightarrow \mathrm{Clinker} + \mathrm{Heat}$$

Combuction of char or fceedstock produces ash, unreacted organic materilal, which can be melted into liquid slag. Slag can be resolidified to form clinke.

In addition to heat, the combuction products are CO_2 and H_2O when clean syngas is burned to provide the required thermal energy.

1.5 Types of Gasification Reactors

The gasification process uses several reactors, which can be classified according to the relative movement of the fuel and the gasifying medium as either fixed beds (updraft, downdraft and crossdraft) or fluidized beds (bubbling, circulating, spouted and swirling)[2].

1.5.1 Fixed Bed Gasifiers :

Fixed bed reactors are those in which solids move either countercurrent or concurrent to the flow of a gas as reaction takes place, and the solids are converted to gases. Fixed beds are particularly suited to solid fuel contacting operations that require close temperature control (especially if the temperature is variable along the flow path), carryover of particles away from the reaction zone, simple operation and minimum erosion of the body of the reactor.[2]

Updraft gasifier

Figure 1.1 illustrates that the flow of the fuel and gases are countercurrent to each other in the updraft gasifier. This is the earliest and simplest type of gasifier reactor known. The high temperature oxidation zone is located at the bottom of the gasifier where part of the fuel is burned. The gasifying agent is injected at the bottom of the reactor and ascends from the bottom to the top while the feedstock is introduced at the top of the reactor and descends from the top to the bottom. The fuel descends through three zones (drying, pyrolysis and oxidation) of progressively increasing temperatures. Temperatures in the oxidation zone can exceed 1500 C. The heat dispersed from the oxidation zone and the gasification zone above it is transferred by forced convection and radiation upwards to the pyrolysis and drying zones, thus providing the heat required for drying, pyrolysis and endothermic char gasification processes. The oxidation zone lies at the bottom of the gasifier and the combustion gas passes through this zone reacting with the char, thereby releasing the required process heat. The produced gases, tar and other volatiles disperse at the top while ashes are removed at the bottom of the reactor. Part of the fuel is burned in the oxidation zone.

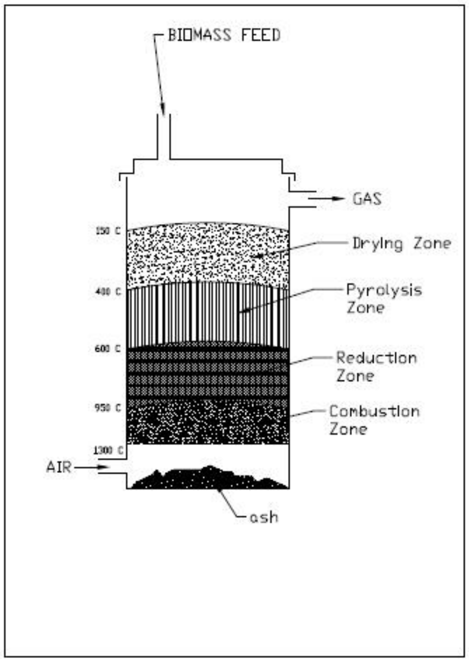


Figure 1.1: Updraft Gasifier [2]

Downdraft gasifier

Reaction zones in a downdraft gasifier are similar to those in the updraft unit, except the locations of the oxidation and reduction zones are interchanged. The most important difference is that the pyrolysis products in the downdraft type are allowed to pass through the high temperature oxidation zone. Hence, they undergo further decomposition. Also, the moisture vaporized from the biomass enters the gasification zone and serves as a gasifying agent. The final product gases, which leave the gasifier from the bottom at a fairly high temperature (700 ^0C), contain substantially less tar than the updraft gasifiers. In a downdraft gasifier, feedstock is introduced at the top and the gasifying agent is introduced through a set of nozzles located on the sides of the reactor.

The benefit of the downdraft gasifier lies in its ability to produce gas with low oil and tar contents, which means less cleaning before use in internal combustion engines. The gas can, therefore, be used with minimal filtering as a fuel for spark ignition and diesel engines. However, due to slag and clinker formation problems, this type of gasifier has been found unsuitable for fuels with high ash content and low ash fusion temperatures, such as crop residues. A major drawback is its inability to handle fine and fluffy (low density) crop residues materials.

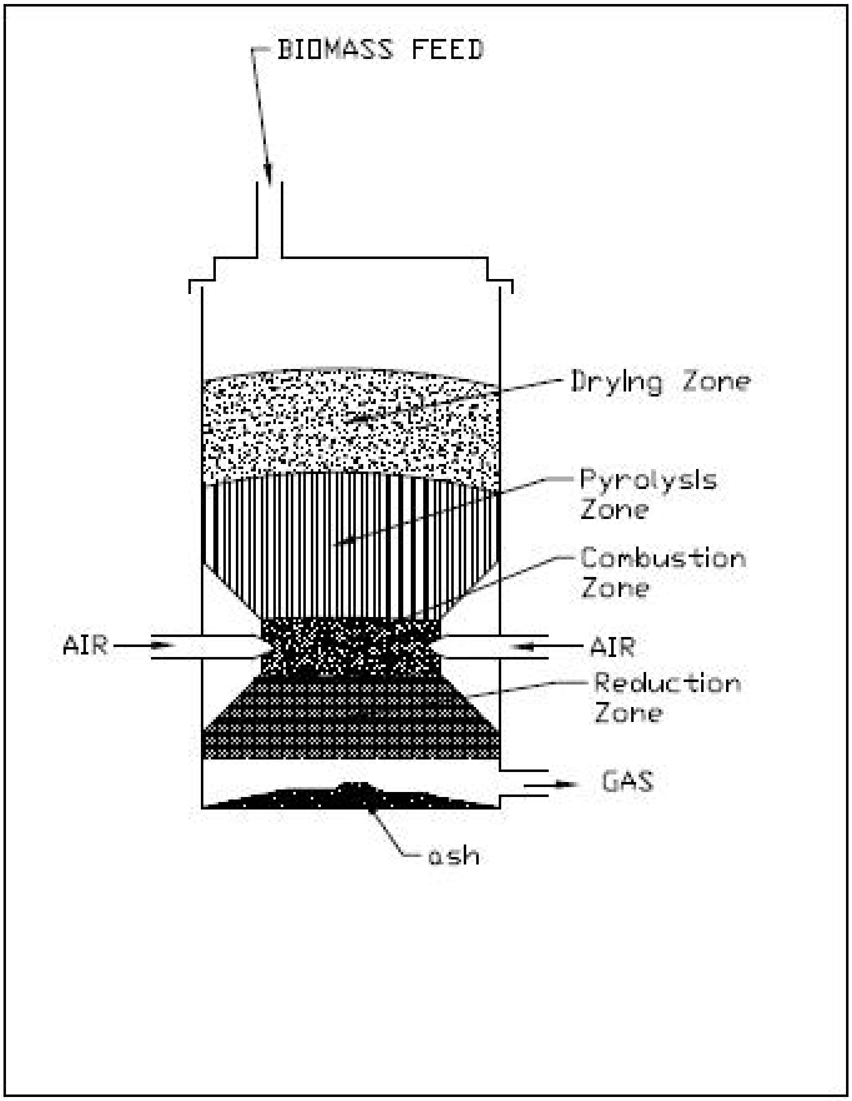


Figure 1.2: Downdraft Gasifier [2]

Crossdraft gasifier

Cross-draft gasifiers exhibit many operating characteristics of the down draft units. Air or air/steam mixtures are introduced in the side of the gasifier near the bottom while the product gas is drawn off on the opposite side. The velocity of the air as it enters the combustion zone is considerably higher in this design, which creates a hot combustion zone.

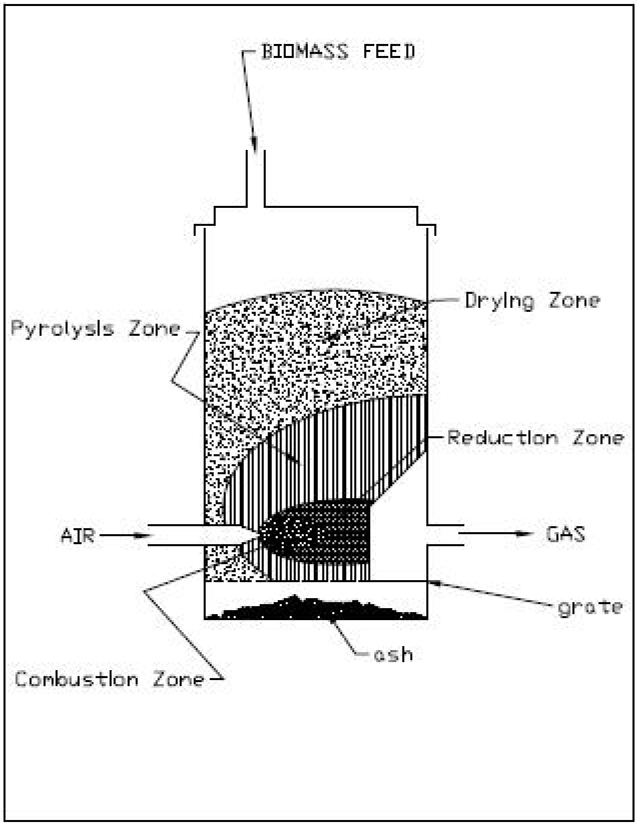


Figure 1.3: Cross-draft gasifier [2]

1.5.2 Fluidized Bed Gasifiers :

Unlike fixed bed reactors, models with a fluidized bed have no distinct reaction zones like drying, pyrolysis and gasification occur simultaneously in the reactor as the reactor is mixed and, thus, closed to isothermal. Fluidized bed reactors can be classified by configuration and the velocity of the gasifying agent, e.g., bubbling, circulating, spouted, and swirling fluidized beds.

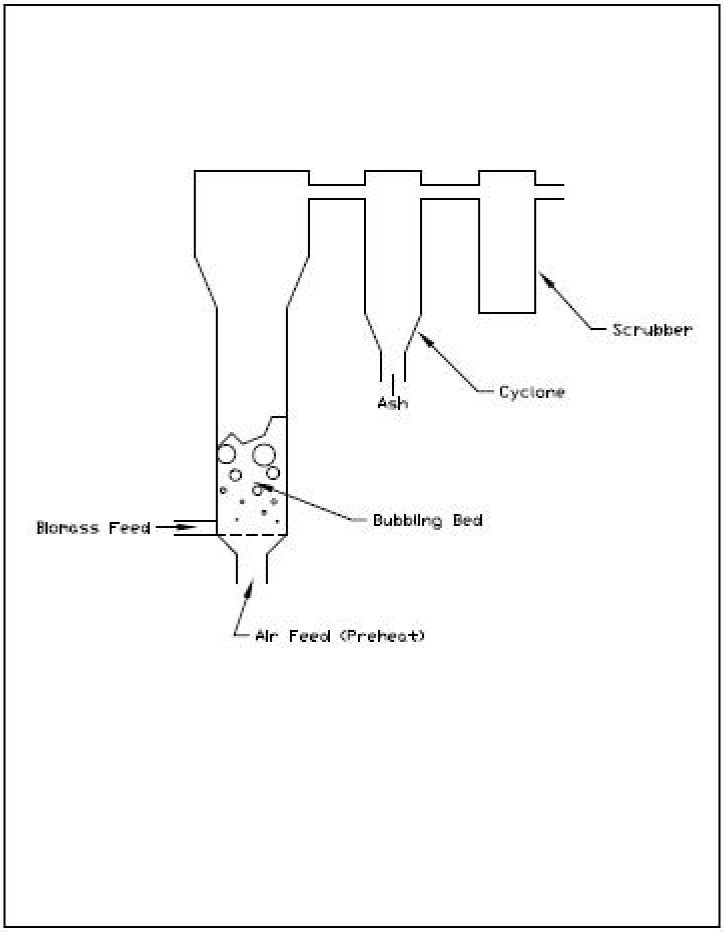


Figure 1.4: Fluidized bed gasifier[2]

Bubbling fluidized bed gasifier

In bubbling fluidized beds, granular material is fed into a vessel through which an upward flow of gas passes at a flow rate where the pressure drop across the particles is sufficient to support their weight (incipient fluidization).

Circulating fluidized bed gasifier

If the gas velocity in a bubbling fluidized bed is further increased, more particles will be entrained in the gas stream and leave the reactor. Eventually the transport velocity for most of the particles is reached, and the vessel can be quickly emptied of solids unless additional particles are fed to the base of the reactor.

Spouted fluidized bed gasifier

A spouted fluidized bed consists of a bed of coarse particles partly filling the vessel, which also has a relatively large control opening at its base. Gas is injected through this aperture. With sufficient gas flow, the particles in the gas can be force to rise in a fountain at the center of the bed and develop cyclic motion on the bed as a whole.

Swirling fluidized bed gasifier

A swirling fluidized bed consists of a bed of granular material in a cylindrical column. Primary air is introduced at the bottom of the bed through a distributor plate at a sufficient velocity to fluidize the bed material in a bubbling regime. Secondary air is introduced through one pair of openings (at least) into the freeboard region of the column to create swirl or vortex flow.

1.6 Motivation

Total world coal resources, all categories combined, may come to more than 1,000 billion tones of proved resources. Although coal deposits are widely distributed, 76 percent of the world's recoverable reserves are located in five countries: the United States (28 percent), Russia (19 percent), China (14 percent), Australia (9 percent) and India (7 percent).

1. A lignite recoverable reserve in world is 150 billion tonnes. So, Lignite represents 18% of world coal reserves.

2. Lignite Cheap, easily available and proven reserves in the India are approximately 4.1 billion tonnes. Occurrence of lignite in India is confined to States of Tamilnadu, Gujarat, Rajasthan, Pondicherry, Jammu & Kashmir and Kerala. In Gujarat, total proven recoverable reserves of Lignite is around 0.785 billion tonnes. So, there is an ample source of Lignite is available in Gujarat. Gujarat being one of the largest producers of the lignite will certainly benefited by this project.

3. Because of its low energy density, brown coal (Lignite) is not traded extensively on the world market compared with higher coal grades.

4. Its high moisture content and susceptibility to spontaneous combustion can cause problems in transportation and storage.

5. Lignite-burning plants also require typical environmental controls for coal-fired power plants to avoid environmental damage from the major air pollutants. These problems could be overcome by gasifying lignite in to producer gas in gasifier.

6. The remote regions of India either face severe shortage of power or are not connected with grid system. For villages/habitations, where grid connectivity would not be feasible or not cost effective, off-grid solutions based on stand-alone systems may on stand-alone systems may be taken up for supply of electricity so that every household gets access to electricity. A small capacity downdraft gasifier could be installed to produce Producer Gas by gasifying lignite. Producer gas can be burned as a fuel gas in an internal combustion gas engine or gas turbine for electricity generation in villages.

Chapter 2

Literature Review

2.1 Review of Gasification

Gasification is very old technology but it having very good growth. Many of projects are under design and construction all around the world. Here is one likely scenario based on the 2004 Gasication Technologies Council survey and general industry consensus is discussed.

2005 to 2010: During this period the IGCC (Integrated gasication combined cycle) process will be used to produce electricity at refineries in the United States from petcoke and similar materials. New coal-based projects will greatly expand the production of chemicals in China. And, an entirely new application will be seen in Canada, where syngas from gasification will be used to increase petroleum production in the Alberta oil sand fields[4].

2010 to 2015: The first generation of large-scale (500 MWeor greater) coal-based IGCC power plants will come online in the United States. These projects will further demonstrate to regulators and lenders that such projects are technically and financially sound. Gasification use for fertilizer and chemical production will grow dramatically (particularly in China)[4].

2015 to 2025: The second generation of large-scale IGCC plants will be built. They will take advantage of lessons learned in prior IGCC installations and may be sited at locations where the carbon dioxide created in the plants can be captured and stored in underground geological formations. Such projects may also be designed with the exibility to produce power, chemicals, fuels, and other products depending upon prevailing market conditions[4].

2.2 Gasification Applications

2.2.1 Gasification Technology for Power Generation and Industrial Applications

Currently, electric utilities and various industrial firms have expressed growing interest in finding economical and environmentally attractive methods of converting coal, wastes, and renewable fuels into replacement energy sources for use in combined heat and power applications. Biomass gasification will become significantly more attractive in industrial shaft power applications in rural area where grid electricity is either expensive or unavailable. In urban areas, the technology will be unattractive since grid electricity is usually a cheaper source of energy.

One industry of prime interest is the forest industry, which supplies residues such as off-cuts, edgings, shavings and sawdust. Exact quantities of these depend upon the tree species being used the end product of the industry and, the efficiency of equipment employed. Combined, residues from such sources amount to about 50% of the total quantity of wood processed. However, these residues would be utilized by a system whose end product is producer gas. Another process of prime interest is the harvesting from which crop residues such as straw could be obtained. The exact quantities of these crop residues depend upon the species being harvested, the end product of the mechanism and the efficiency of equipment used. These residues could be utilized using a fluidized bed gasifier to produce gas. The gas could be used for direct burning to produce heat for kiln drying or steam generation. Steam could be used to generate electricity through turbines or for the production of mechanical power. Alternatively, the producer gas could be purified and used in internal combustion engines for the generation of mechanical power or on-site electricity[2].

2.2.2 Shaft Power

Shaft power is significantly demanded in developing countries for irrigation. Currently many fossil-powered units are in use; thus. where the interruption of fossil fuel supply is common, alternative energy sources such as producer gas are being sought.

As an alternative to internal combustion engines that use producer gas exclusively, there are engines that are operated on the dual-more principle. In such systems, the producer gas is used as a supplement to diesel fuel. Here the consumption of wood would be approximately 1.4 kg per kWh of shaft power. Where the availability of suitable biomass is scarce, the possibility always exists for the cultivation of trees that take approximately three to four years to mature. The possibility of using crop residues in gasifiers has also gained great attention. Although the questions about the technical suitability of crop residues as gasifier fuel remains to be answered, the concept shows promise.

A practical example of this technology is the use of gasifier-powered irrigation pumps in Brazil. The production of shaft power for irrigation pumps, sawmills, milling and shelling of maize in isolated rural communities in developing countries is a promising application of the producer gas. In these operations, a potential gasification feedstock is produced as part of the process[2].

2.2.3 Vehicular Power

Inconvenience of gasifiers and the detrimental effects on engine performance are the main constraints of the gasification technology in vehicular applications. The next major limitation is the availability of readable biomass. During the two World Wars, wood chips and charcoal were suitable fuel for vehicle gasifiers. Fuel consumption will depend on factors such as type of gasifier, the load demand, driving conditions, type of vehicle and skill of the driver.

To avoid excessive engine wear and plugging of valves, gas supply lines and carburetors, the produced gas must be free of tars, dust, and acids. The presence of sticky and corrosive components (tars) is actually a major drawback to the introduction of biomass gasifiers in internal combustion engine application. However, with the present technology and continuing research, this problem should eventually be overcome. Due to its low heating value, producer gas causes a 30-40% de-rating of engine designed for gasoline fuel. An engine designed to use diesel fuel, on the other hand, is de-rated by only 10% to 20%. A dual fuel operation mode in which the engine draws 0-90% of its power output from producer gas and the rest from diesel oil is also possible.

The need to improve the power output from single-cylinder gasoline engine fueled with rice hull-produced gas was investigated by Camacho (1988). The normal compression ratio of the engine was 6.2. Standard engine cylinder head castings were machined to give compression ratios of 7.3 and 8.2. The engine test data indicated about a 10 to 16% power output for the 7.3 and 8.2, respectively, over the normal compression ratio 6.2. The comparison values for gasoline rated 3.7 kW engine on rice hull produced gas were: 1.42 kW vs. 1.57 kW (6.2 vs 7.3 compression ratio) and 1.42 kW vs 1.66 kW (6.2 vs 8.2 compression ratio)[2].

2.2.4 Direct Heat Applications

Most commercial gasifiers currently in operation are used to produce heat rather than fuel for internal combustion engine, primarily because the requirements for heating fuel are less stringent. When the gasifier is close coupled to a burning system, higher temperatures can be reached and the efficiency and output of the overall system can be enhanced.

All gasifiers can be used to provide producer gas for combustion purposes. However, the updraft is preferred in systems rated below 1 MW thermal power while the fluidized bed gasifiers are appropriate for ranges above this. Where fuel oil is being used to generate process heat, run furnaces or kilns, the gasification technology is a viable option.

The economic and technical problems of using direct heat gasifiers appear to be relatively minor. With more experience and better design, the range of potential uses will expand. However, fuel availability constraints will remain and, in the long term, will probably be the principal limitation on the spread of the biomass gasification technology. Countries that have large forest and agricultural resources are obviously suitable for the application of the gasification technology to direct heating. Logging residues, wood wastes and agricultural crops can all contribute to the heating needs of a wide range of nearby industries[2].

2.3 Downdraft Gasifier

A.Kr. Sharma / Renewable Energy 34 (2009) 1726–1733[6] concludes that Experimental study on a 75 kWth, downdraft (biomass) gasifier system has been carried out for obtaining temperature profile, gas composition, calorific value and trends for pressure drop across the porous gasifier bed, cooling–cleaning train and across the system as a whole in both firing as well as non-firing mode. The issues related to re-fabrication of damaged components/parts are also discussed in order to avoid any kind of leakage. For non-firing gasifier, the extinguished bed (progressively decreasing particle size distribution) shows much higher pressure drop as compared to a freshly charged gasifier bed (uniformly distributed particle size). The pressure drop across the porous bed, cooling–cleaning train is found to be sensitive to the increase in flow rate. The pressure drop across the spray coolers is also found sensitive to the gas flow rate, while the sand bed filters is found to be a strong function of quartz particle size in addition to the flow rate through them. The tar/ particulate deposited over the quartz particles constituting the filter bed gives comparatively higher pressure drop across them. The progressively decreasing particle size arrangement and higher operation time (more ash deposition in bed) is found to cause a marked increase in pressure drop through gasifier bed as well as through the entire system. Therefore, the shaking of grate is essential before a certain interval (i.e. w250 min in present case).

In firing mode, the higher temperature in bed tends to better conversion of non-combustibles component (like CO_2, H_2O) into combustible component (like CO, H_2) in the resulting gas and, thus, improves in the calorific value of product gas. For progressively decreasing particle size distribution, and with increasing gas flow rates leads to more rise in bed temperature resulting much higher pressure drop across the bed. Any increase in temperature in bed either due to energetics of reactions or any other reason like increase in gas flow rates tends to higher resistance to flow through the porous bed and thus higher pressure drops.

2.4 Effecting Parameters to Quality of Gas

A wide range of biomass fuels such as wood, charcoal, wood waste (branches, roots, bark, saw dust as well agricultural residues- maize cobs, coconut shells, cereal straws, rice husks, can be used as fuel for biomass gasication. Theoretically, almost all kinds of biomass with moisture content of 5-30% can be gasied; however, not every biomass fuel leads to the successful gasification. Most of the development work is carried out with common fuels such as coal, charcoal and wood. Key to a successful design of gasifier is to understand properties and thermal behavior of fuel as fed to the gasifier[3].

The properties of fuel which inuence the gasication are described below :

1. Moisture content
2. Particle size and distribution
3. Bulk density of fuel
4. Volatile matter content
5. Ash content and composition and slagging characteristics
6. Energy content of fuel
7. Fuel form
8. Reactivity of fuel
9. Dust content

10. Tar content
11. Caloric value

2.4.1 Moisture Content

In most fuels there is very little choice in moisture content since it is determined by the type of fuel, its origin and treatment. It is desirable to use fuel with low moisture content because heat loss due to its evaporation before gasification is considerable and the heat budget of the gasification reaction is impaired. The moisture content of the most biomass fuel depends on the type of fuel, it´s origin and treatment before it is used for gasification. Moisture content of the fuel is usually referred to inherent moisture plus surface moisture. The moisture content below 15% by weight is desirable for trouble free and economical operation of the gasifier. Higher moisture contents reduce the thermal efficiency of gasifier and results in low gas heating values. Igniting the fuel with higher moisture content becomes increasingly difficult, and the gas quality and the yield are also poor.

2.4.2 Particle Size and Distribution

The fuel size affects the pressure drop across the gasifier and power that must be supplied to draw the air and gas through gasifier. Large pressure drops will lead to reduction of the gas flow rate in downdraft gasifier, resulting in low temperature and tar production. Excessively large sizes of particles give rise to reduced reactivity of fuel, causing start-up problem and poor gas quality.

Acceptable fuel sizes depend to certain extent on the design of gasifier. In general, wood gasifier work well on wood blocks and wood chips ranging from 80x40x40 mm to 10x5x5 mm. For charcoal gasifier, charcoal with size ranging from 10x10x10 mm to 30x30x30 mm is quite suitable.

2.4.3 Bulk Density of Fuel

Bulk density is defined as the weight per unit volume of loosely tipped fuel. Bulk density varies significantly with moisture content and particle size of fuel. Volume occupied by stored fuel depends on not only the bulk density of fuel, but also on the manner in which fuel is piled. It is also recognized that bulk density has considerable impact on gas quality, as it influences the fuel residence time in the fire box, fuel velocity and gas flow rate.

2.4.4 Volatile Matter Content

Volatile matter and inherently bound water in the fuel are driven off in pyrolysis zone at the temperatures of 100°C-150°C forming a vapor consisting of water, tar, oils and gases. Fuel with high volatile matter content produces more tar, causing problems to internal combustion engine. Volatile matters in the fuel determine the design of gasifier for removal of tar. Compared to other biomass materials (crop residue: 63-80 %, Wood: 72-78 %, Peat: 70 %, Coal: up to 40 %), charcoal contains least percentage of volatile matter (3-30 %).

2.4.5 Ash Content and Composition and Slagging Characteristics

A mineral content of fuel which remains in oxidized form after combustion of fuel is called ash. In practice, ash also contains some unburned fuel. Ash content and ash composition have impact on smooth running of gasifier. Melting and agglomeration of ashes in reactor causes slagging and clinker formation. If no measures are taken, slagging or clinker formation leads to excessive tar formation or complete blocking of reactor.

In general, no slagging occurs with fuel having ash content below 5 %. Ash content varies fuel to fuel. Wood chips has contains 0.1% ash, while rice husk contains high amount of ash (16-23%).

2.4.6 Energy Content of Fuel

Energy content of fuel is obtained in most cases in an adiabatic, constant volume bomb calorimeter. The values obtained are higher heating values which include the heat of condensation from water formed in the combustion of fuel. The heating values are also reported on moisture and ash basis. Fuel with higher energy content is always better for gasification. The most of the biomass fuels (wood, straw) has heating value in the range of 10-16 MJ/kg, whereas liquid fuel (diesel, gasoline) posses higher heating value. The higher the energy content of fuel, the similar is the gasifier volume since for one charge one can get power for longer time.

2.4.7 Fuel Form

The form in which fuel is fed to gasifier has an economical impact on gasification. Cupers and Pelletizers densify all kinds of biomass and municipal waste into energy cubes. These cubes are available in cylindrical or cubic form and have a high density of 600-1000 kg/m3 the specific volumetric content of cubes is much higher than the raw material from which they are made.

2.4.8 Reactivity of Fuel

Reactivity determines the rate of reduction of carbon dioxide to carbon monoxide in the gasifier. Reactivity depends upon the type of fuel. It has found that wood and charcoal are more reactive than coal. There is relationship between reactivity and the number of active places on the char surfaces.

It is well known fact that reactivity of char surface can be improved through various processes including stream treatment (activated carbon) or treatment with lime and sodium carbonate. There are number of elements which act as catalyst and influence the gasification process. Small quantities of potassium, sodium and zink can have large influence on reactivity of the fuel.

2.4.9 Dust Content

All gasifier fuels produce dust. This dust is a nuisance since it can clog the internal combustion engine and hence has to be removed. The gasifier design should be such that it should not produce more than 2-6 g/m^3 of dust. The higher the dust produced, more load is put on filters necessitating their frequent flushing and increased maintenance.

2.4.10 Tar Content

Tar is one of the most unpleasant constituents of the gas as it tends to deposit in the carburetor and intake valves causing sticking and troublesome operations. It is a product of highly irreversible process taking place in the pyrolysis zone. The physical property of tar depends upon temperature and heat rate and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water).

Very little research work has been done in the area of removing or burning tar in the gasifier so that relatively tar free gas comes out. Thus the major effort has been devoted to cleaning this tar by filters and coolers. A well-designed gasifier should put out less than 1 g/m^3 of tar. Usually it is assumed that a downdraft gasifier produces less tar than other gasifiers. However because of localized inefficient processes taking place in the throat of the downdraft gasifier it does not allow the complete dissociation of tar.

2.4.11 Calorific Value

It is a well-established fact that when the same weight of the same substance burns to form the same products of combustion at the same temperature, the quantity of heat evolved is a constant, the value of which is independent of the rate of combustion.

This quantity is known as the heat of chemical combination of the substance with oxygen. In relation to substances used as fuels, it is also known as the "caloric value.". Thus, 1 gram of carbon burning to carbon dioxide evolves 8,080 gram-calories of heat, and 1 gram of hydrogen burning to liquid water evolves 34,462 gram-calories. The caloric value of carbon is therefore said to be 8,080 gram-calories, and of hydrogen 34,462 gramcalories. The gramcalorie is defined as the quantity of heat required to raise the temperature of 1 gram of water by one degree Centigrade.

2.5 Review of Coal Gasification

A. Williams[5] noted in his book that Coal gasification is a well-established technology in which coal is gasified with oxygen in an exothermic reaction to produce a combustible gas consisting of carbon monoxide, hydrogen, and some methane and carbon dioxide. This combustible mixture can be used as a fuel, and usually this is with a gas turbine to produce electricity, or it can be used to make a synthetic natural gas or chemical feedstock. Sometimes pure oxygen is used, in a process termed “air gasification” and then the product gas also contains nitrogen. Steam can be added to the oxidant stream to increase the amount of hydrogen in the gas produced; alternatively, water can be added as a liquid when the coal is injected in the form of coal-water slurry. Coal gasification has a widehistory is associated with their development. Coal may be used as a feedstock, but the technique is applicable to any hydrocarbon, including natural gas and heavy refinery residues for example.

Coal gasification can produce a gas used for synthesis(syngas), or as source of hydrogen for the manufacture of ammonia or hydrogenation applications in refineries, and many of the technologies have been developed by petroleum companies with these applications in mind. However, one of the main current interests is in the application of the gasified products in electricity generation. The conversion of coal to electricity, via such an itermediate gaseous product stage, can be achieved by employing the integrated gasification combined cycle (IGCC) technology. Here, a gasifier produces a fuel gas that is cleaned and then burned with compressed air in the combustor of a gas turbine to produce hot gases at high pressure. Gasification is recognized as a clean and efficient alternative to coal combustion for power generation, and this could become an increasingly important aspect of coal utilization[5].

2.6 Process Problems and Environmental Considerations of Coal Gasification

Producer gas consists of carbon monoxide, and it is extremely toxic and dangerous as it combines with hemoglobin in the blood, preventing oxygen absorption and distribution. Carbon monoxide concentration of 50 PPM produces no effect. As concentration increases there arises problems of headache, dizziness and even death also. No chronic symptoms can occur as the result of prolonged inhalation of relatively small amounts carbon monoxide. Fortunately, there is less of gas escape during operation as gasification works under suction. However situation is quite different during starting and closing installations. To avoid trapping of gas it is recommended to install the gasifier plant in the open air. During the gasification of biomass, ashes and condensate (mainly water) are produced. Ashes do not contribute to any environmental hazards and can be safely disposed. However for the tar containing condensate, the situation is different and disposable of those forms can have undesirable environmental effects. No specific information is available about the bio- degradation of the phenolic and tarry constituents of the condensates. Properties of exhaust emission of engines running on producer gas are generally acceptable[3].

2.7 Comparison between Coal, Wood and Co-gasification

Numerous reviews have been found related to individual studies on coal gasification(CG) and biomass gasification (BG). However, this review deals mainly with the Co-gasification of numerous types of coal and biomass and then compares their results with those obtained using coal adn biomass gasifcation in detail. There are several process parameters which have a direct effect on the gasification[7].

Table 2.1: Comparison between Coal, biomass and Co-gasification by fuel parameters[7]

Properties	**Coal Gasification**	**Biomass Gasification**	**Co-gasification**
Ash	High	Low	Low
Sulfur	High	Low	Low
Nitrogen	High	Low	Low
Voatile Matter	Low	High	High
Energy density	High	Low	High

Other paramentes which are also more important are as below :

Table 2.2: Comparison between Coal, Wood and Co-gasification by different parameters[7]

Properties	**Coal Gasification**	**Biomass Gasification**	**Co-gasification**
Bulk Density	High	Low	High
Calorific Value	High	Low	High
Moisture Content	Low	High	Low
Avai(Specially for coal and waste wood)lability	No Season limitation	Season limitation	No season limitation
Transportation and Storage Cost	Low	High	Low
Environmental Pollution	Increase	Decrease	Decrease in SO_X and NO_X
Scale	Large	-	Large (economically)
Gasification Temperature	High	Low	High
Carbon Conversion	Low	High	High
Char Production	Yes	No	Low
Efficiency	Low	High	High

This review widely reports that Co-gasification can be improved by optimum values of thise aforementined parameters. It can be conclude that it is promising technology. which can reduce consumption of fossil fuels and increase the use of renewable resources.

Kazuhiro Kumade [8] in his research paper Co-gasification of woody biomass and coal with air and steam noted below conclusions: A mixture of woody biomass and coal was gasified with air and steam in order to investigate the effect of mixtures with a varying content of biomass and coal on the behavior of co-gasification with air and steam. The following conclusions were drawn:

1. The conversion to gas increased with the biomass ratio while the conversions to char and tar decreased. No apparent synergy was observed due to the mixture of Japanese cedar and Mulia coal in terms of the carbon distribution of products.
2. The main product gases were H_2, CO and CO_2. With the increasing biomass ratio, the H_2 composition decreased and the CO_2 composition increased; the CO and hydrocarbon compositions were independent of the biomass ratio.
3. The low biomass ratio led to the production of a gas favorable for the syntheses of methanol and hydrocarbon fuel, and the high biomass ratio led to the production of a gas favorable for the DME synthesis on the present experimental conditions.
4. The extent of the shift reaction in the experiment was much lower than that in the equilibrium state. The extent of the shift reaction in the equilibrium state was independent of the biomass ratio. In contrast, the extent of the shift reaction in the experiment was dependent on the biomass ratio and reached the maximum value at a biomass ratio of 0.5. This might be because of the synergy due to the mixture of Japanese cedar and Mulia coal.
5. The cold gas efficiency of 65% to 85% was obtained under the condition of co-gasification in the present study.

Magin Lapuerta [9] investigated that in Co-gasification experiments showed the improvement on the producer gas quality when biomass was used, as a consequence of the high ash (up to 25% by weight) and to the low volatile (below 15% by weight) content of coal, and also of the low reactivity of coal as compared to biomass. Thus, cogasification would allow a more efficient use of autochthonous coals, reducing CO_2 emissions and other problems derived from the ash and sulphur content of coal. Synergic effects between biomass and coal have been observed since the gasification efficiency increases exponentially with the biomass content in the mixture.

I.I. Ahmed[10] carried out some experiments and noted that Gasification of polyethylene (PE) and woodchips (WC) mixtures had been investigated. Superior results in terms of syngas yield, hydrogen yield, total hydrocarbons yield, energy yield and apparent thermal efficiency had been shown from PE–WC blends as compared to expected weighed average yields from the individual components. Peak values of syngas yield, hydrogen yield energy yield, apparent thermal efficiency and carbon yield was obtained at PE percentage of approximately 60–80%. Results confirm synergistic interaction between PE and WC during high temperature steam gasification. These results reveal the importance of input feed composition to a gasifier. Small amounts of biomass (WC) material to the PE sample could result in higher energy yield than that obtained from 100%PE sample.

Pratik N. Sheth[11] observed tha a process of conversion of solid carbonaceous fuel into combustible gas by partial combustion is known as gasification. The resulting gas, known as producer gas, is more versatile in its use than the original solid biomass. In the present study, a downdraft biomass gasifier was used to carry out the gasification experiments with the waste generated while making furniture in the carpentry section of the institute's workshop. Dalbergia sisoo, generally known as sesame wood or rose wood was mainly used in the furniture and wastage of the same was used as a biomass material in the present gasification studies. The effects of air flow rate and moisture content on biomass consumption rate and quality of the producer gas generated were studied by performing experiments. The performance of the biomass gasifier system was evaluated in terms of equivalence ratio, producer gas composition, calorific value of the producer gas, gas production rate, zone temperatures and cold gas efficiency. Material balance was carried out to examine the reliability of the results generated. The experimental results were compared with those reported in the literature.

Based on the results of this study, the conclusions were drawn as :

- With an increase in the moisture content, biomass consumption rate decreases and with an increase in the air flow rate biomass consumption rate increases.
- Molar fraction of N_2 andCO_2 decrease with an increase in equivalence ratio till ER = 0.205, and for higher values of ER, they increase. The fraction of CO and H_2 shows increasing and decreasing trend exactly opposite to that of N_2 and CO_2.
- The calorific value, pyrolysis zone temperature and the oxidation zone temperature are maximum at ER = 0.205. However, the calorific value decreases for an equivalence ratio ranging from 0.205 to 0.35.
- With an increase in ER, the production rate of producer gas continuously increases.
- The value of cold gas efficiency is 0.25 for ER = 0.17. It becomes almost double with a small increase of 0.035 in the value of ER. The effect of ER on cold gas efficiency is comparatively lower for higher values of ER.
- The optimum equivalence ratio is 0.205 for the downdraft biomass gasifier studied.

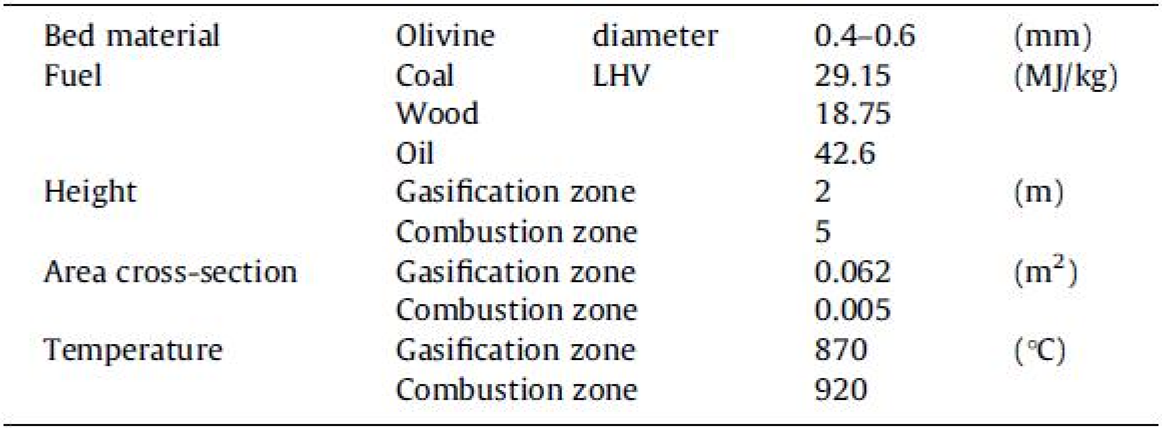
J S Brar [12] investigated that the tar evolution profile from the cogasification of forest residue and coal requires further investigation to customize the design of the gasifier, its operating conditions, and tar removal system. Along with this, the use of an entrained flow gasifier for the cogasification of coal and biomass can also be a research opportunity for the future because different types of feedstock can be used in it. Moreover, it has other advantages like uniform temperature profile inside the reaction zone, short reactor residence time, and high carbon conversions.

2.8 Review of Co-gasification of Coal and Wood

Isabella Aigner[13] in his paper "Co-gasification of coal and wood in a dual fluidized bed gasifier" done Co-gasification with coal and waste wood in fluidzed bed gasifier. In the last decade the reduction of CO_2 emissions from fossil fuels became a worldwide topic. Co-gasification of coal and wood provides an opportunity to combine the advantages of the well-researched usage of fossil fuels such as coal with CO_2-neutral biomass. Gasification itself is a technology with many advantages. The producer gas can be used in many ways; for electric power generation in a gas engine or gas turbine, for Fischer–Tropsch synthesis of liquid fuels and also for production of gaseous products such as synthetic natural gas (bio SNG). Moreover, the use of the producer gas in fuel cells is under investigation. The mixture of coal and wood leads to the opportunity to choose the gas composition as best befits the desired process. Within this study the focus of investigation was of gasification of coal and wood in various ratios and the resulting changes in producer gas composition. Co-gasification of coal and wood leads to linear producer gas composition changes with linear changing load ratios (coal/wood). Hydrogen concentrations rise with increasing coal ratio, while CO concentrations decrease. Due to the lower sulfur and nitrogen content of wood, levels of the impurities NH3 and H2S in the producer gas fall with decreasing coal ratio. It is also shown that the majority of sulfur is released in the gasification zone and, therefore, no further cleaning of the flue gas is necessary. All mixture ratios, from 100 % to 0 % coal, performed well in the 100 kW dual fluidized bed gasifier. Although the gasifier was originally designed for wood, an addition of coal as fuel in industrial sized plants based on the same technology should pose no problems.

Experiment properties are as shown in fingure.

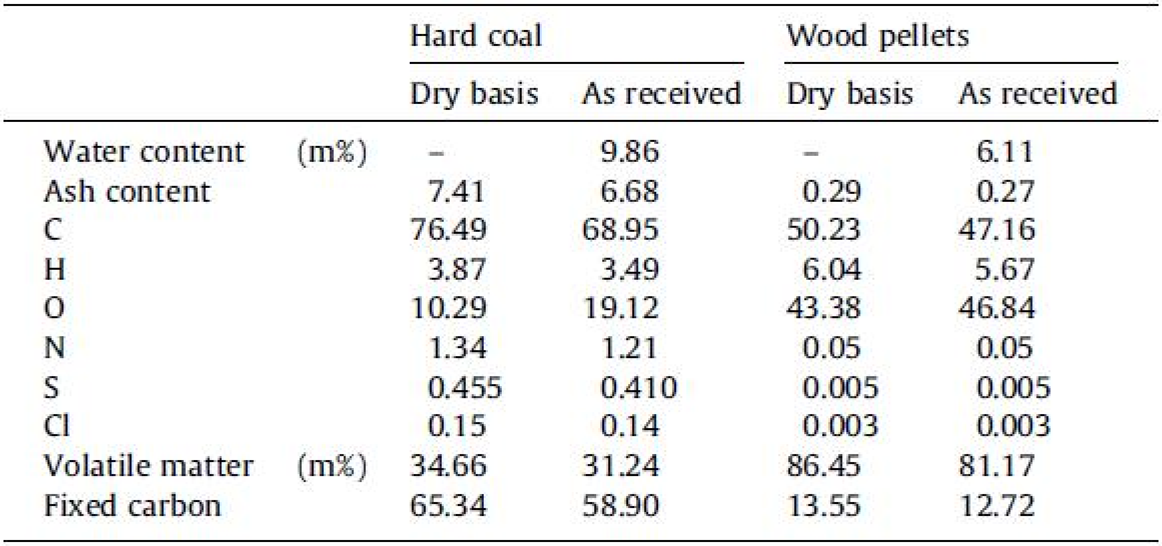
Table 2.3: Experimental properties [13]



Bed material	Olivine	diameter	0.4–0.6	(mm)
Fuel	Coal	LHV	29.15	(MJ/kg)
	Wood		18.75	
	Oil		42.6	
Height	Gasification zone		2	(m)
	Combustion zone		5	
Area cross-section	Gasification zone		0.062	(m^2)
	Combustion zone		0.005	
Temperature	Gasification zone		870	(°C)
	Combustion zone		920	

Since the facility works under atmospheric pressure, only pressure differences within the gasifier are measured and hence the most important pressure measurement is the pressure drop in the bubbling fluidized bed of the gasifier. There are five temperature measurement points in each reactor, at different heights. The heights in Table 2 are given as measured from the ground.

Properties of coal and wood are as below :



		Hard coal		Wood pellets	
		Dry basis	As received	Dry basis	As received
Water content	(m%)	–	9.86	–	6.11
Ash content		7.41	6.68	0.29	0.27
C		76.49	68.95	50.23	47.16
H		3.87	3.49	6.04	5.67
O		10.29	19.12	43.38	46.84
N		1.34	1.21	0.05	0.05
S		0.455	0.410	0.005	0.005
Cl		0.15	0.14	0.003	0.003
Volatile matter	(m%)	34.66	31.24	86.45	81.17
Fixed carbon		65.34	58.90	13.55	12.72

Figure 2.2: Ultimate and proximate analysis of coal and wood

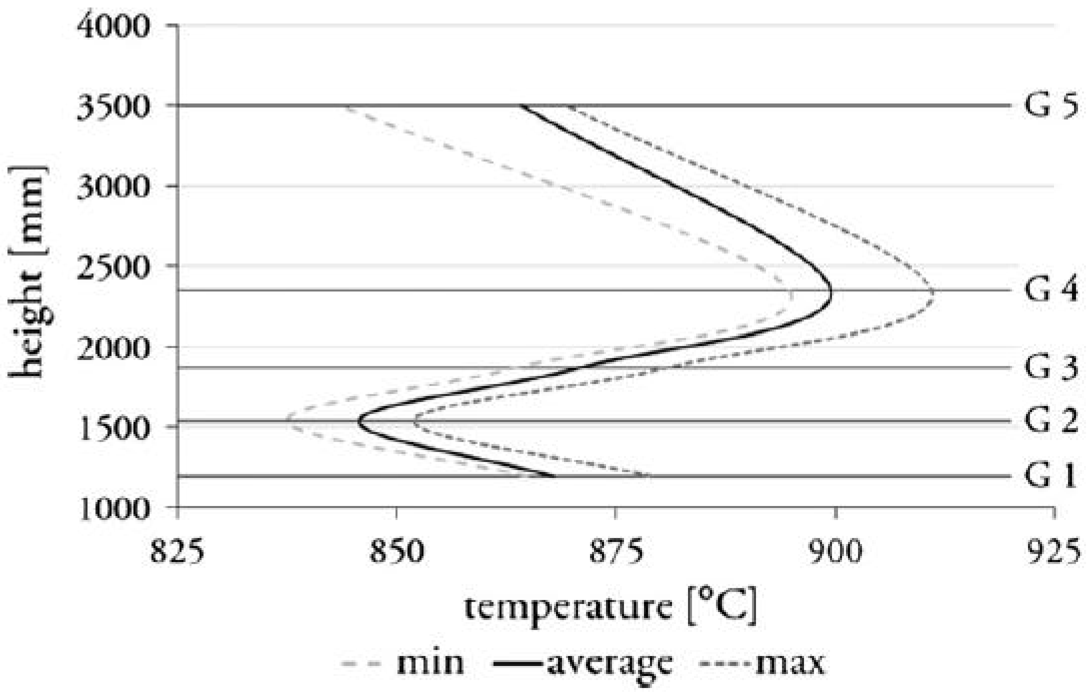


Figure 2.1: Temperature distribution in the gasifier

Major producer gas comonents details are as below :

As expected, for coal gasification the hydrogen concentration rises with increasing coal ratio . Carbon monoxide content, as well as ethane, increases with rising wood ratio. Methane and ethane also show a slight increase with rising wood ratio, whereas propane shows no significant change. Kumabe and co-workers found no relationship between wood ratio and methane concentration, CO or higher hydrocarbons, although increasing CO_2 concentration with rising wood ratio was mentioned.

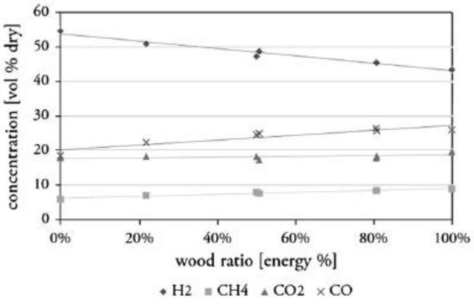


Figure 2.3: Main producer gas components dry and nitrogen free[13]

The results show a linear relationship between wood ratio and CO concentration in the dry producer gas. Apparently the different experimental conditions as well as reaction media also have a significant influence on the sensitivity of producer gas concentration change in relation to changing wood ratio.

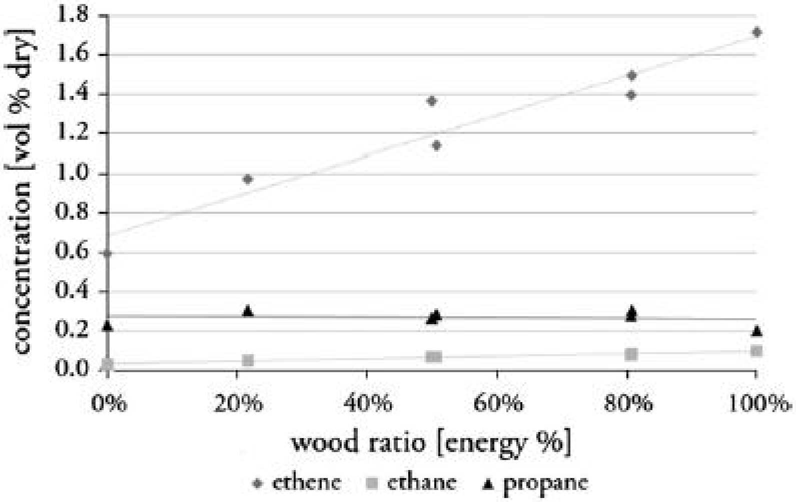


Figure 2.4: Hydrocarbons in the producer gas[13]

Both H_2S and NH_3 show linear increases in concentration with increasing coal ratio. This effect was expected since the majority of coal and wood reacts with the steam in the gasification zone, with mainly char transported to the combustion zone. Thus it is assumed that most of the fuel's sulfur and nitrogen reacts in the gasifier by forming gaseous molecules.

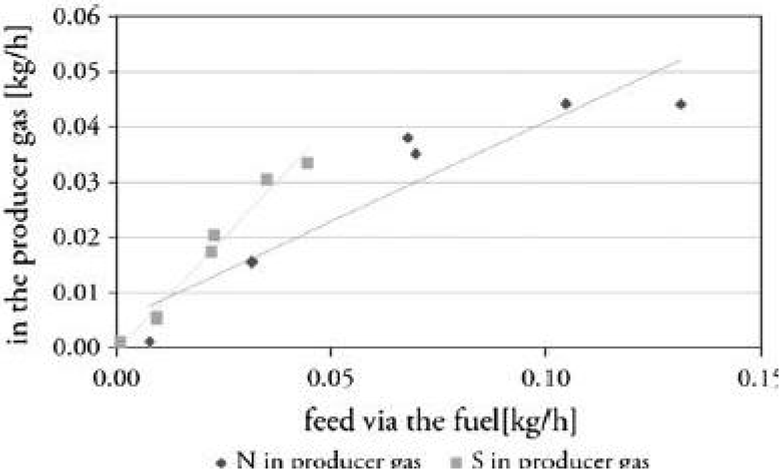


Figure 2.5: Sulfur and nitrogen flows in the fuel and in the producer gas

Nearly all sulfur which is transported to the gasifier via the fuel is found in the producer gas as H2S. According to research at Vienna University of Technology it can be assumed that nitrogen also forms N2 as well as NH3. The results show that about 50% of the nitrogen form NH3.

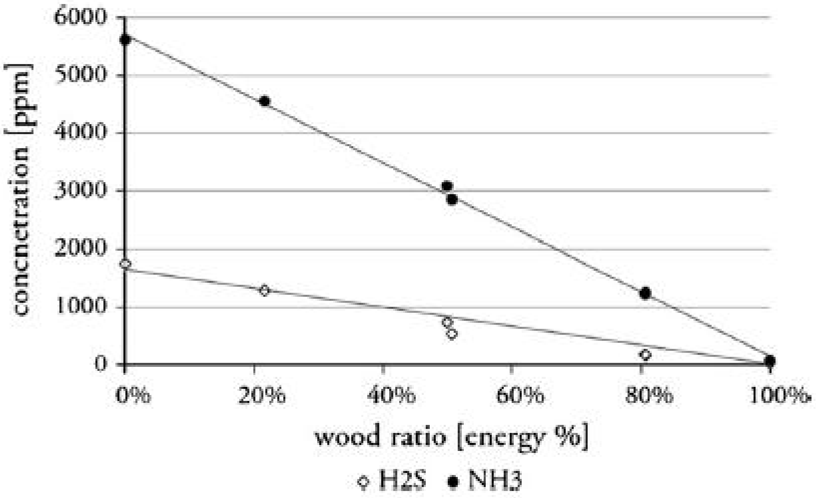


Figure 2.6: H_2S and NH_3 concentration in the producer gas.

In producer gas from gasification at temperatures of about 870 C, mainly tertiary tars are found which do not exist in natural biomass or coal. Tertiary tars are formed from secondary and primary tars. Primary tar originates from cellulose and hemicellulose and mostly consists of oxygen rich reactive molecules, which are more likely to be degenerated to smaller gaseous molecules than to form higher tars. It can be found in the literature that primary tars which emerge from lignin are more likely to form secondary and the tertiary tar.

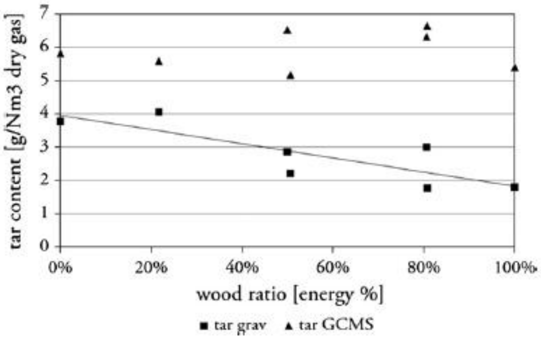


Figure 2.7: Dust and entrained char in the producer gas.

The increasing coal ratio also has an influence on the additional fuel flow which is needed for regulation and additional heat supply in the combustion zone. Due to the lower reaction rate of coal in the gasification process, more coal char is transported to the combustion zone and therefore the demand on external energy in the combustion zone decreases.

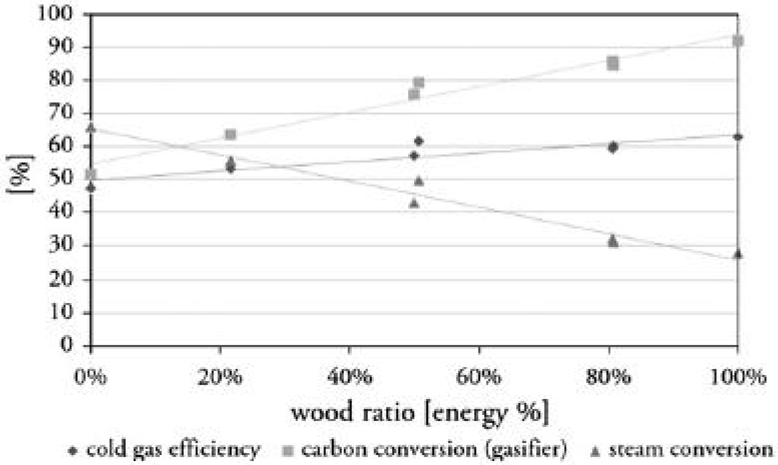


Figure 2.8: Cold gas efficiency, conversion of carbon and steam

Conclusions of this review is as below :

Coal and biomass were successfully gasified in a mixture range of 0–100%. The main producer gas components were H_2, CO, CO_2 and CH_4, while ethene, ethane and propane were also formed but only in amounts below 1.8 vol.% dry gas. All gas components show a linear relationship with linearly changing fuel ratios. No synergetic effects of co-gasification between coal and biomass were found. With a coal ratio above 50 energy%, hydrogen concentrations above 50 vol.% dry were achieved. High wood ratios lead to a gas which is more suitable for Fischer–Tropsch synthesis and SNG production due to a higher H_2/CO ratio.

Tar content decreases with increasing wood ratios, but is generally low due to the presence of the catalytically active bed material olivine. Concentrations of NH_3 and H_2S increase linearly with an increasing coal ratio due to the higher sulfur and nitrogen content of the coal. The coal ash content is also higher and so consequently the dust content of the producer gas increases with the coal ratio.

Cold gas efficiencies from 48% (100% coal) to 62% (100% wood) were achieved. The cold gas efficiency should be even higher in an industrial sized plant because of the relatively high heat loss (9%) of the test facility. The carbon conversion of wood is higher than that of coal due to higher volatiles content of wood and hence the carbon conversion increases with increasing wood ratio.

World energy demands are increasing from year to year. But renewable resources, especially biomass, are limited in their production and therefore fossil fuels will still form a significant part of future energy supplies. The technology described within this paper provides an opportunity for the flexible use of renewable fuels such as biomass, together with fossil fuels.

2.9 Objectives of Study

Objectives decided from above literature reviews are as below :

1. To check the effect of co-gasification by adding wood on performance of the gasifier.
2. To check the reduction of clinker formation by adding wood with lignite.
3. To study effect of co-gasification of lignite and waste wood on GGR, GCV of syngas, fuel consumption and gasifier efficiency.

Chapter 3

Experimental Methodology

3.1 Experimental Setup Details

Downdraft gasifier having capacity of 10 kWe.

The system consists of the following:

- Gasifier Reactor
- Cyclone
- Orifice Meter
- Surge tank
- Ball valve
- Filter
- Engine

A 10 kWe Downdraft gasifier has been developed. The instrumentations on this gasifier include calibrated 8 nos. K type thermocouple probes for the measurement of temperature along the length of gasifier, gas sampling, and measurement of pressure drop with the help of U tube manometer. Gas analysis is carried using computer controlled gas chromatograph. The thermocouple probes are developed using 14 gauge k type thermocouple wires. These wires were inserted in Chromium/aluminum bids. The lead coming out of the tube is thoroughly sealed using asbestos powder so that the atmospheric air is minimized and thereby permits more realistic measurement of temperature along the length of gasifier. 0.75 HP pump placed to circulate water in water tank for suction on gas from gasifier system.

In order to measure the pressure drop across each element the pet cock are inserted on inlet and outlet respectively. Orifice is placed across the system. The temperature in gasifier is measured with eight thermocouples at regular distance. The volume of surge tank is kept 100 times the volume of pipe in order to avoid chock up. Ball valve is placed below and after blower which maintains the flow rate of the system. I.C. Engine having 10 kWe capacity is also connected with the system. Cyclone separator, Surge tank, filter are kept to clean and cool gas via removing ash and tar from syngas.

It was noticed during cleaning of the gasifier gasket was damaged very frequently due to large weight of gasifier. Therefore chain kappa was installed to lift the lead of the gasifier. So that gasket may not be damaged. Chain kappa is mounted with the help of C channel on two sides of wall.

Air tuyere is important part for gasifier. It supplies air to combustion zone of gasifier as per requirement. There are two way to control air which is passing throw air tuyere. One is to regulate from air tuyere regulator and other is to regulate through water pump valve.

Vibrating device is mounted on upper part of gasifier. It vibrates the upper part of the gasifier continuously. At the bottom of gasifier, a small mechanism is fixed which rotates the grates at regular interval. These two devices help in improving the flowability of fuel which in turn improve the quality and flow of gas.[3]

3.2 Pre-preparation for Experimen

3.2.1 Lignite Sizing

Figure 3.1: Lignite

Lignite is available in rock form in nature. Due to high contain of volatile matter, it is soft. In order to use lignite as a fuel in gasifier, it is required to break lignite in predetermine sizes. However, as lignite is soft material, it is very dificult to break in exact size. So, it was decided to perform the experiments with lignite in following sizes.

The maximum and minimum size of lignite was selected and then accordingly the sieves were prepared.

Experiments were plan with following particle sizes:

1. 13 mm to 16 mm
2. 16 mm to 19 mm
3. 19 mm to 22 mm
4. 22 mm to 25 mm
5. 25 mm to 28 mm
6. 28 mm to 31 mm

Table 3.1: Selection of particle size

Actual particle size (mm)	Selected particle range (mm)		Sieve hole dia,(mm)	
	max	min	max	min
14.5	16	13	16	13
17.5	19	16	19	16
20.5	22	19	22	19
23.5	25	22	25	22
26.5	28	25	28	25
29.5	31	28	31	28
33	35	31	35	31

3.2.2 Wood Sizing

Wood is used as a size of 50 * 40 * 5 mm for all experiments. For experiments waste furniture wood is used.

3.2.3 Char Preparation

It is dificult to burn coal or lignite in gasifier when initial temperature is very low. In order to initiate the combustion of these fuels, char is used as an igniter, since it burns very easily. Generally char is prepared from wood. Required quantity of wood is taken. With the help of kerosene, wood is fired and allow it to burn for 20 minuts. After that, it is covered with suitable vessel in order to burn fuel in the absence of oxygen. Approximately after 2 hours, char is prepared which is blackish in color and shining in nature

3.3 Experiment Procedure

First of all, pump is started. Pressurize Water from pump reach nozzle and because of water velocity, suction occurs and gas is sucked from gasifier. Regulate the water flow with valve. Gas is generated in gasifiier because of burning of fuel and is passing through the cyclone separator where the tar content is removed. Then the gas is passed through surge tank where is furthered cleaned and temperature is also reduce because surge tank is filled with saw dust. Then gas passes to the filter for further cleaning. Ball valve is situated just after filter. From this valve, gas sample may be taken for gas chromatography. After ball valve, gas is further diverted into two passages; one is leading to gas burner and other towards I.C. Engine. Both the passages are provided with flow regulators.

3.4 Measuring and Calculating Parameters

3.4.1 Proximate and Ultimate Analysis of Lignite

The proximate analysis was carried out by using simple test method explain in following sections. Proximate analysis of biomass includes measurement of moisture content, ash content, volatile matter and fixed carbon.

Moisture content

The moisture content of fuel is determined by following methods. A known weight of fuel sample is placed in a crucible. It is than placed in a hot air oven, which is minted at temperature of 110 °C for about 2 hours. At that temperature the moisture in sample is evaporates. After 2 hours the sample is taken out of oven and its weight is again measured. The moisture content in percentage of fuel is calculated as:

$$m = (\frac{m_i - m_f}{m_i}) \times 100 \tag{3.1}$$

Figure 3.2: Crucible

Ash content

Ash is non-combustible components of the fuel. The calofiric value of the fuel depends on the ash amount. Higher the ash amount lower will be the calorific value of fuel. A known weight of fuel sample is placed in a crucible. It is than placed in a muffle furnace, at 750°C temperature for about 15 minutes so that all fuel is burn completely. Sample is taken out of furnace and the fuel remaining in crucible is ash amount in sample. Sample is put in desiccators and cools at atmospheric temperature, then again measuring the weight of sample.

$$a = (\frac{m_f}{m_i}) \times 100 \tag{3.2}$$

Figure 3.3: Muffle Furnace

Volatile matter

The volatile matter of fuel is the actual carbon present in fuel, which when heated convert into volatiles. For determining the amount of volatile matter, known weight of dried and ground (Heated at 110°C C and cooled in desiccators to normal temperature) sample of fuel is taken in an air tight closed crucible. This sample is then placed in a muffle furnace at 900°C for about 15 minutes. Then sample is put in desiccators and cools at atmospheric temperature, and again measuring the weight of sample. The residue left in crucible is fixed carbon and ash. The percentage volatile matter in given fuel sample is calculated by following formula.

$$V_m = (\frac{m_i - m_f}{m_i}) \times 100\% \tag{3.3}$$

Fixed carbon

Fixed carbon in the given fuel sample is calculated by weight balance. It is obtained by subtracting the percentage of moisture, ash and volatile matter from 100 %.

$$F_c = 100 \tag{3.4}$$

Calorific value of fuel

The Caloric value of fuel is defined as the amount of heat evolved when a unit weight of fuel is completely burned and the combustion product are cooled at normal temperature. The calorific value of any given fuel is dependent on the moisture content and its density. The caloric value is determined by bomb calorimeter. A sample of dry lignite with a known mass is burnt in atmosphere of oxygen in stainless steel high pressure vessel, known as bomb. The bomb is then placed in calorimeter which highly polished outer vessel containing a known weight of water with is known temperature. The combustion products CO2 and H2O are allowed to cool to the normal temperature. The resulting heat of combustion is measured from the accurate measurement of the rise in temperature of water in calorimeter, the calorimeter itself and the bomb. The caloric value so estimated is the gross caloric value.

Figure 3.4: Bomb calorimeter

Result of Proximate analysis, Gross calorific value and Sulfur content

Proximate analysis, Gross calorific value and Sulfur content are very important parameters to analyze the quality of fuel. The tests were performed in Ahmedabad Textile Industry's Research Association and Sardar Patel Renewable Energy & Research Institute. Results of proximate analysis for Lignite, wood and char are as below :

Table 3.2: Results of proximate analysis, sulfur content and GCV for lignite, wood and char[3]

	Moisture (%)	Voatile matter (%)	Ash (%)	Fixed Carbon (%)	Sulfur(%)	GCV (kcal/kg)
Lignite	10.198	45.115	12.789	31.898	0.7	3778
Wood	6.696	82.846	4.551	5.907	N/A	3496
Char	4.861	11.139	6.276	77.724	N/A	N/A

3.4.2 Bulk Density of Lignite and Wood

Density of lignite changes with change in particle size. The main reason behind that is air gap between particle sizes. Smaller size has less air gap so more density and vice versa. All the dimensions of a box were measured. Fuel having definite particle size was filled in box and fuel mass was measured.

Table 3.3: Density of fuel for different particle size

Fuel	Particle Size (mm)	Density (kg/m^3)
Lignite	31-35	582.16
	28-31	669.25
	25-28	716.16
	22-25	776.34
	19-22	899.52
	16-19	1020.8
	13-16	1080.76
Wood	50 * 40 * 5	413.76

3.4.3 Equivalence Ratio

Equivalent ratio (ER) is very important term in gasification and combustion. In simple word, equivalent ratio means ratio of actual fuel air ratio to stoichiometric fuel air ratio. The equivalence ratio of a system is defined as the ratio of the fuel-to-oxidizer ratio to the stoichiometric fuel-to-oxidizer ratio. Mathematically,

$$ER = \frac{Fuel\,to\,Oxidizer\,ratio}{(Fuel\,to\,Oxidizer\,ratio)_{stoichiometric}} \tag{3.5}$$

3.4.4 Temperature Profile

Calibrated 8 nos. K-type thermocouple probes are used for measurement of temperature along the length of gasifier. The thermocouple probes are developed using 22 gauge K-type thermocouple wire. These wires were inserted in ceramic bids, which were placed inside the inconel tube of 8 mm diameter. The lead coming out of the tube is thoroughly sealed using asbestos powder so that atmospheric air in gas is minimized and there by permits more realistic measurement of temperature.

Temperature probe of gasifier is obtained by taking temperatures at different zone at regular time intervals. There are mainly four processes in gasifier. The temperatures are taken in drying zone, Pyrolysis zone, Oxidation zone and reduction zone at seven different places along the length of gasifier.

3.4.5 Gas Generation Rate

Gas generation rate can be calculated from various devices like U Tube manometer, Gas flow meter, anemometer etc. Gas flow meter is accurate device but because of tar, normal gas flow meter can't be used for this application. Gas flow rate (Gas generation rate) is calculated by measuring pressure difference at orifice.

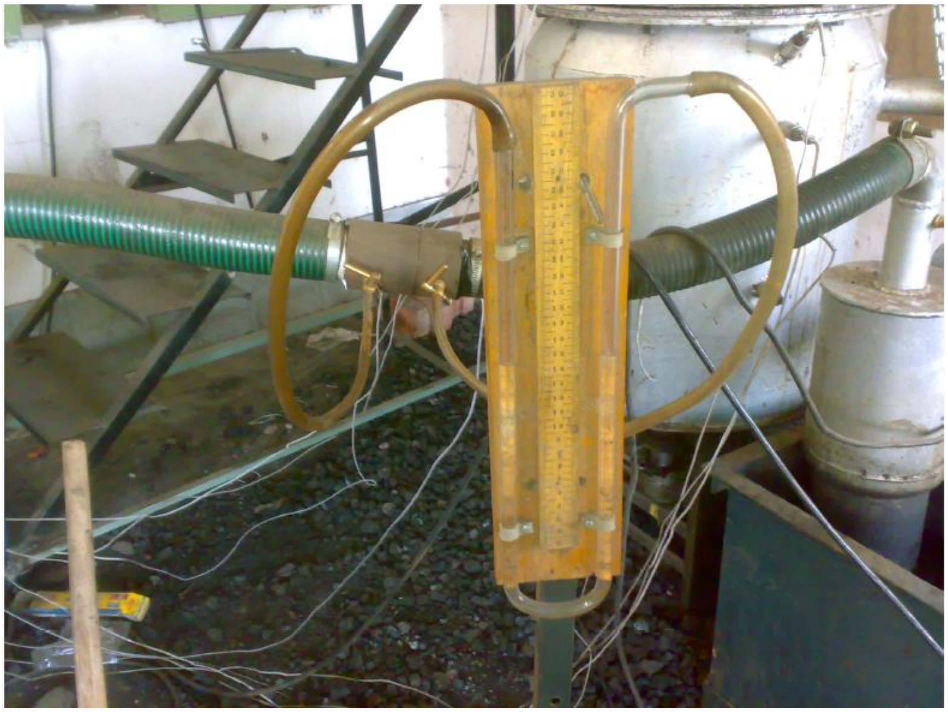


Figure 3.5: U tube manometer[3]

Gas flow rate is measured with the help of calibrated orifice meter, which is kept in main line and with differential U- tube manometer. The orifice is having 50.8 mm inlet diameter and

25.4 mm throat or orifice plate diameter. Gas generation rate was calculated by following equation:

$$Q = C_d \times \frac{a_1 * a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2 * g * h * (\frac{\rho_w}{\rho_g} - 1)} \tag{3.6}$$

Figure 3.6: Electronic anemometer

Alternate equipment for finding gas flow rate is Anemometer. Anemometer, intell safe model AR816 was used to measure linear velocity. Gas flow rate is calculated by multiplying linear velocity with flow area.

3.4.6 Fuel(Lignite + Wood) Consumption

Gasifier is initially topped with Char and lignite feedstock. After regular time interval mixture of lignite and wood is topped up. Fuel consumption is calculated by measuring weight of initial topped material, Weight of mixture topped up in time interval, Weight of material remaining in gasifier after experiment and time duration of experiment.

$$FC = \frac{W_{im} + W_{mt} - W_{mr}}{t_{td}} \tag{3.7}$$

3.4.7 Calorific Value of Producer Gas

It is very important to measure calorific value of producer gas to analyze efficiency of gasifier. The composition of producer gas is measured by Gas Chromatograph. Here the concentration of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen in producer gas is measured. Caloric value of the producer gas on the basis of the above mentioned gases is also evaluated. The caloric value of producer gas mainly depends on concentration of carbon monoxide, hydrogen, methane in producer gas. Producer gas was filled in gas collecting balloon and did gas chromatography on it to find percentage of gas composition.

Figure 3.7: Gas chromatograph (GC)

Table 3.4: Gas composition in producer gas[3]

Components	Range of Composition (%)
Hydrogen	8-18
Nitrogen	45-60
Methane	2-5
Carbon Monoxide	5-20
Carbon Dioxide	5-15
H_2O	6-8

This Gas chromatograph (GC) set up is situated in Chemical Laboratory, Nirma University. It is Gas chromatograph machine model SHIMANDZU GC-2010. Tubular filed bed reactor of GC made of stainless steel tube of 18.05 mm inner, 19.05 mm outer diameter and tube length 500 mm. The producer gas products are analyzed using gas chromatography equipped with thermal conductivity detector (TCD) and Carbosieves 11 column or porupakk Q and 5 A modular sieve column with Ar, N_2 and He as the carrier gas for the H_2, CO, CH_4, CO_2 gas composition.

1 kcal= 4.18 KJ

Table 3.5: Calculation for caloric value of producer gas components

Name of Component	Formula	Higher Heating value (MJ/m^3)	Lower Heating value(MJ/m^3)
Hydrogen	H_2	13.2 * $\%H_2$	11.2 * $\%H_2$
Carbon Monoxide	CO	13.1 * %CO	13.1 * %CO
Methane	CH_4	41.2 * $\%CH_4$	37.1 * $\%CH_4$

(**Reference: Handbook of Biomass Downdraft Gasier Engine Systems By Thomas B. Reed and Agua Das)

3.4.8 Heat Generation Rate

Heat generation rate is the amount of heat generated from gasifier in unit time. It measures the capacity of gasifier. Heat generation rate calculate from caloric value of gas and gas generation rate of producer gas by following equation:

$$\text{HGR} = \text{CV of producer gas (kcal / N } m^3\text{)* GGR (N } m^3\text{/ hr)}$$

3.4.9 Efficiency of Gasifier

Gasifier efficiency is the ratio of total energy in supply fuel and total energy in producer gas. So the gasifier efficiency is depending upon Caloric value of Lignite, Fuel consumption, Caloric value of producer gas and Gas flow rate. The efficiency is calculated by,

$$\eta = \frac{CV\,of\,gas\,kcal/m^3 * GGR\,in\,m^3/hr}{CV\,of\,Lignite\,in\,kcal/kg * FC\,in\,kg/hr} \tag{3.8}$$

3.5 Uncertainty Analysis

Uncertainty is also known as "error." Any measured or calculated value has some uncertainty in the reported value. This does not refer to mistakes, but rather unavoidable error due to the nature of the experiment. For example, if you were measuring the width of a grape using a ruler, you might report a value of 12.3 mm but there would definitely be some error incorporated in that last digit.

All uncertainties are reported to 1 significant figure. The reported value should then be rounded to the same digit as the uncertainty. When you know uncertainties, the significant figures of the reported value should be determined by the uncertainty rather than by standard sig fig rules.

It is also vital that you use several significant figures throughout your uncertainty calculations, so as to get an accurate representation of your overall uncertainty. If you are performing a series of calculations, keep all digits in your calculations until you complete ALL of your calculations. Then go back and report intermediate and final uncertainties with one significant figure.

There are two ways to represent uncertainty:

- Absolute uncertainty (AU) is a measure of uncertainty with the same units as the reported value. For example, the grape's width is 12.3 ± 0.2 mm, where 0.2 mm is the AU.
- Relative uncertainty (RU) represents AU as a fraction or percentage. For example, 0.2mm/12.3mm = 0.02 = 2%. The grape's width is 12.3 mm ± 2%, where 2% is the RU. Absolute uncertainty (AU)

A measured quantity is often reported with uncertainty. Absolute uncertainty is the uncertainty given in the same units as the measurement:

meas = (23.27 ± 0.01) g

where 0.01 g is the absolute uncertainty.

Reference: Taylor, John R., An Introduction to Error Analysis

3.5.1 Uncertainy Analysis of Gas generation Rate Measurement

Gas generation rate (Q) measured by Anemometer which gives velocity of gas. Least count of U-tube manometer is 0.1 m/s.

$$Q = V \times A \tag{3.9}$$

$$\frac{\partial Q}{\partial V} = A \tag{3.10}$$

$$\nabla Q = \sqrt{(\frac{\partial Q}{\partial V} \times w_v)^2} \tag{3.11}$$

Where,

A = 0.00206829 Area of outlet pipeline

∇Q = Absolute uncertainty in Gas generation Rate

w_v= 0.1 m/s (Least count of Anemometer)

By above calculation absolute and relative uncertainty in gas generation rate measurement is ±0.00020 and 0.00063% respectively.

3.5.2 Uncertainty Analysis of Measurement of Fuel consumption

Fuel consumption measure by following equation :

$$F.C. = \frac{(w_1 - w_2)}{t} \tag{3.12}$$

$$\nabla F.C. = \sqrt{(\frac{\partial F.C.}{\partial w_1} \times Ww_1)^2 + (\frac{\partial F.C.}{\partial w_2} \times Ww_2)^2} \tag{3.13}$$

Where,

$\nabla F.C.$= Absolute unceratinty in fuel consuption

w_1=w_2= Least count of Weight measurement machine = 0.001

t = time run of experiment

By above calculation absolute and relative unceratinty in fuel consumption measurement is ±0.0041 and 0.0152% respectively.

3.5.3 Uncertainty Analysis of Measurement of Calorific Value of fuel

Calorific value of fuel is measure by Ahmedabad Textile Industry's Research Association.

As per their report it is taken as below :

$\nabla CV_f = 0.1$

By above calculation absolute and relative uncertainty in CV of fuel measurement is ±0.1and 0.02% respectively.

3.5.4 Uncertainty Analysis of Measurement of Calorific Value of Syngas

As discussed above measurement technique of measurement of CV of syngas. Following equation is formulated for calculating uncertainty :

$$\nabla CV_g = \sqrt{(\frac{\partial CV_g}{\partial A_{H_2}} \times wA_{H_2})^2 + (\frac{\partial CV_g}{\partial A_{CO}} \times w_{Aco})^2 + (\frac{\partial CV_g}{\partial A_{CH_4}} \times w_{A_{CH_4}})^2} \tag{3.14}$$

Where,

∇CV_g =Absolute uncertainty in measurement of CV of Syngas

$w_{A_{H_2}} = w_{Aco} = w_{A_{CH_4}}$ =Least count of Area of H_2,CO, CH_4which are measured by Gas Chromatography of Syngas = 0.00001

By above calculation absolute uncertainty and relative uncertainty in CV of syngas measurement is ±0.000049 and 0.0000062% respectively.

3.5.5 Uncertainty Analysis of Measurement of Efficiency of Gasifier

Efficiency of gasifier measured by following equation :

$$\eta = \frac{CV_g \times Q}{CV_f \times F.C.} \tag{3.15}$$

From that absolute ancertainty in measurement of efficiency as below equation :

$$\nabla\eta = \sqrt{(\frac{\partial\eta}{\partial CV_g} \times w_{CV_g})^2 + (\frac{\partial\eta}{\partial Q} \times w_Q)^2 + (\frac{\partial\eta}{\partial} \times w_{CV_f})^2 + (\frac{\partial\eta}{\partial F.C.} \times w_{F.C.})^2} \tag{3.16}$$

$\nabla\eta$ =Uncertainty of measurement of efficiency of gasifier

w_{CV_g} =Uncertainty of CV of syngas

w_Q = Uncertainty of Gas generation rate

w_{CV_f} = Uncertainty of CV of fuel

$w_{F.C.}$ = Uncertainty of fuel consumption

By this calculation we get absolute uncertainty of efficiency measurement is ±0.00011 and relative uncertainty is 0.0164%

3.5.6 Uncertainty Analysis of Measurement of Temperature

Temperature is measured by K-Type thermocouple with sensor. Least count of sensor is 1 degree.

Which means absolute uncertainty of temperature measurement is $\pm 1^oC$ and relative uncertainty of temperature measurement is 1.33%

Chapter 4

Results and Discussion

Experiments were conducted on 10 kWe downdraft gasifier to analyze effect on fuel flow rate, syngas generation rate, gross calorific value of syngas, cold gas efficiency of gasifier and temperature profile of different zone.

Experiments were conducted as below conditions :

- Cone angle 45°
- Throat diameter 125 mm
- Lignite size is 22-25 mm for past work [3]
- Wood size is selected in between 50 ×50×5 mm from Literature review [7]
- Experiments were carried out with increasing wood proportion 0%, 10%, 15%, 20%, 25% in wood to lignite ratio.

4.1 Experiment Observations

Experiments were conducted with lignite and waste wood in different proportion as a fuel for gasifier. Five different wood to lignite ratio were selected.Wood proportion in mixture of wood and lignite was taken as 0%, 10%, 15%, 20%, 25% respectively. In all experiments fuel consumption, gcv of fuel and syngas, gas generation rate were measured. Temperature in different zones viz. drying, pyrolysis, combustion and reduction zone measure with the help of thermocouple. It was observed while using only lignite as a fuel in downdraft gasifier that quality of gas was poor. As lignite contains higher moisture and ash, the tendency for clinker formation is high. During all experiments with lignite clinker formation was observed which resulted into lower CV of syngas along with reduced volumetric flow rate. Therfore, it was decided to mix wood in different proportion to evalute the performance of gasifier, since wood contains low moist and less ash.

Themperature profile for different wood to lignite fuel ratio are given in following sections.

4.1.1 Fuel Ratio (100% Lignite : 0% Waste Wood, by weight)

Table 4.1indicates fuel consumption, GCV of fuel and syngas and syngas generation rate obtained by 100% lignite as a fuel.

Table 4.1: Data Sheet of Experiment 0% Wood + 100% Lignite

Fuel Comsumption (kg/hr)	8.68
GCV of Fuel (kCal/kg)	3778
Syngas Generation Rate (m^3/hr)	30.05
GCV of Syngas (kCal/m^3)	715

Fig4.1indicates that the temperatures of all zones. It is also observed that the combustion zone temperature is in the range of 100% C to 900% C indicating gasification of lignite. However, drop in combustion zone tempuratuare after 100 minutes indicates that the quality of syngas would be detoriating.

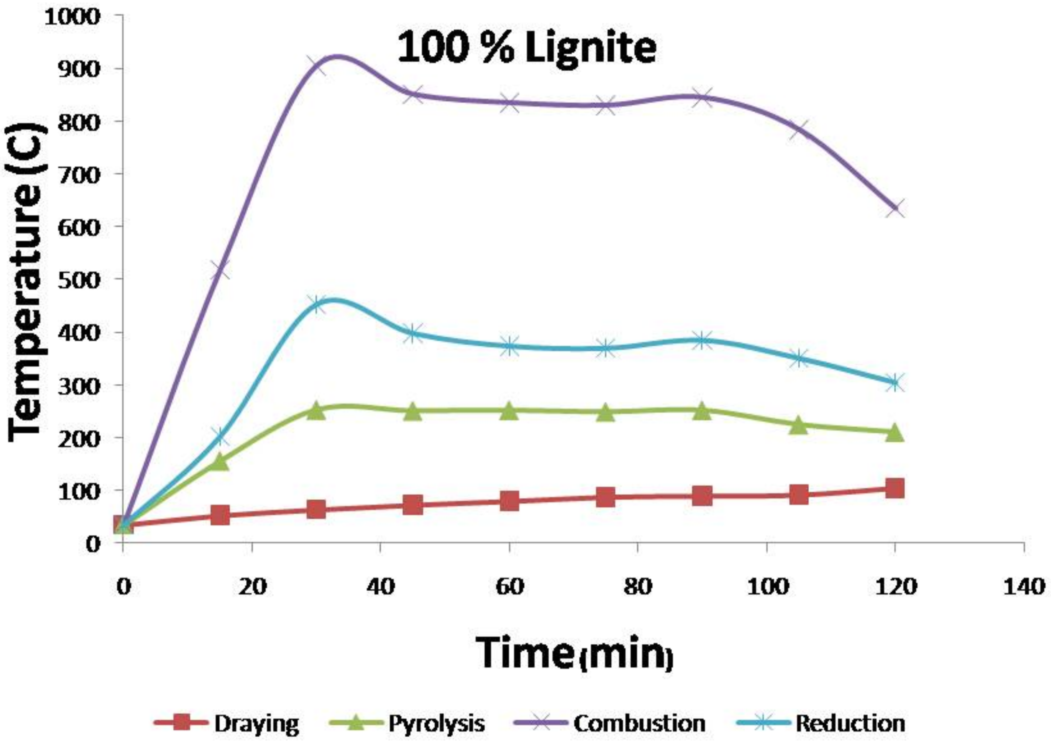


Figure 4.1: Temperature Profie of Experiment 0% Wood + 100% Lignite

4.1.2 Fuel Ratio (90% Lignite : 10% Waste Wood, by weight)

Table4.2 indicates fuel consumption, GCV of fuel and syngas and syngas generation rate obtained by 90% lignite and 10% wood as a fuel.

Table 4.2: Data Sheet of Experiment 10% Wood + 90% Lignite

Fuel Comsumption (kg/hr)	8.92
GCV of Fuel (kCal/kg)	3749
Syngas Generation Rate (m^3/hr)	30.65
GCV of Syngas (kCal/m^3)	740

Fig.4.2indicates that the tempurature of all zones are in the range as reported in literature with this fuel mix. It was observed that the flame sustainability (quality of gas) was batter as compare to previous case. It was also observed the temperature in combustion zone sustain for a longer time.

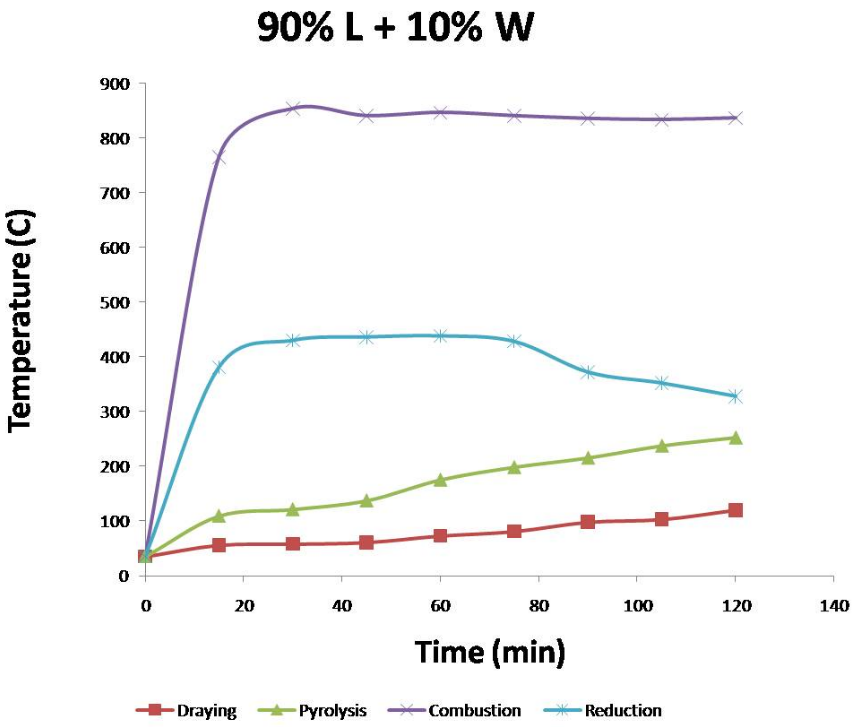


Figure 4.2: Temperature Profie of Experiment 10% Wood + 90% Lignite

4.1.3 Fuel Ratio (85% Lignite : 15% Waste Wood, by weight)

Table4.3indicates fuel consumption, GCV of fuel and syngas and syngas generation rate obtained by 90% lignite and 10% wood as a fuel.

Table 4.3: Data Sheet of Experiment 15% Wood + 85% Lignite

Fuel Comsumption (kg/hr)	9.041
GCV of Fuel (kCal/kg)	3735
Syngas Generation Rate (m^3/hr)	30.97
GCV of Syngas (kCal/m^3)	753

Fig.4.3indicates that the tempurature of all zones are in the range as reported in literature with this fuel mix. It was observed that the flame sustainability (quality of gas) was batter as compare to previous case. It was also observed the temperature in combustion zone sustain for a longer time.It is also noted that temperature in other zones like drying, pyrolysis and reduction zone sustain for equally longer time.

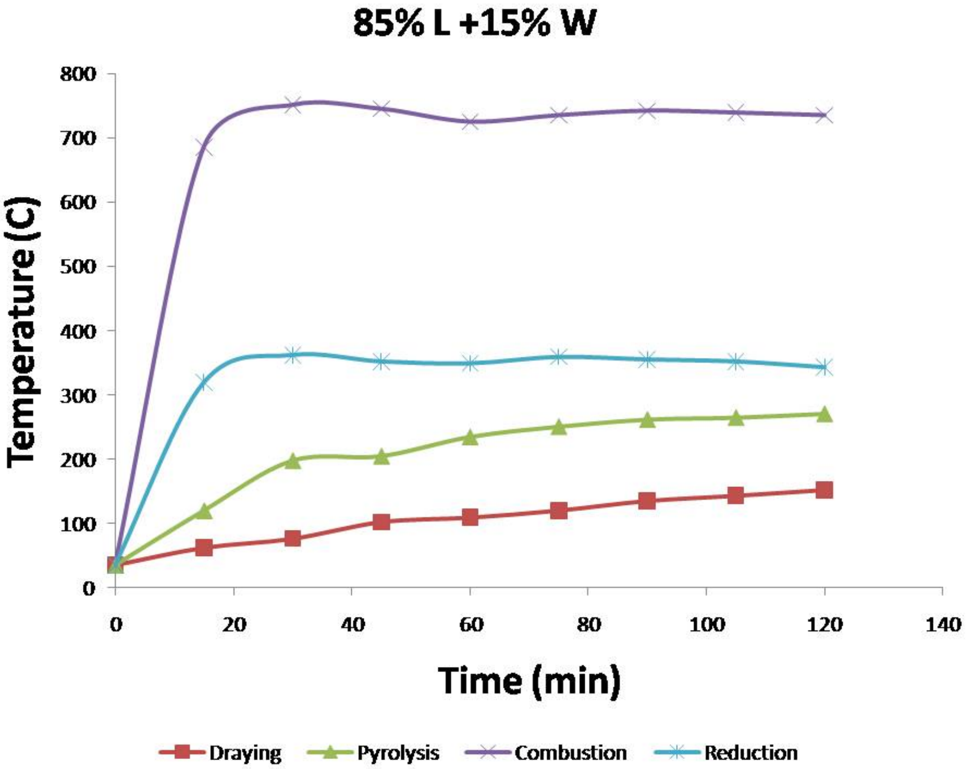


Figure 4.3: Temperature Profie of Experiment 15% Wood + 85% Lignite

4.1.4 Fuel Ratio (80% Lignite : 20% Waste Wood, by weight)

Table4.4 indicates fuel consumption, GCV of fuel and syngas and syngas generation rate obtained by 90% lignite and 10% wood as a fuel.

Table 4.4: Data Sheet of Experiment 20% Wood + 80% Lignite

Fuel Comsumption (kg/hr)	9.162
GCV of Fuel (kCal/kg)	3721
Syngas Generation Rate (m^3/hr)	31.62
GCV of Syngas (kCal/m^3)	762

Fig.4.4indicates that the tempurature of all zones are in the range as reported in literature with this fuel mix. It was observed that the flame sustainability (quality of gas) was batter as compare to previous case. It was also observed the temperature in combustion zone sustain for a longer time.

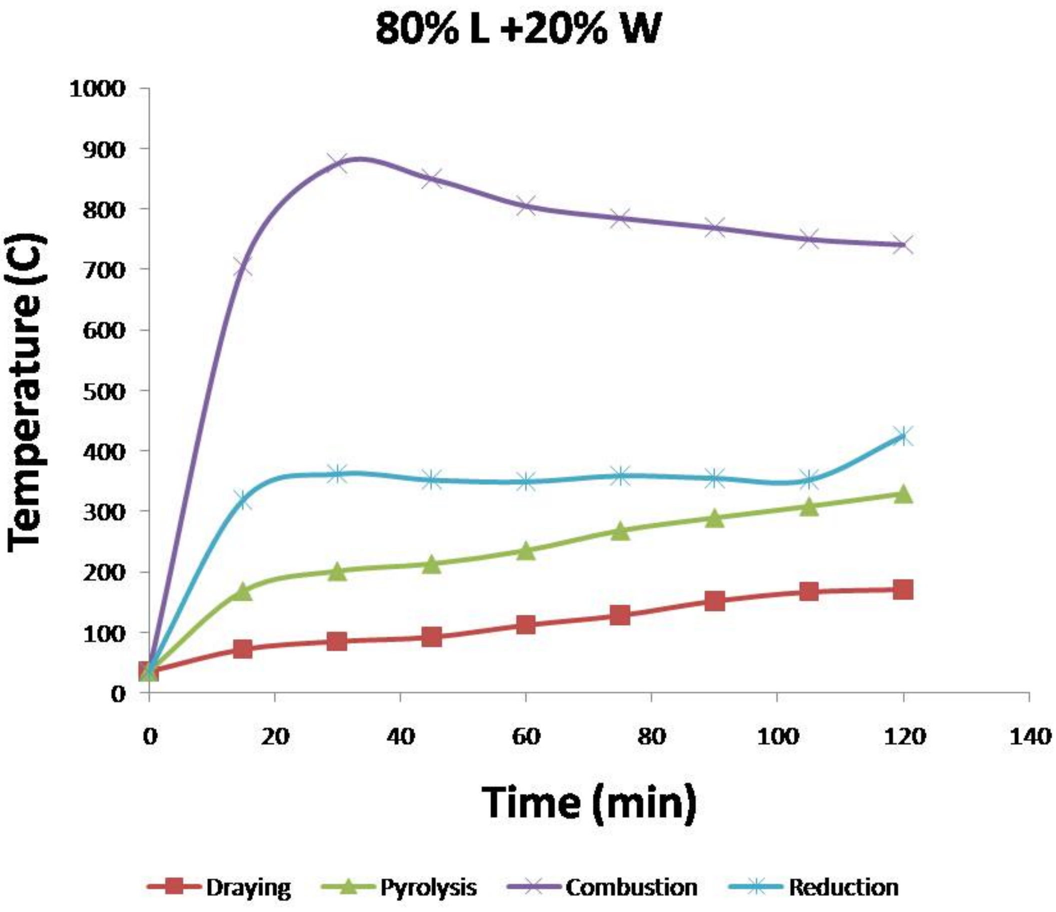


Figure 4.4: Temperature Profie of Experiment 20% Wood + 80% Lignite

4.1.5 Fuel Ratio (75% Lignite : 25% Waste Wood, by weight)

Table4.5 indicates fuel consumption, GCV of fuel and syngas and syngas generation rate obtained by 90% lignite and 10% wood as a fuel.

Table 4.5: Data Sheet of Experiment 25% Wood + 75% Lignite

Fuel Comsumption (kg/hr)	9.28
GCV of Fuel (kCal/kg)	3707
Syngas Generation Rate (m^3/hr)	31.72
GCV of Syngas (kCal/m^3)	782

Fig.4.5indicates that the tempurature of all zones are in the range as reported in literature with this fuel mix. It was observed that the flame sustainability (quality of gas) was batter as compare to qrevious case. It was also observed the temperature in combustion zone sustaion for a longer time.

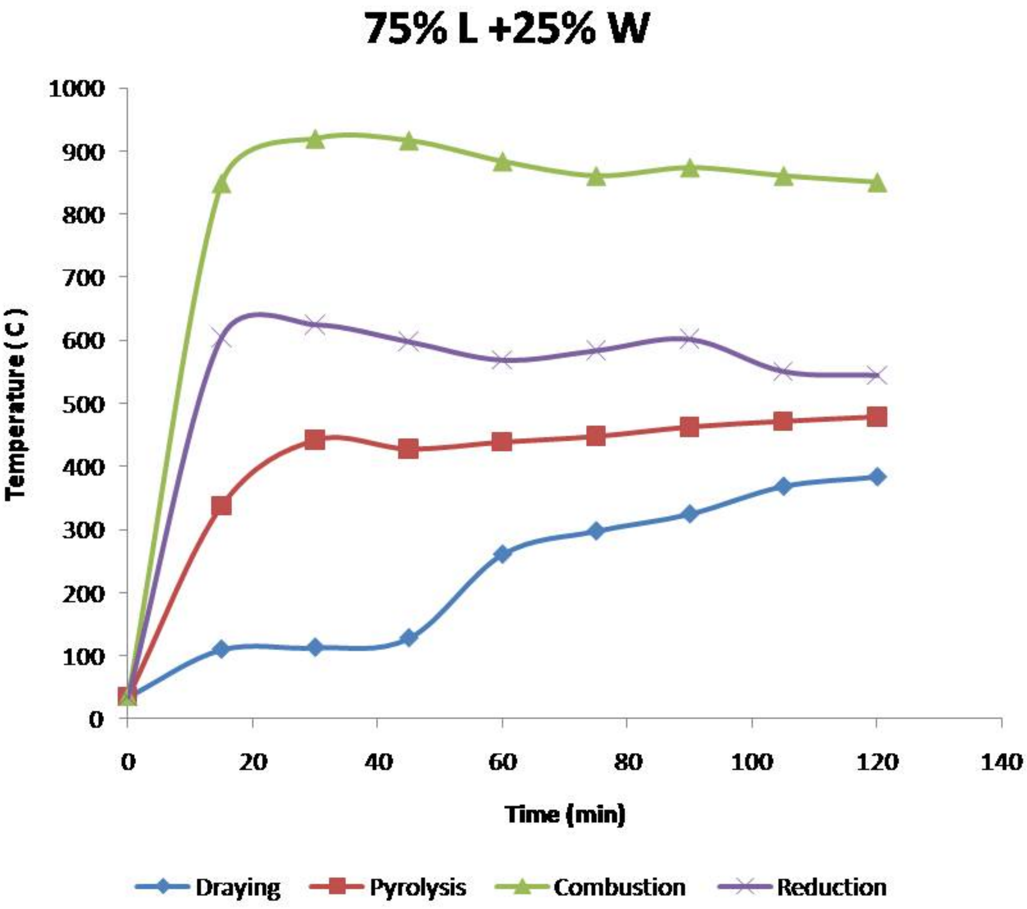


Figure 4.5: Temperature Profie of Experiment 25% Wood + 75% Lignite

4.2 Comparision Analysis

4.2.1 Temperature Profile in different zones :

As discussed in chepter 3 temperature in drying, pyrolysis, combustion and reduction zone are measured by K Type thermocouple having range -250 ^oC to 1350 ^oC. Temperature were recorded at a interval of 15 minutes. Each drop in temperature after 30 minutes of operations for all fuel mix experiments was noticed. It could be due to the reason that in initial face the char was burnt, producing higher temperature and subsequently oxidation of lignite and wood mix is taking place which may have resulted into lower temperature. Temperature profile at different time interval with different wood proportion in lignite in drying, pyrolysis, combustion and reduction zone are shown in figure 4.6 to 4.9. It was found that temperature remain almost constant after 30 minutes of operation indicating the gasification of lignite and waste wood mix fuel. Detailed temperature profile study in different zones of gasifier is given in following sections.

Drying zone :

Fig.4.6indicates the temperature profile of different fuel mix in drying zone. It is observed that temperature in drying zone is tune of 70 ^oC to 150 ^oC at different time interval for different fuel mix. Higher temperature in drying zone was noticed for the fuel mix having more wood percentage. It may be due to the fact that the wood contains less moisture and hence, observed temperature may be higher for that fuel mix.

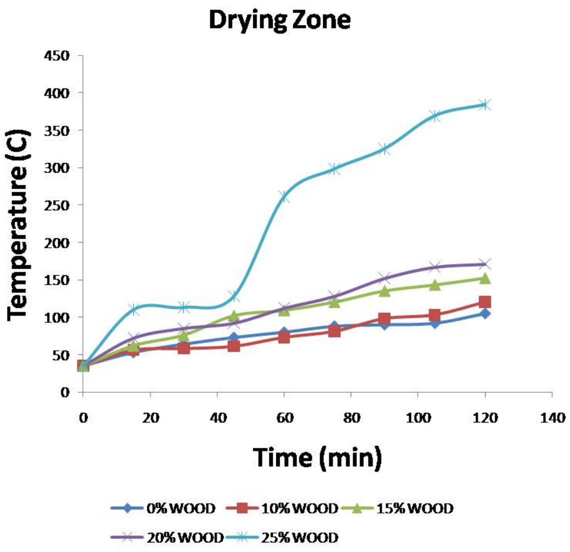


Figure 4.6: Temperature Profie of Drying Zone

Pyrolysis Zone :

Fig.4.7 indicats the temperature profile of different fuel mix in pyrolysis zone. Is is observed from figure that temperature in pyrolysis zone is in order of 250 ^oC to 450 ^oC (after 60 minutes of operation). Since, wood contains less ash and less moisture, temperature of the fuel mix having more percentage of wood expected to be highed in pyrolysis zone and same can be observed from figure4.7.

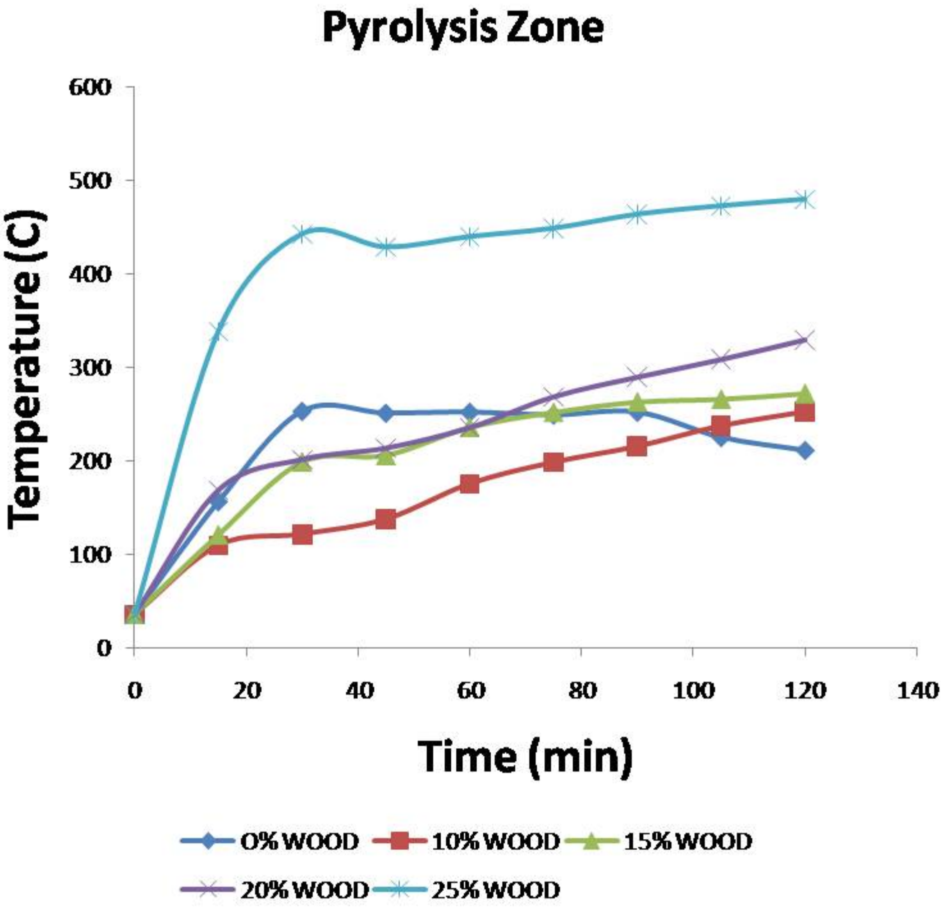


Figure 4.7: Temperature Profie of Pyrolysis Zone

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Combustion Zone :

Fig.4.8 indicates the temperature profile in combustion zone for different fuel mix. As discussed earlier, here it is observed that temperature after 30 minutes of the process remains almost constant. However, higher temperature was observed in the fuel mix having higher wood percentage. It can also be seen that temperature for different fuel mix, at different time interval in the zone is in the range of 700^oC to 900 ^oC. These values are in line with the temperature values reported in literature for different fuels.

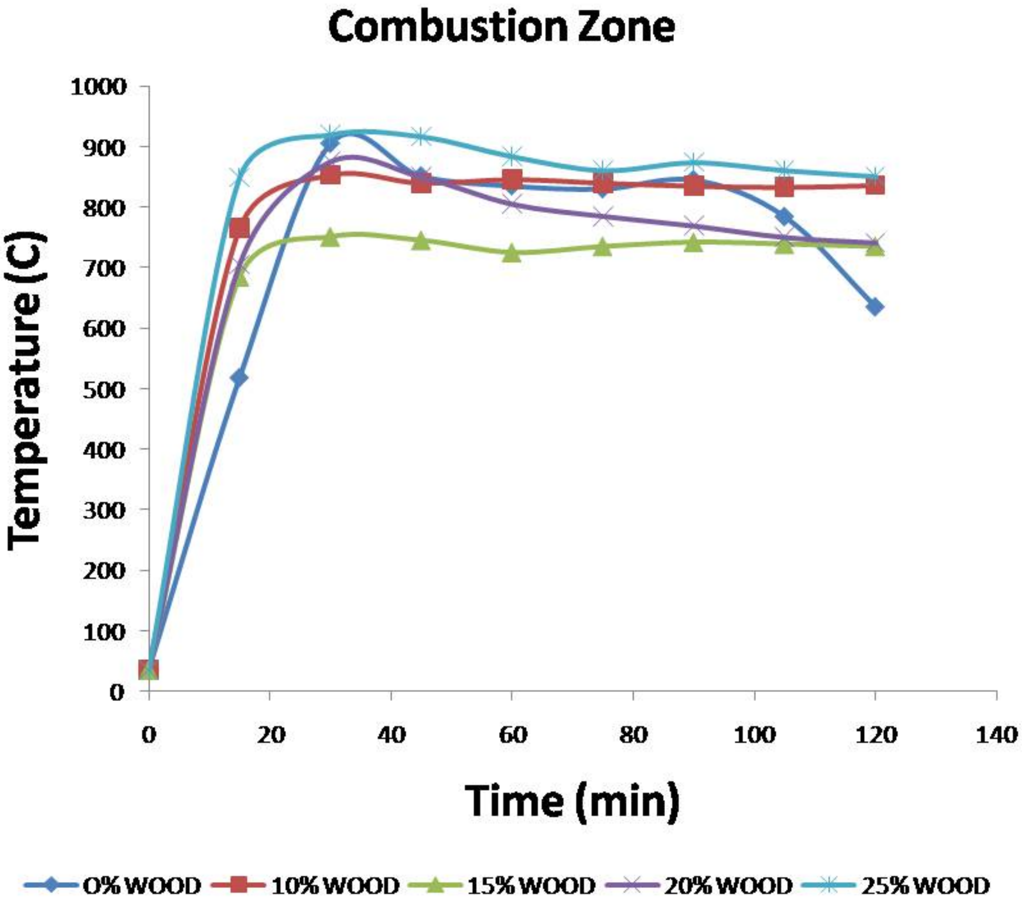

Figure 4.8: Temperature Profie of Combustion Zone

Reduction zone :

Fig.4.9indicates the temperature profile in reduction zone for different fuel mix. It can be seen from temperature profile that, in reduction zone temperature in the zone of 350 ^oC to 550 ^oC for diffferent fuel mix at different time interval. Here, also higher temperatures were observed for fuel mix having higher wood concentration. The difference in temperature at a given time for fuel mix having less wood concentration was very less.

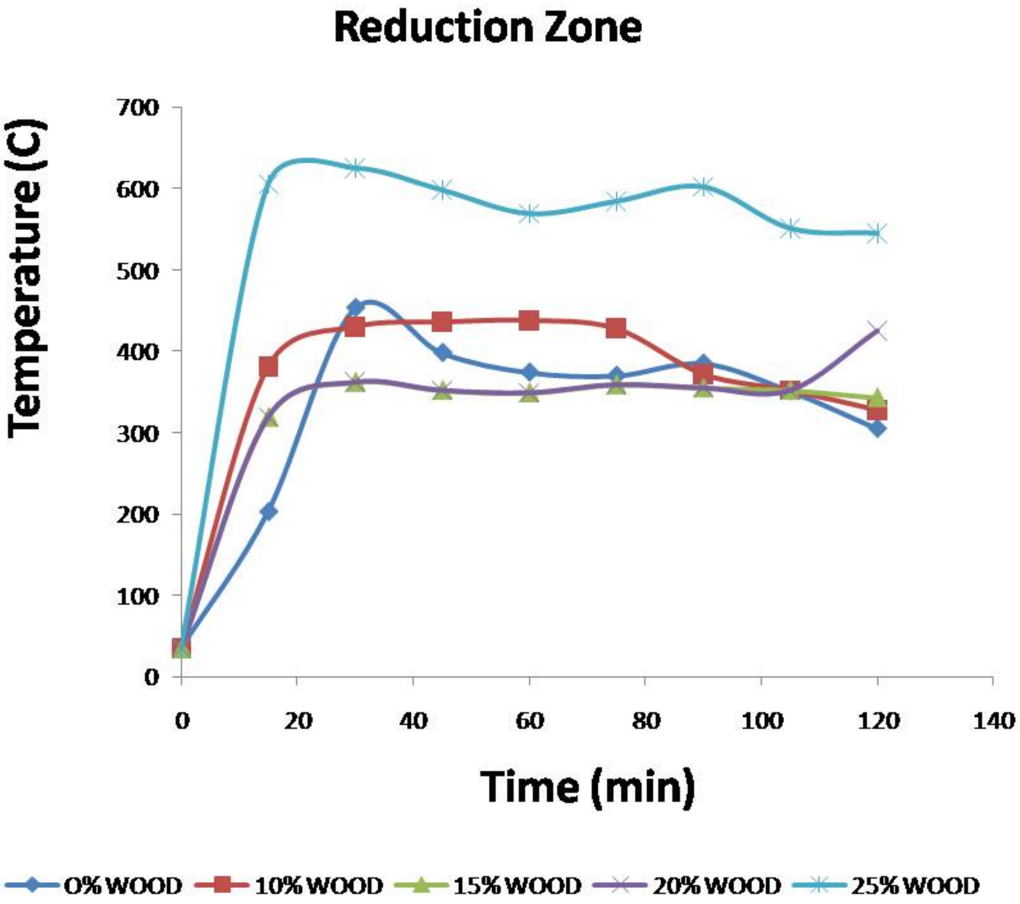

Figure 4.9: Temperature Profie of Reduction Zone

4.2.2 Fuel consumption

Fig.4.10 indicates fuel consumption (kg/hr) for different fuel mix. It was observed that fuel consumption was in the range of 8.69 kg/hr to 9.29 kg/hr for different fuel mix. Figure clearly indicates that fuel consumption increases with increasing in wood concentration in fuel mix. It may be due to the face that, since lignite is having more ash content as compared to wood, flowability of fuel mix having higher content of lignite is poor. The results of fuel consumption are inline with the values reproted in literature for 10 kWe gasifier.

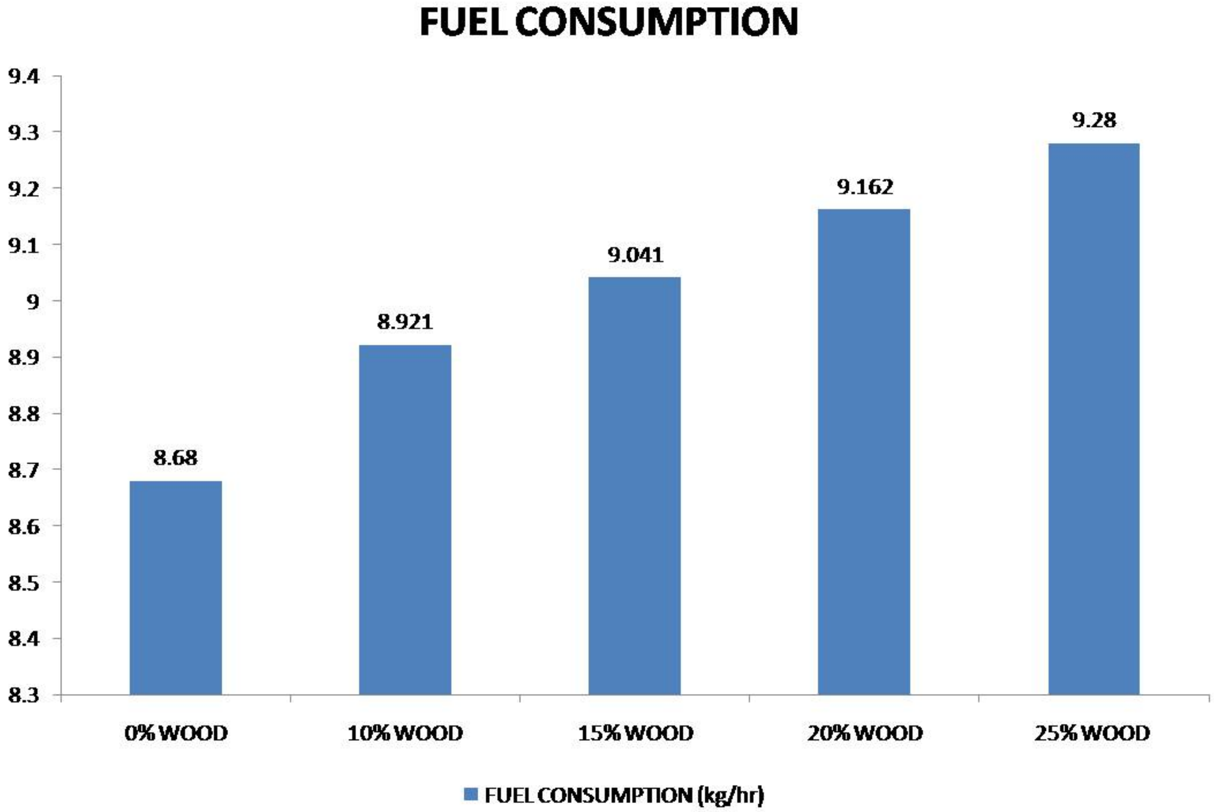

Figure 4.10: Fuel Consumption

4.2.3 Flow Rate of Gassing

Flow rate of syngas was measure by orifice meter coupled with U-tube menometer. The procedure of measurement of gas generation rate is explanied in chapter 3. Fig4.11 indicates the flow rate of gas in m^3/hr in different fuel mix. This flow rate was measure at atmospheric temperature and pressure condition. Flow rate of syngas varies form 30 m^3/hr to 31 m^3/hr for different fuel mix.

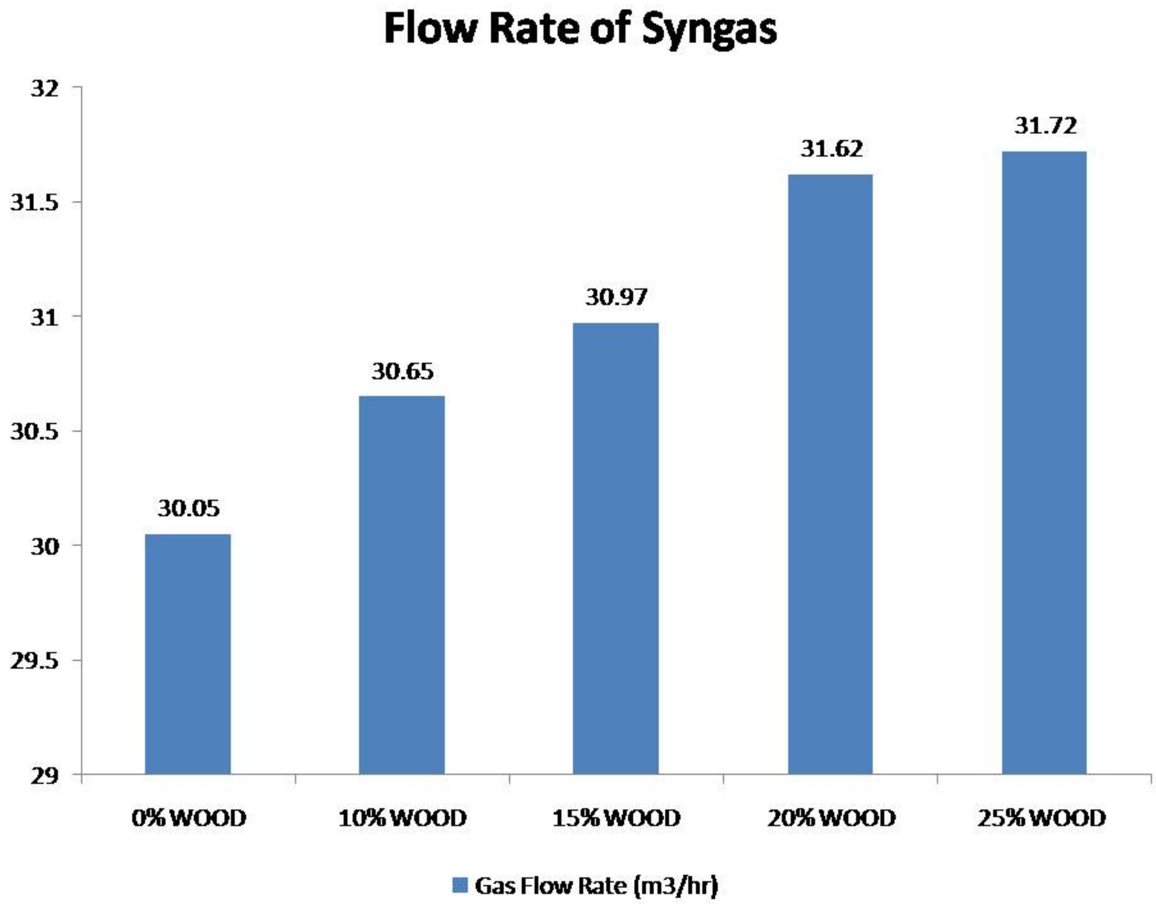

Figure 4.11: Flow Rate of Syngas

4.2.4 Gross Calorific Value of Syngas

GCV of syngas measured using co-relation available in literature handbook of biomass downdraft gasifier engine system by Thomas B. Reed and Agua Das . This co-relation require the concentration of different gases like H_2, CO, CH_4, etc. in syngas. Concentration of these gases in syngas was measured using Gas Chromatography (GC). It is reported that CV of fuel increases with increasing wood concentration. This may be due to the fact that the CV of wood greater than the CV of lignite, CV of syngas varies in the range of 715 kCal/m^3 to 782 kCal/$m^3$for different fuel mix. The higher CV of syngas with high concentration of wood may also be due to fact that less clinker formation. Tendancy to clinker formation dependent with higher concentration of which contains more volatile matter and less ash contents.

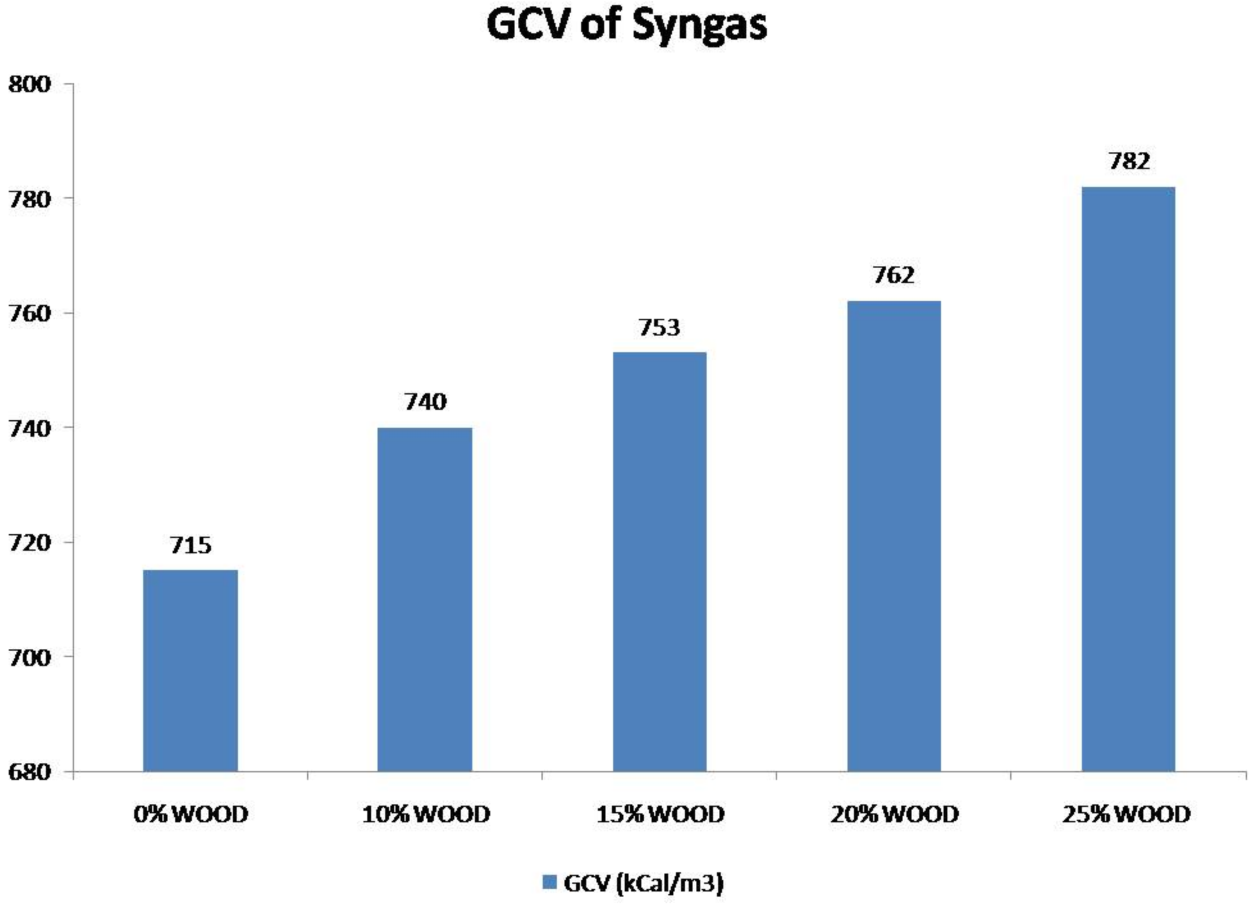

Figure 4.12: Gross Calorific Value of Syngas

4.2.5 Cold Gas Efficiency of Gasifier

Fig.4.13shows the efficiency of gasifier with different wood proportion. Percentage of wood incereses in fuel mix playing significant role in efficiency of gasifier. It is observed that the efficiency of gasifier varies from 65% to 72% for co-gasification. By increasing wood proportion in fuel mix efficiency of gasifier gradually increasing.

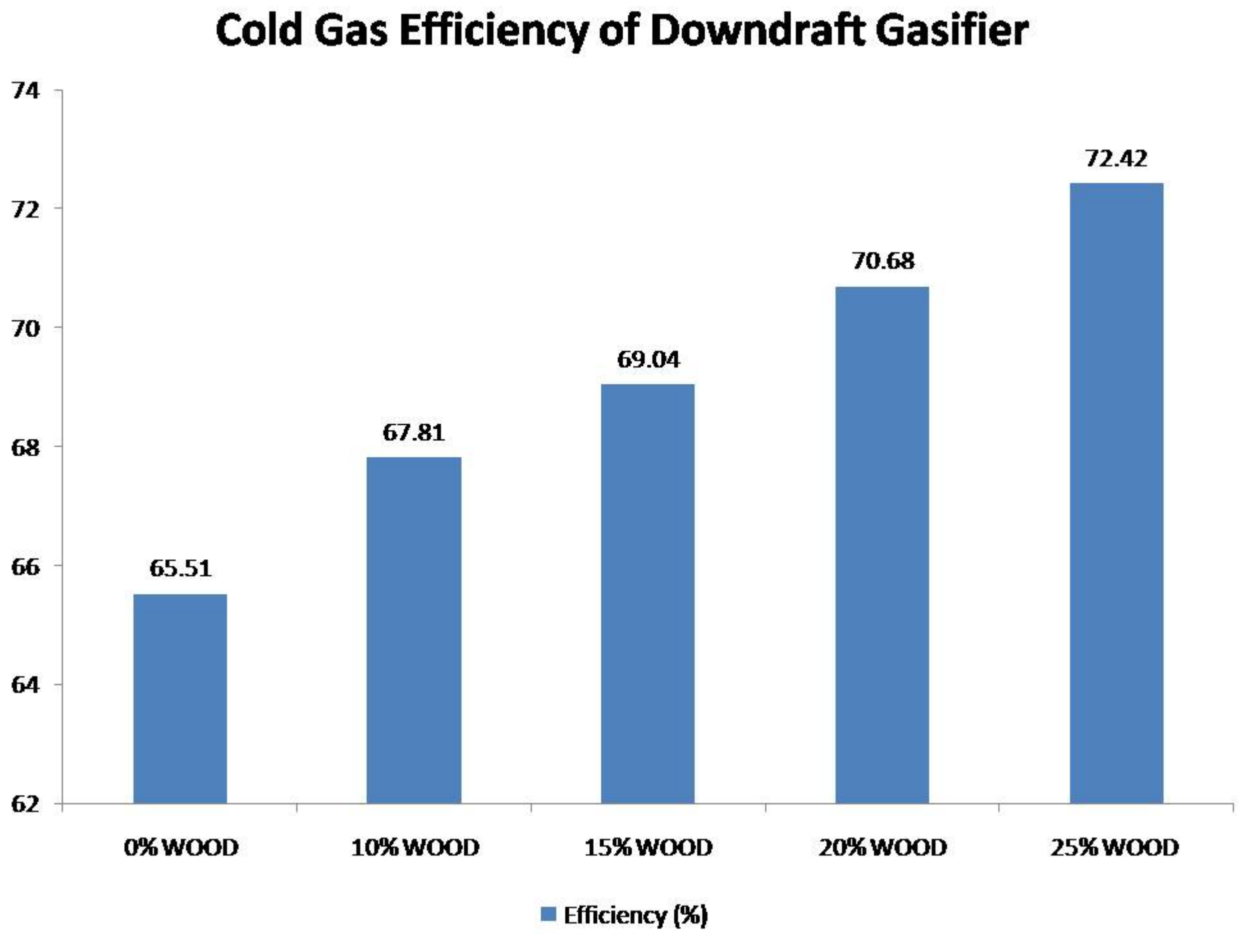

Figure 4.13: Cold Gas Efficiency of Gasifier

Chapter 5

Conclusions and Future Scope

5.1 Conclusions

Exhaustive experiments were carried out both on pure lignite and with lignite and waste wood with different proportion. The major conclusions derived form present study are as below :

- Typically fuel consumption for 10 kWe downdraft gasifier working on pure lignite about 8.6 kg/hr. The fuel consumption increases with increases wood concentration in fuel mix. The fuel consumption is in the range of 8.9 kg/hr to 9.3 kg/hr for different fuel mix.GCV of syngas with different fuel mix indicates that GCV of syngas varies between 715 kCal/m^3 to 782 kCal/m^3.GCV and fuel consumption was observed higher for fuel mix which having high contents of wood.
- Flow rate of syngas was nearly constant with the tune of 30 m^3/ hr for all fuel mix.
- Efficiency of gasifier much dependent of wood concentration in fuel mix. It was observed maximum efficiency of the order of 72% was obtained with 25% wood concentration. If experiments were conducted with more high wood concentration in fuel mix, certainly efficiency would have increased. Since the major objective of present work is to analyze the use of lignite in downdraft gasifier, the concetration of wood higher than 25% would have not the served the purpose. So from present study looking to objectives and observations made from present study, it could be concluded that 15% to 20% wood in fuel mix would give the reasonably good performance of downdraft gasifier. This mix will eliminate the difficulties observed during lignite gasification.

5.2 Future Scope

The following are the work that can be done in future :

- Engine performance coupled with present gasifier system on dual fuel mode(diesel and syngas).
- Exhaust gas analysis of dual fuel engine with different fuel mix.
- Wear analysis of engine components of dual fuel engine for different producer gas to diesel ratio in fuel mix.

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