Effect of Size of Lignite on Gas Generation Rate, Calorific Value of Gas and Gasifier Efficiency of Downdraft Gasifier

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Effect of Size of Lignite on Gas Generation Rate, Calorific Value of Gas and Gasifier Efficiency of Downdraft Gasifier

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(09MMET05)

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INSTITUTE OF TECHNOLOGY
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MAY 2011

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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Certificate

This is to certify that the Major Project Entitled "**Effect of Size of Lignite on Gas Generation Rate, Calorific Value of Gas and Gasifier Efficiency of Downdraft Gasifier**" submitted by **Hardik B. Kothadia (09MMET05)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Thermal Engineering of Nirma University, Ahmedabad is the record of the work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, have not been submitted to any other university or institution for award of any degree or diploma.

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Abstract

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 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. It observed that very little information on parametric influence of gas generation rate, fuel variation and particles size variation on performance and temperature level of downdraft gasifier is available in literature. While studying the effect of gas generation rate, the choice of particle size is an important factor for flowability study and performance of gasifier, based on this realization This thesis presents the result of the experimental investigations carried out using lignite to investigate the effect of fuel size variation on gas generation rate and performance parameter in term of calorific value of gas and gasifier efficiency in downdraft gasifier. The present work also investigates the effect of lignite size variation on temperature profile at different zones in gasifier. For this purpose different size of lignite as the ranges from 16mm to 19mm, 19mm to 22mm and 22mm to 25mm are selected. it is observed that calorific value and efficiency is highly dependent on feedstock size.

Keywords – Lignite gasification; Particle size; Downdraft gasifier

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Nomenclature

Fig.	Figure
min	Minute
[ ]	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	Calorific Value
Q	Gas generation rate
GGR	Gas generation rate
C_d	Coefficient of discharge
a_1	Cross section area at inlet
a_2	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
t_{td}	Total time duration
HGR	Heat generation rate
η_g	Gasifier Efficiency

Chapter 1

Introduction

1.1 Overview of Gasification Technology

Gasification is a century old technology, which flourished quite well before and during the second world war. The technology disappeared soon after the second world war, when liquid fuel became easily available. The interests in the gasification technology have undergone many ups and downs in running century. Today, because of increased fuel prices and environmental concern, there is renewed interest in this century old technology. Gasification has become more modern and quite sophisticated technology.

The advantage of this technology is decentralized energy conversion system which operates economically even for small scale. A gas producer is a simple device consisting of usually cylindrical container with space for fuel, air inlet, gas exit and grate. It can be made of fire bricks, steel or concrete and oil barrels. The design of gasifier depends upon type of fuel used and whether gasifier is portable or stationary. Gasifier alone itself is of little use. The complete gasification system consists of gasification unit (gasifier), purification unit and energy converter - burners or internal combustion engine.

As shown in Fig. 1.1 Gasification is basically a thermo chemical process which converts coal, lignite, petcoke, biomass and various combustible wastes, into syngas (Synthesis Gas) or producer gas. Syngas can be used to produce electric power and a number of high-value, clean energy products such as chemicals, fertilizers, substitute natural gas, hydrogen, steam, and transportation fuels. The producer gas, containing carbon monoxide, hydrogen, methane and some other inert gases mixed with air, can be used in gasoline or diesel engine with little modifications. Gasification produces nearly zero emissions and the by-products (sulfur and slag) are non hazardous and marketable as it is. (According to the U.S. Department of Energy) Furthermore, gasification plants use significantly less water than traditional coal-based plants and CO_2 can be captured for storage, sold for EOR (Enhanced Oil Recovery) or ECBM (Enhanced Coal Bed Methane) using available, commercially proven technology.

Based on the design of gasifier and type of fuels used, there exists different kinds of gasifier. Portable gasifier is mostly used for running vehicles. Stationary gasifier combined with engines is widely used in rural areas of developing countries for many purposes including generation of electricity and running irrigation pumps. Technologies such biomass gasification which allows utilization of biomass fuel is of great importance. Theoretically, almost all kinds of Fuel with moisture content of 5-30% can be gasified; however, not every fuel can lead to the successful gasification. Most of the development work is carried out with common fuels such as coal, charcoal and wood. It was recognized that fuel properties such as surface, size, shape as well as moisture content, volatile matter and carbon content influence gasification.

The key to a successful design of gasifier is to understand the properties and thermal behavior of the fuel as fed to the gasifier. Operation of gasification system demands knowledgeable and skilled operator. Those interested in this technology must remember that it requires hard work and tolerance. Compared to conventional system such as liquid fuel run engines, gasification technology is inconvenient. But it is economical at many places and may lead to self-reliance in the crucial time of fuel crisis.

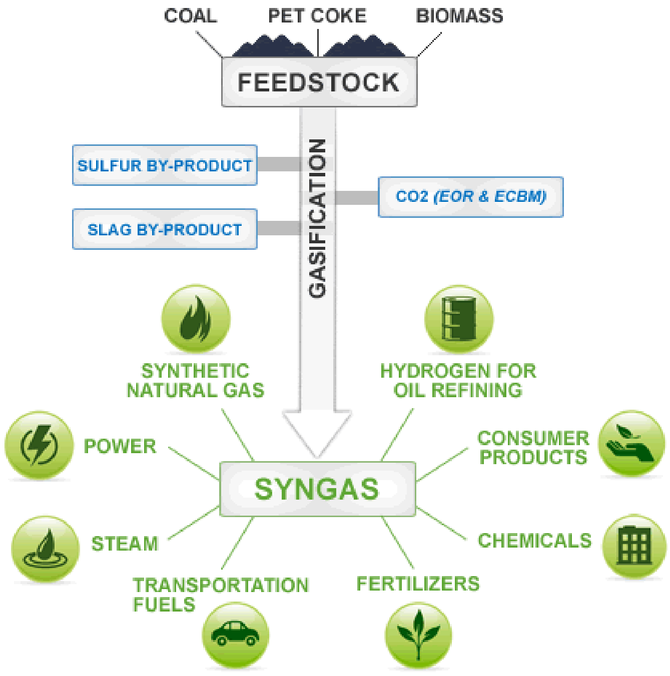


Figure 1.1: Use of Gasification Technology [14]

1.2 Thermo-chemical conversion of fuel

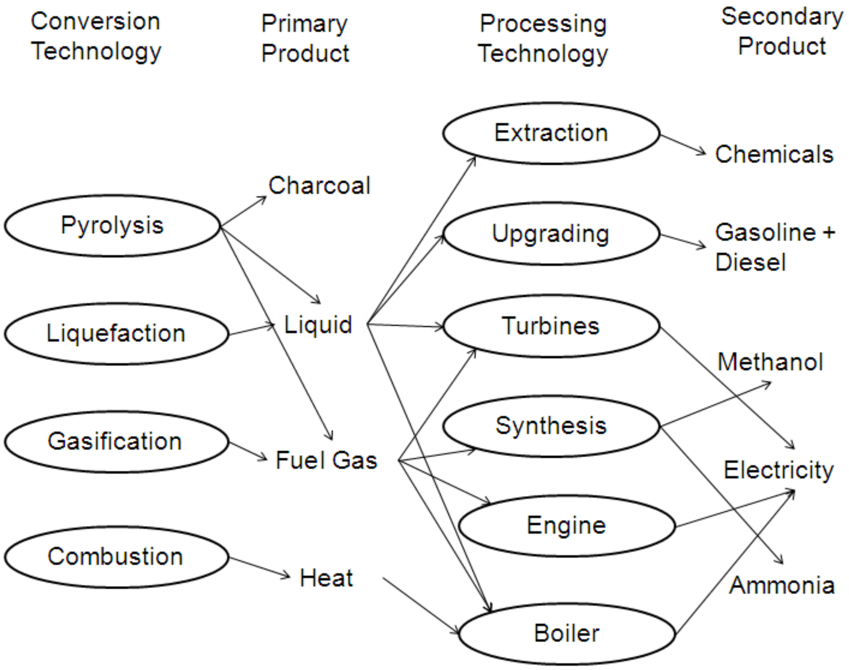
The thermo chemical conversion of biomass can be classified into four processes namely Combustion, Gasification Pyrolysis and liquefaction. Each method gives different range of products and employs different equipment configurations, operating in different modes. The primary products being converted to secondary products using an intermediate processing technology. Different conversion technology along with their primary product and applications are presented in Fig. 1.2.

Combustion involves direct burning of biomass to get heat. This is a process in which the biomass is degraded at higher temperatures, to char and volatiles which in turn are oxidized with the excess oxygen provided. A large amount of heat of reaction is released along with formation of carbon dioxide and water as gaseous emittants.

With the present state of various technologies biomass based steam power plant are still the most economical route.

Gasification is carried out in sub-stoichiometric oxygen atmosphere at temperature ranging from 700°C to 1000°C. The final product, called as "producer gas" is low calorific value or medium calorific value gas, based on medium of gasification. Air gasification leading to a lower calorific value producer gas, is however most common, particularly in scale of economic operation. The gasification is used to substitute fuel oil in furnace, as well as in engine for power generation. With the diesel prices increasing steeply in last some year, the gasification market has seen a boom. Moreover, the development and subsequent availability of Spark Ignition Producer Gas Engine (SIPGE) will further boost the use of gasification for Power generation-within the economic scale of operation with respect to the biomass availability, transportability and storability.

Figure 1.2: Thermo-chemical conversion of fuel



1.3 Gasifier – Type, Difference between design

1.3.1 Up draught or counter current gasifier

The oldest and simplest type of gasifier is the counter current or updraught gasifier shown schematically in Fig. 1.3.

The air intake is at the bottom and the gas leaves at the top. Near the grate at the bottom the combustion reactions occur, which are followed by reduction reactions somewhat higher up in the gasifier. In the upper part of the gasifier, heating and pyrolysis of the feedstock occur as a result of heat transfer by forced convection and radiation from the lower zones. The tars and volatiles produced during this process will be carried in the gas stream. Ashes are removed from the bottom of the gasifier.

The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high equipment efficiency, as well as the possibility of operation with many types of feedstock (sawdust, cereal hulls, etc.).

Major drawbacks result from the possibility of "channelling" in the equipment, which can lead to oxygen break-through and dangerous, explosive situations and the necessity to install automatic moving grates, as well as from the problems associated with disposal of the tar-containing condensates that result from the gas cleaning operations. The latter is of minor importance if the gas is used for direct heat applications, in which case the tars are simply burnt.

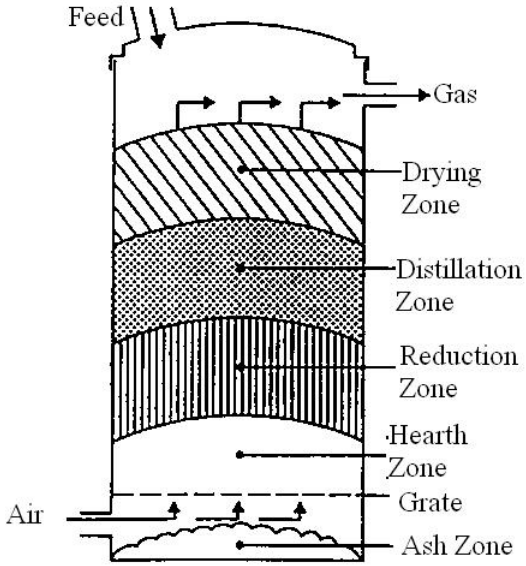


Figure 1.3: Up draught or counter current gasifier [15]

1.3.2 Down draught or co-current gasifier

A solution to the problem of tar entrainment in the gas stream has been found by designing co-current or downdraught gasifier, in which primary gasification air is introduced at or above the oxidation zone in the gasifier. The producer gas is removed at the bottom of the apparatus, so that fuel and gas move in the same direction, as schematically shown in Fig. 1.4.

On their way down the acid and tarry distillation products from the fuel must pass through a glowing bed of charcoal and therefore are converted into permanent gases hydrogen, carbon dioxide, carbon monoxide and methane.

Depending on the temperature of the hot zone and the residence time of the tarry vapours, a more or less complete breakdown of the tars is achieved.

The main advantage of downdraught gasifier lies in the possibility of producing a tar-free gas suitable for engine applications.

In practice, however, a tar-free gas is seldom if ever achieved over the whole operating range of the equipment: tar-free operating turn-down ratios of a factor 3 are considered standard; a factor 5-6 is considered excellent.

Because of the lower level of organic components in the condensate, downdraught gasifier suffer less from environmental objections than updraught gasifier.

A major drawback of downdraught equipment lies in its inability to operate on a number of unprocessed fuels. In particular, fluffy, low density materials give rise to flow problems and excessive pressure drop, and the solid fuel must be pelletized or briquetted before use. Downdraught gasifiers also suffer from the problems associated with high ash content fuels (slagging) to a larger extent than updraught gasifier.

Minor drawbacks of the downdraught system, as compared to updraught, are somewhat lower efficiency resulting from the lack of internal heat exchange as well as the lower heating value of the gas. Besides this, the necessity to maintain uniform high temperatures over a given cross-sectional area makes impractical the use of downdraught gasifier in a power range above about 350 kW (shaft power).

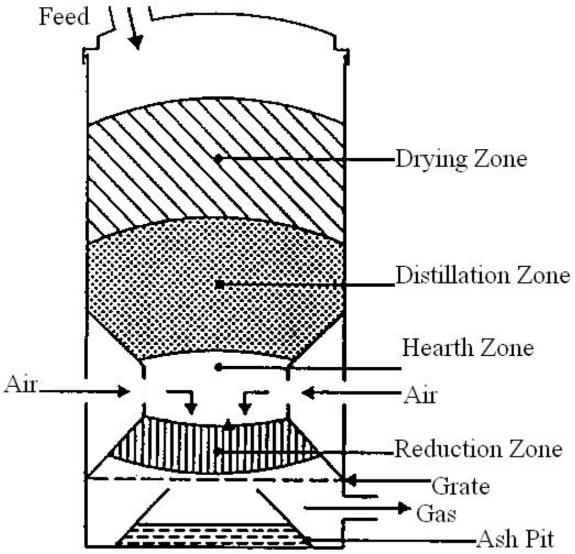


Figure 1.4: Down draught or co-current gasifier [15]

1.3.3 Cross-draught gasifier

Cross-draught gasifier, schematically illustrated in Fig. 1.5 is an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500 °C and higher) in the oxidation zone which can lead to material problems. In cross draught gasifier insulation against these high temperatures is provided by the fuel (charcoal) itself.

Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible. The reason is the very simple gas-cleaning train (only a cyclone and a hot filter) which can be employed when using this type of gasifier in conjunction with small engines.

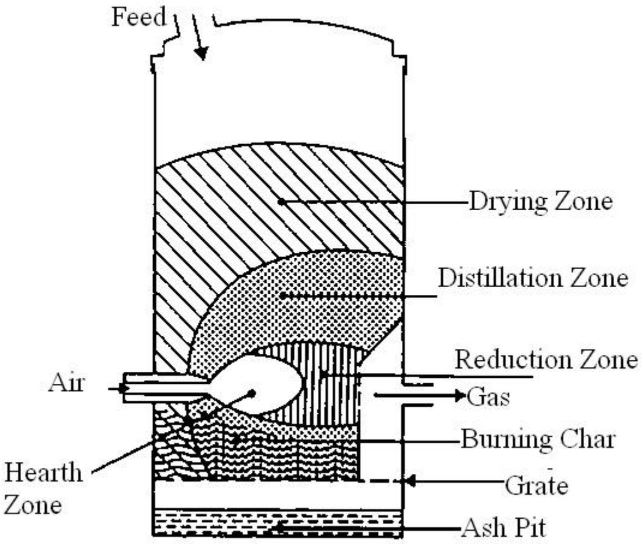


Figure 1.5: Cross-draught gasifier [15]

A disadvantage of cross-draught gasifier is their minimal tar-converting capabilities and the consequent need for high quality (low volatile content) charcoal.

It is because of the uncertainty of charcoal quality that a number of charcoal gasifier employ the downdraught principle, in order to maintain at least a minimal tar-cracking capability.

1.3.4 Fluidized bed gasifier

The operation of both up and downdraught gasifiers is influenced by the morphological, physical and chemical properties of the fuel. Problems commonly encountered are: lack of bunker flow, Slagging and extreme pressure drop over the gasifier.

A design approach aiming at the removal of the above difficulties is the fluidized bed gasifier illustrated schematically in Fig. 1.6.

Air is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is originally externally heated and the feedstock is introduced as soon as a sufficiently high temperature is reached. The fuel particles are introduced at the bottom of the reactor, very quickly mixed with the bed material and almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Most systems are equipped with an internal cyclone in order to minimize char blow-out as much as possible. Ash particles are also carried over the top of the reactor and have to be removed from the gas stream if the gas is used in engine applications.

The major advantages of fluidized bed gasifier are their feedstock flexibility resulting from easy control of temperature, which can be kept below the melting or fusion point of the ash (rice husks), and their ability to deal with fluffy and fine grained materials (sawdust etc.) without the need of pre-processing. Problems with feeding, instability of the bed and fly-ash sintering in the gas channels can occur with some fuels.

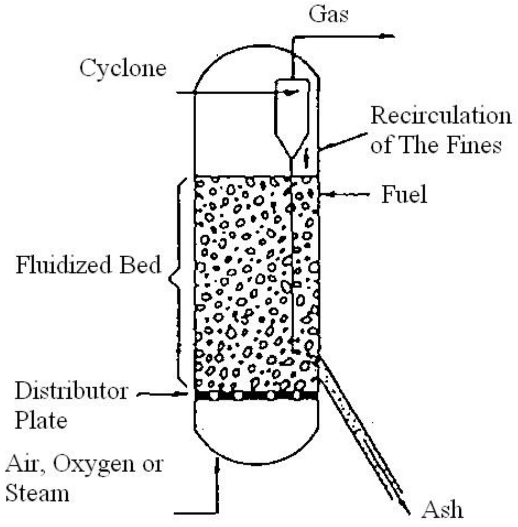


Figure 1.6: Fluidized bed gasifier [15]

Other drawbacks of the fluidized bed gasifier lie in the rather high tar content of the product gas (up to 500 mg/m^3 gas), the incomplete carbon burn-out, and poor response to load changes.

Particularly because of the control equipment needed to cater for the latter difficulty, very small fluidized bed gasifier are not foreseen and the application range must be tentatively set at above 500 kW (shaft power).

Fluidized bed gasifiers are currently available on a semi-commercial basis from several manufacturers in Europe and U.S.A.

1.3.5 Other types of gasifier

A number of other gasifier systems (double fired, entrained bed, molten bath), which are partly spin-offs from coal gasification technology, are currently under development. In some cases these systems incorporate unnecessary refinements and complications, in others both the size and sophistication of the equipment make near term application in developing countries unlikely. For these reasons they are omitted from this account.

Table 1.1: Advantages and Disadvantages of various Gasifiers

Sr. No.	Gasifier Type	Advantage	Disadvantages
1.	Updraft	- Small pressure drop - good thermal efficiency - little tendency towards slag formation	- Great sensitivity to tar and moisture and moisture content of fuel - relatively long time required for start up of IC engine - poor reaction capability with heavy gas load
2.	Downdraft	- Flexible adaptation of gas production to load - low sensitivity to charcoal dust and tar content of fuel	- Design tends to be tall - not feasible for very small particle size of fuel
3.	Cross draft	- Short design height - very fast response time to load - flexible gas production	- Very high sensitivity to slag formation - high pressure drop

1.4 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).

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

Lignite 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.

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 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.

Gujarat being one of the largest producers of the lignite will certainly benefited by this project.

1.5 Justification for taking this project

- To ensure successful cost-effective feedstock assembly and delivery operation must provides consistent supply of low cost, highly efficient operation.
- Distributions of fuel in fire zone are dependent on the fuel size. To obtain favorable gasification rate, calorific value and producer gas efficiency of gasifier it is desirable too offer incoming air as much fuel surface as possible.
- The fuel sizes influence the pressure drop across gasifier.
- Therefore, the size of feedstock determine the prefer size of feedstock to be used for gasification.

1.6 Objective of study

Following are the objective of present study.

- To study working of downdraft gasifier on lignite.
- To study the temperature profiles across the different zone of gasifier with different feedstock size.
- To study effect of size of lignite on Gas generation rate, Calorific value of gas and gasifier efficiency.

1.7 Organization of thesis

Chapter 2 deals with the literature survey, it cover the history and development of gasifier, stages in gasification process, chemical reaction in gasification process, impact of fuel properties on gasification and current status of gasification technology. It also discusses lignite as gasifier fuel, producer gas and the review of present work in effect of fuel particle size on gasifier parameter.

The experiment studies are discussed in chapter 3. It includes experimental procedure, experimental set-up, feedstock sample preparation and methods and equipment used for finding different fuel and gasifier parameters.

Chapter 4 deals with the results and analysis of the experiments performed in the present study with different size of lignite. The outcomes and results conclusions are detailed in chapter 5. Effect of size of lignite on gas generation rate, calorific value of gas and gasifier efficiency of downdraft gasifier is discussed in the same chapter.

Chapter 2

Literature Review

2.1 History and Development

- 1620 To 1720 Fuel Wood Shortage Resulted in Drop in Iron Production, from 180,000 Tons to 18,000 Tons Per Year.
- 1669 Thomas Shirley Conducted Crude Experiments with Carbonated Hydrogen.
- 1699 Dean Clayton Obtained Coal Gas from Pyrolitic Experiment.
- 1788 Robert Gardner Obtained the First Patent with Regard to Gasification.
- 1792 First Confirmed Use of Producer Gas Reported, Murdoc Used the Gas Generated from Coal to Light a Room in His House. For Many Years after Coal Gas was used for Heating and Cooking.
- 1801 Lampodium Proved the Possibility of using Waste Gases Escaping from the Charring of Wood.
- 1804 Fourcroy Found the Water Gas by Reaction of Water with a Hot Carbon.
- 1812 The Development of the First Gas Producer which uses Oil as Fuel.

- 1840 The First Commercially Used Gasifier was built in France.
- 1861 Real Breakthrough in Technology with introduction of Siemens Gasifier. This Gasifier is considered to be the First Successful Unit.
- 1878 Gasifiers were Successfully Used with Engines for Power Generation.
- 1900 The First 600 Horsepower Gasifier was Exhibited in Paris. Thereafter, Larger Engines up to 5400 Horsepower were put into Service.
- 1901 J.W. Parker Runs a Passenger Vehicle with Producer Gas.
- 1901-1920 Many Gasifier-Engine Systems were sold and used for Power and Electricity Generation. Until this Period all Processes Involving Coal were Cyclical.
- 1920 Carl Von Linde Commercialized the Cryogenic Separation of Air. This Allowed the First Fully Continuous Gasification Process.
- 1926 Winkler Fluid Bed Process.
- 1930 Nazi Germany Accelerated Effort to Convert Existing Vehicles to Producer Gas Drive as part of a Plan for National Security and Independence from Imported Oil.
- 1930 Began Development for Small Automotive and Portable Gas Producer. The British and French Governments Felt that Automotive Charcoal Gas Producer is more suitable for their colonies where supplies of Gasoline were Scarce and Wood that could be charred to Charcoal was readily available.
- 1931 Lurgi Moving Bed Pressurized Process.
- 1939 About 250,000 Vehicles were registered in Sweden. Of those90% were converted to producer gas drive. Almost all of the 20,000 tractors were operated on producer gas. 40% of the Fuel was Wood and the Remainder Charcoal.

- 1940 Koppers –Totzek Entrained Flow.
- 1945 After the End of World War II, with Plentiful Gasoline and Diesel Available at Low Cost, Gasification Technology Lost its Glory and Importance.
- 1950 –1969 during these Decades, Gasification was a Forgotten Technology. Many Governments in Europe believed that consumption of Wood at the Prevailing Rate would reduce the Forests, Creating Several Environmental Problems.
- 1970 The 1970's brought a Renewed Interest in the Technology for Power Generation in Small Scale. Since then Work is also concentrated to use fuels other than Wood and Charcoal.
- 1970 IGCC Studies by U.S. DOE.
- 1970 Gasification of Oil for Hydrogen in the Refining Industry.
- 1983 Gasification of Coal to Chemicals Plant (Eastman Chemical).
- 1984 First Coal IGCC Demonstration (Cool water Plant).
- 1990 First Non-Recourse Project Financed Oil IGCC Projects (Italy).
- 1993 First Natural Gas Gasification F-T Project (Shell Bintulu).
- 1994 NUON/Demkolec's 253 MWe Buggenum Plant Begins Operation.
- 1995 PSI Walbash, Indiana Coal IGCC Begins Operation.
- 1996 Tampa Electric Polk Coal IGCC Begins Operation.
- 1997 First Oil Hydrogen/IGCC Plant Begin Operations (Shell Pernis).
- 1998 ELCOGAS 298 MWe Puertollano Plant.

- 2002 IGCC is now an Accepted Refinery and Coal Plant Option.
- 2007 Clean Coal Power R&D 250 MWe IGCC Plant Begins Operation (Japan)

2.2 Gasification Process

The gasifier is a reactor that converts any organic material into clean gaseous fuel called producer gas. The gasifier is essentially a chemical reactor where various complex physical and chemical processes take place. Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are: (1) Drying of fuel (2) Pyrolysis- a process in which tar and other volatiles are driven off (3) Combustion (4) Reduction.. A summary of the gasification processes is shown below in Fig. 2.1.Distribution of heat in each stage of process, movement of composition of reaction in each stage and compositions of producer gas is shown in Fig. 2.2.

2.2.1 Drying

All moisture must be removed from the wood chips in order to successfully produce wood gas. While all water in the wood will be vaporized eventually by heat of pyrolysis, combustion, and reduction, failure to remove moisture from the wood beforehand results in the inability to produce clean fuel. Therefore, in an ideal gasifier, some of the heat produced during combustion is used to completely dry the wood. Since the lack of clean gas could be catastrophic to our project, we have chosen to either pre-bake or purchase pre-dried wood chips [13].

2.2.2 Pyrolysis

Pyrolysis occurs when the wood chips are heated without enough oxygen to burn. Fast pyrolysis does not begin until the wood has reached a minimum temperature of about 550 K [13]. This causes the wood chips to decompose into tars (gasses and liquids) and charcoal. The tars are burned off, leaving charcoal with high carbon content. This charcoal is integral for the reduction process.

2.2.3 Combustion

Combustion is the exothermic combination of hydrocarbons with oxygen. The heat for all processes is generated from combustion of the tars produced during pyrolysis. In addition, combustion produces carbon dioxide and hydrogen gas, which will become reactants in the reduction step. Adequate mixing and high temperature flame is key, since the lack of either could permit the tars to still be present in the wood gas, which in turn could lead to engine failure. Therefore, producing clean fuel is largely dependent on the combustion dynamics in the gasifier. The United Nations Forestry and Agriculture Organization suggests that the combustion zone should reach a minimum of 1473 K to ensure a clean burning fuel [13].

2.2.4 Reduction

Reduction reverts completely combusted hydrocarbons into a form that can be used as fuel. Note that reduction is the opposite of combustion - it is the endothermic removal of oxygen from hydrocarbons. Typically combustion and reduction exist in equilibrium in any burning process. Reduction in a gasifier occurs when carbon dioxide and water vapor flows through heated charcoal (primarily carbon). The heated carbon removes the oxygen from both the carbon dioxide and the water vapor. The oxygen is spread to the carbon atoms, forming covalent bonds in the form of carbon monoxide. Oxygen has a higher affinity for carbon than either hydrogen or itself. This leaves the remaining hydrogen atoms to form their natural diatomic. Therefore, two reactions occur from the addition of carbon and heat: carbon dioxide is reduced to carbon monoxide and water vapor is reduced to diatomic hydrogen

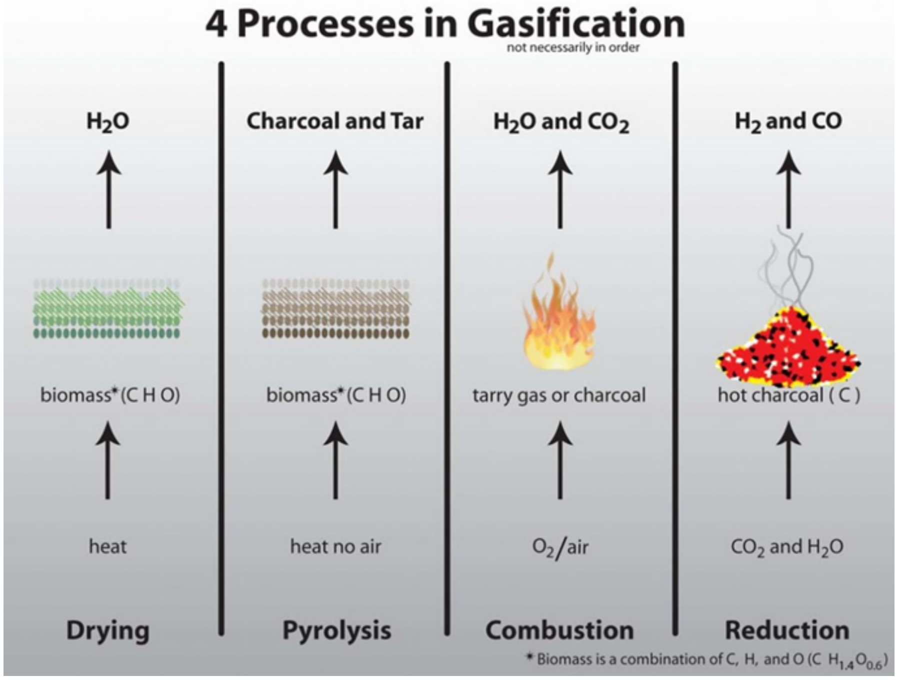


Figure 2.1: Gasification Processes [13]

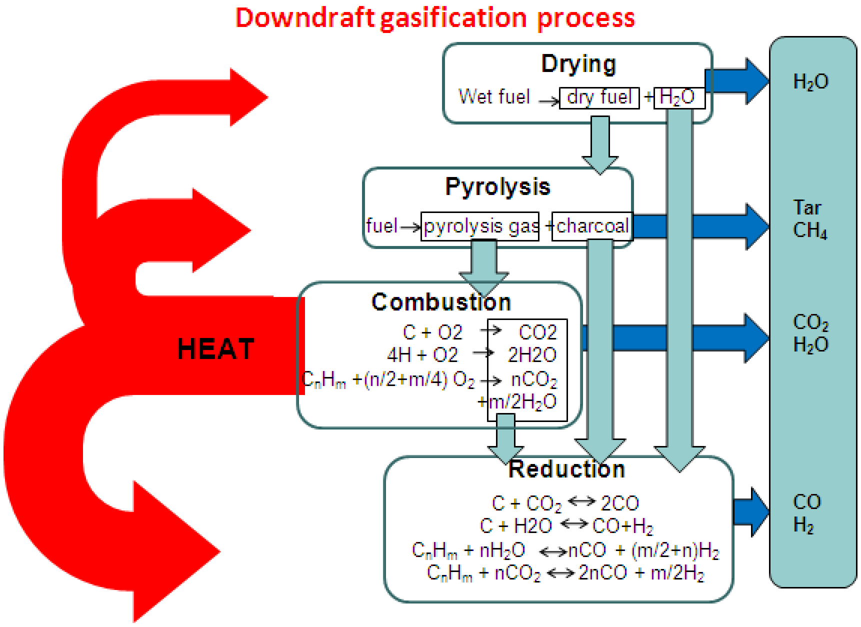


Figure 2.2: Downdraft Gasification [13]

and carbon monoxide. The FAO study found that the rate of reduction is only high enough to run a gasifier at temperatures above about 973 K [13].

2.2.5 Post-Reduction

After the reduction process, the products are ready for combustion once again. These gases will be drawn into the cylinders of an internal combustion engine. There, they will be mixed with air, compressed, and then ignited to produce power for the go-kart. The additional oxygen present in the air will react with carbon monoxide to form carbon dioxide and with hydrogen to form water vapor as products, which will be our primary exhaust components.

2.3 Chemical Reaction of Gasification

The chemical reactions in gasification process take place in the presence of air in an oxygen-lean, reducing atmosphere. The ratio of oxygen molecules to carbon molecules is far less than one in the gasification reactor.

A portion of the fuel undergoes partial oxidation by precisely controlling the amount of oxygen fed to the gasifier. The heat released in the first reaction provides the necessary energy for the other gasification reaction to proceed very rapidly. gasification temperatures and pressures within the refractory-lined reactor typically range from 800 °C to 1200 °C and near atmospheric pressure to few inches of water respectively.

At higher temperatures the endothermic reactions of carbon with air are favored. A wide variety of carbonaceous feed stocks can be used in the gasification process. Low-BTU wastes may be blended with high - BTU supplementary fuels such as coal or petroleum coke to maintain the desired gasification temperatures in the reactor.

The reducing atmosphere within the gasification reactor prevents the formation of oxidized species such as SO_2 and NOx which are replaced by H_2S (with lesser amounts

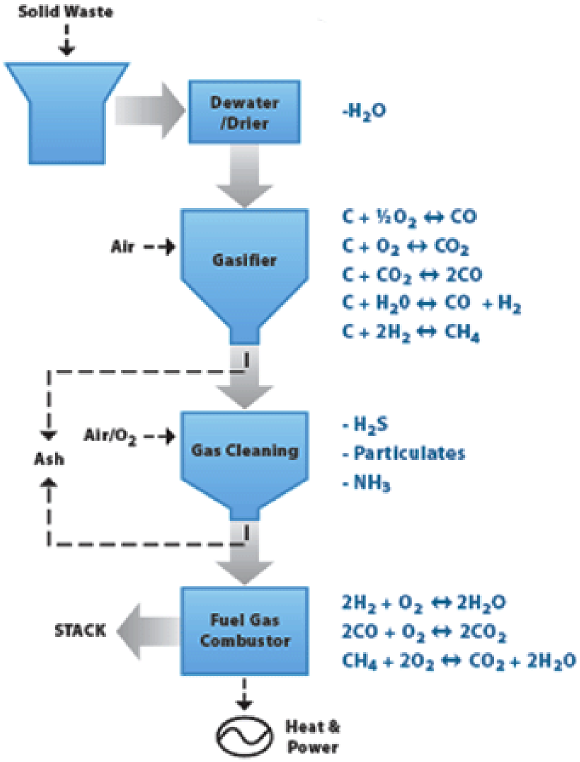


Figure 2.3: Reaction in Gasification [12]

of COS), ammonia, and nitrogen (N_2). These species are much easier to scrub from the syngas than their oxidized counterparts before the syngas is utilized for power.

2.4 Impact of fuel properties on gasification

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 gasification. Theoretically, almost all kinds of biomass with moisture content of 5-30% can be gasified; however, not every biomass fuel lead 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. The properties of fuel which influence the gasification are described below.

- Moisture content
- Particle size and distribution
- Bulk density of the fuel
- Volatile matter content
- Ash content and composition
- Energy content of fuel
- Fuel form
- Reactivity of fuel

2.4.1 Moisture content

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 load 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 of fuel

Volatile matter and inherently bound water in the fuel are given up in pyrolysis zone at the temperatures of 100-150 o 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 %) [17].

2.4.5 Ash content of fuel

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 hust contains high amount of ash (16-23%) [17].

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.

2.4.7 Fuel form

The form in which fuel is fed to gasifier has an economical impact on gasification. Dandifying biomass has been practiced in the US for the past 40 years. 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/m^3 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.

2.5 Lignite as gasifier fuel

Coal is the fossil fuel that has been longest in use. Four types of coal available worldwide, Lignite is one of them. Lignite, often referred to as brown coal, or Rosebud coal, it is a soft brown fuel with characteristics that put it somewhere between coal and peat. It is considered the lowest rank of coal. Most lignite is geologically young, generally having formed during the Cenozoic and Mesozoic eras (approximately 2 to 250 million years ago). Many lignite beds lie close to the surface and are of great thickness, sometimes greater than 30 m (about 100 feet); they are easily worked, and the cost of production is low and it is used almost exclusively as a fuel for steam-electric power generation.

Lignite is brownish-black in color and has a carbon content of around 25-35%, a high inherent moisture content sometimes as high as 66%, and an ash content ranging from 6% to 19% compared with 6% to 12% for bituminous coal.

The energy content of lignite ranges from 10 to 20 MJ/kg on a moist, mineral-matter-free basis.

Worldwide about 79% of lignite coal is used to generate electricity, 13.5% is used to generate synthetic natural gas, and 7.55% is used to produce fertilizer products (anhydrous ammonia & ammonium sulphate). A very small percentage is used as home heating fuel.

Because of its low energy density, brown coal is inefficient to transport and is not traded extensively on the world market compared with higher coal grades.

Lignite has a high content of volatile matter which makes it easier to convert into gas. However, its high moisture content and susceptibility to spontaneous combustion can cause problems in transportation and storage. So, it is often burned in power stations constructed very close to any mines.

Lignite-fired power plants generate electricity at lower prices than other fuels because of their low mining and minimal transportation costs. However, burning it can result in low efficiencies because lignite has a high-moisture content and low heating value. Slagging and fouling problems are also common consequences of lignite firing—either from the high quantity of ash. Lignite-burning plants also require typical environmental controls for coal- fired power plants to avoid environmental damage from the major air pollutants.

However, these problems could be overcome by gasifying lignite in to producer gas in downdraft gasifier. The gases after scrubbing, so produced could be utilized for running I.C.Engine or gas turbine for power generation [18].

2.6 Current status of gasification technology

Excellent survey of current status of gasification technology has been carried out by in both developed and developing countries.

However there is confusion regarding the number of manufacturers of gasification equipment. Quite a number of these manufacturers have just produced few units, which are still in experimental stages. There are therefore, close to 64 manufacturers all over the world. In U.S. alone there are 27 manufacturers and about 13 Universities and USDA research stations working on various aspects of biomass gasification.

The world's largest gasification manufacturing facility is Gasifier and Equipment Manufacturing Corporation (GEMCOR) in Philippines. They produce about 3000 units/year ranging in size from 10-250 kW. Besides they have recently started producing gasifiers for direct heat applications. Their primary applications have been for irrigation pumps and power generating sets. To date about 1000 units have been installed within Philippines running on charcoal, wood chips and briquettes. Brazil is another country where large scale gasification manufacturing program has been undertaken. About 650 units of various sizes and applications have been installed.

In both the Brazilian and Philippines program the gasifiers are mostly charcoal powered. In this a strict quality control of the fuel has to be maintained. Thus the companies involved in gasifier manufacturing also supply the quality fuel. Inadequate fuel quality is the biggest problem in running these gasifiers.

In Europe there are many manufacturers especially in Sweden, France, West Germany and Netherlands. Who are engaged in manufacturing gasification systems for stationery application. Most of market for these European manufacturers has been in developing countries.

The U.S. and North American manufacturing activities the most active program in gasification is at University of California, Davis and University of Florida, Gainesville. Many systems in the range of 10-100 kW have been developed at Davis. U.S. also is ahead of the rest of world in direct heat application gasifiers.

In other countries of Asia and Africa the work is being carried out in research institution and few prototypes have been made and tested. Interestingly enough no mention of Japan is there in any worldwide gasification literature. However if the gasification technology does pick up it will be only a matter of time before Japan flexes its economic muscle and mass produces the gasifiers at cheaper rates.

Most of the gasifiers (up to 100 kW range) being sold by different manufacturers show a leveling off price of $ 380/KW for plant prices and about $ 150 KW for basic gasifier price. This leveling off comes at about 100 kW system. However, for small systems the prices are extremely high. Thus a 10 KW, gasifier plant costs about $ 840/KW. While the basic gasifier is $ 350/KW. To this must be added the transportation costs (especially for shipment to developing countries). These prices therefore can make the gasifiers uneconomic. This explains the big gasifier manufacturing push being given in countries like Philippines, Brazil etc.

Unfortunately with all the activities going around the world the impact of gasification technology till to date on the economy has been negligible and far smaller than that of other renewable energy namely Solar. However gasification is a recently rediscovered technology and most of the development is still on learning curve [19].

2.7 Review of present work in effect of fuel particle size on gasifier parameter

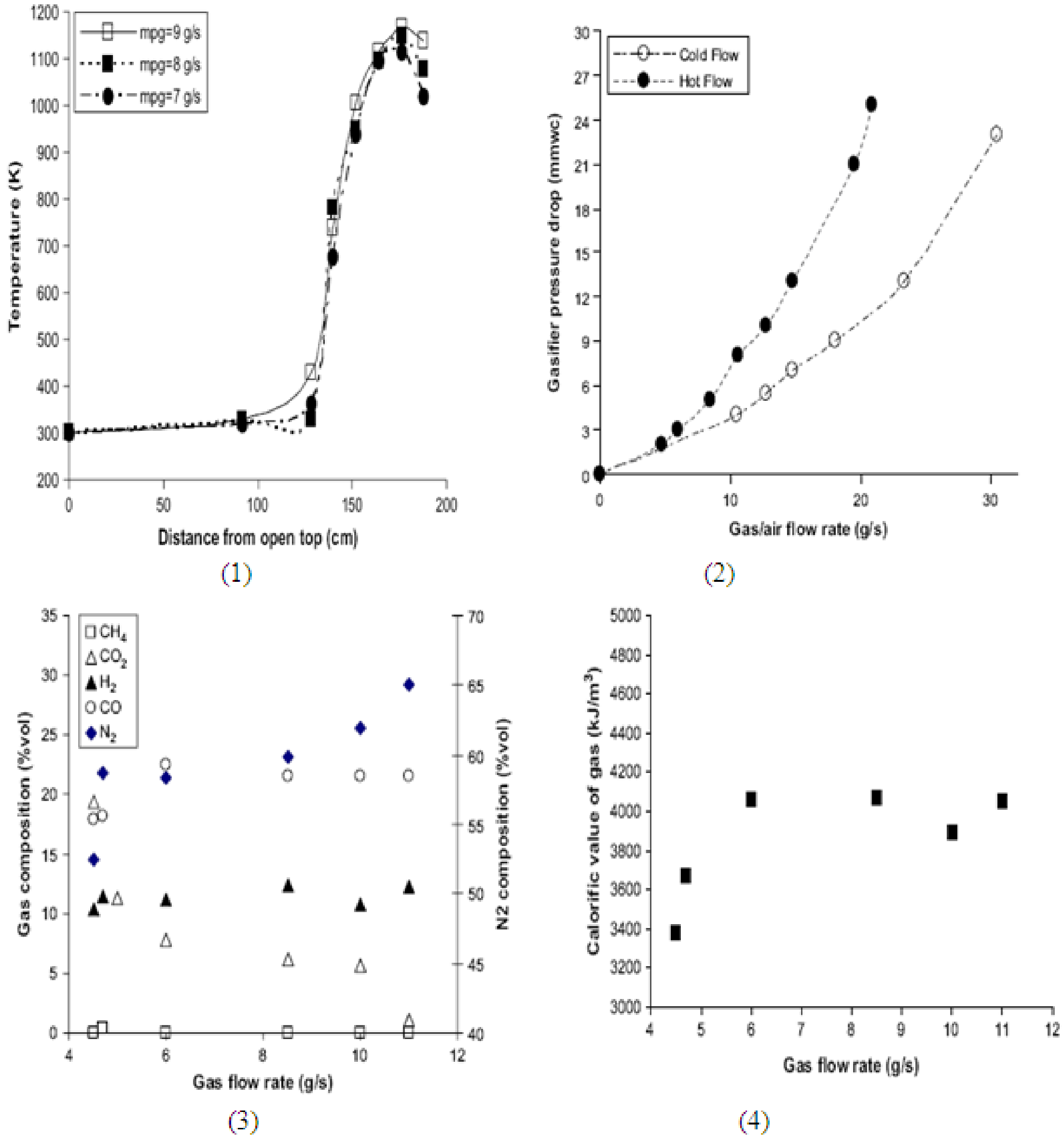
In order to do experiment on effect of size variation of lignite on performance parameter of gasifier some research paper were refereed on gasifier and gasification process

Avdhesh Kr. Sharma [1] carried out Experimental study on 75 kW_{th} downdraft (biomass) gasifier system to obtain 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. Some issues related to re-fabrication of damaged components/parts have been discussed in order to avoid any kind of leakage. In firing mode, the pressure drop across the porous bed, cooling cleaning train, bed temperature profile, gas composition and gas calorific value are found to be sensitive to the gas flow rate. The rise in the bed temperature due to chemical reactions strongly influences the pressure drop through the porous gasifier bed. In non-firing mode, the extinguished gasifier bed arrangement (progressively decreasing particle size distribution) gives much higher resistance to flow as compared to a freshly charged gasifier bed (uniformly distributed particle size). The influence of ash deposition infired-gasifier bed and tar deposition in sand filters is also examined on the pressure drop through them. The experimental data generated in this article may be useful for validation of any simulation codes for gasifiers and the pressure drop characteristics may be useful towards the coupling of a gasifier to the gas engine for motive power generation or decentralized electrification applications.

The temperatures at various locations in the reactive gasifier bed are measured to plot its profile for three consecutively increasing gas flow rates (i.e. 7, 8 and 9 g/s) as shown in Fig. 2.4 (1) The experimentally obtained temperature profile is found to improve with increase in gas flow rate through the gasifier bed. The results also show the highest temperature is maintained near the tuyeres (oxidation zone), as expected.

It can be seen by comparing the results of Fig. 2.4(2) for same type of gasifier bed arrangement that the pressure drop across gasifier bed in firing mode gives much higher values as compared to non-firing extinguished gasifier bed.

The gas sample is collected at gas venturi after cooling–cleaning operation. The measured variation in composition of CO, CO_2, H_2 and N_2 at different gas flow rates are plotted in Fig.2.4(3) . Figure shows that CO and H_2 contents in product gas increase gently with increase in producer gas flow rate, while CO_2 shows decreasing trends with gas flow rate. The CH_4 content in product gas is observed to be very small in these experiments. The calorific value of the product gas can be obtained from the heating values of individual combustible component available in literature.



(1) (2) (3) (4)

Figure 2.4: Experimental results of study on 75 kWth, downdraft (biomass) gasifier system [1]
(1) Experimental temperature profile in the bed for different gas flow rate (mpg), db=36mm, hardwood.
(2) Comparing gasifier pressure drop in firing and nonfiring mode.
(3) Composition versus gas flow rate.
(4) Calorific value of gas versus gas flow rate.

The variation of calorific value of gas is plotted against the gas flow rate as shown in Fig.2.4(4). which is find to be increasing for initial increase in gas flow rate, thereafter, it does not shows any significant variation with further increase in any gas flow rate.

Juan et. al.[2] carried out Several experimental schedules in an atmospheric entrained flow gasifier in order to determine the effect of the fuel particle size (dp) and the space residence time (tr) on several gasification parameters, such as the producer gas composition (in particular, the CO and H_2 content), the gas heating value, the gas yield and the cold gas efficiency. Different types of biomass (agricultural, forestry and industrial wastes) with a high interest in the southern regions of Europe have been tested and the results have been compared to those obtained for a conventional fossil fuel (a coal–coke blend). The main conclusions obtained are the following:

- Fig 2.5 shows that a reduction in the fuel particle size leads to an improvement in the gas quality (represented by an increase in the combustible species), and thus to a higher producer gas heating value. Cold gas efficiency, H_2/CO ratio and fuel conversion are also enhanced. Maximum fuel conversion was obtained for the smallest particle size tested (0.5 mm).
- Thermo chemical characterization of the char–ash residue shows that as the fuel particle size is reduced, the release of volatile matter during suggesting that pyrolysis reactions take place to a greater extent. However, for fuel particles below 1 mm, char gasification reactions start to become more relevant, contributing to the improvement of the fuel conversion and the producer gas composition.

- Longer space residence time inside the reactor (achieved by means of lower air velocities) causes significant benefits for the gasification process, since all the

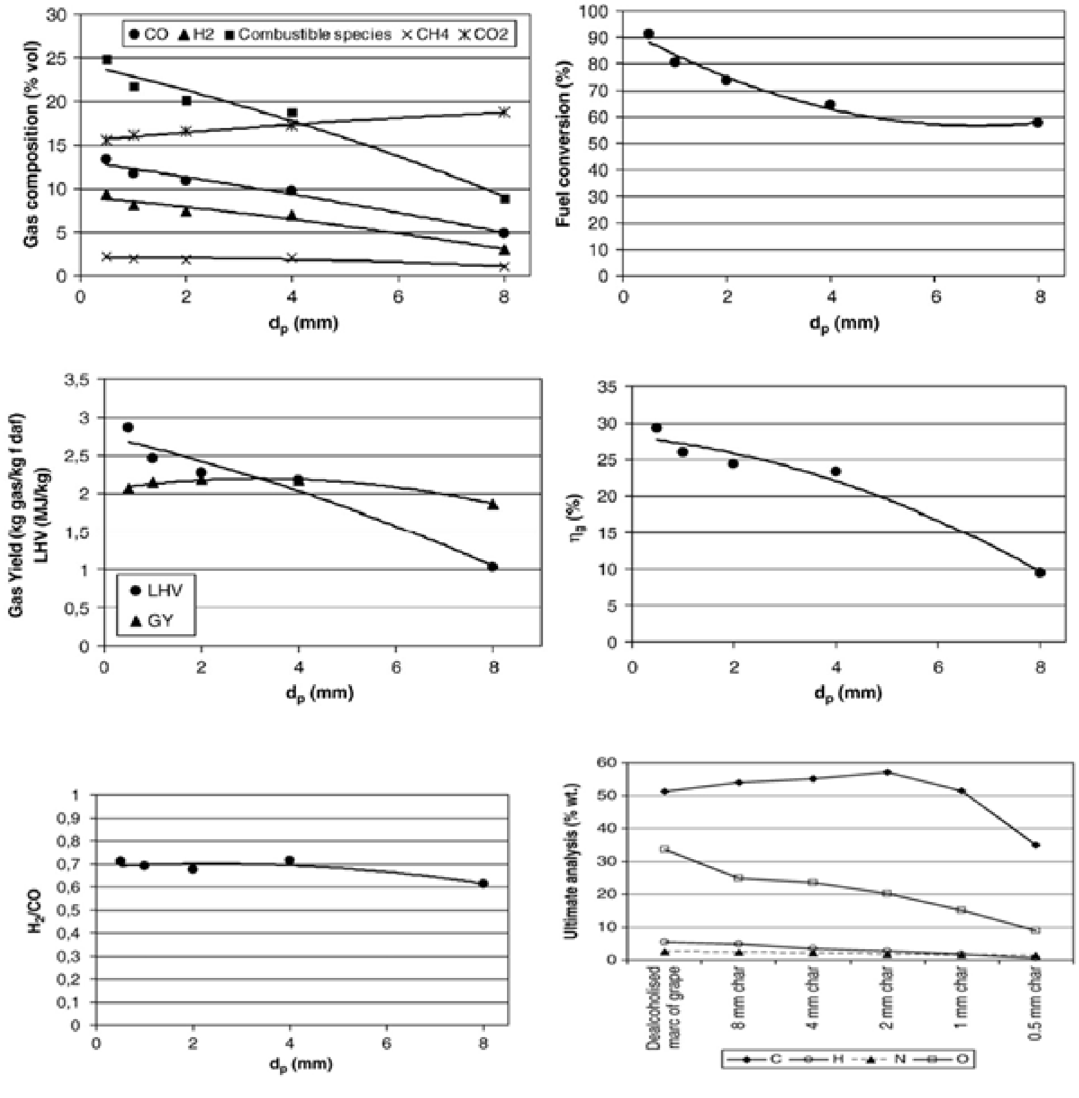


Figure 2.5: Experimental results of effect of the fuel particle size (dp) on gasification parameters [2]

parameters (CO and H_2 content, gas lower heating value, cold gas efficiency, and fuel conversion) are improved. In general, the gas yield and the H_2/CO ratio showed a constant value around 0.5, or even a very slight decrease, in the case of the biomass fuels tested at 1050 °C. On the contrary, the coal–coke blend showed both higher and increasing H_2/CO ratios when increasing the space residence time, which might be due to the combined effect of the catalytic enhancement of the water–gas shift reaction by some ash elements (Fe, Ni, Zn, and Al) and longer space times. This indicates that if biomass is used to produce syngas for biofuel production, the latter would require an upgrading stage in order to adjust the H_2/CO ratio.

- The combined effect of higher reaction temperature and higher space residence time has a positive effect on the gasification process, leading to an upgrade of the gas composition and higher gasification efficiencies. However, the increase in the H_2/CO ratio when the space time increases has been observed just for a temperature above 1000 °C, this ratio decreasing with tr for lower temperature. On the other hand, the fuel particle size has a negligible effect on the H_2/CO ratio.
- All the biomass fuels tested showed a better behavior as compared to coal–coke, since they led to higher quality producer gas and higher gasification efficiencies, due to their higher reactivity.

Siyi Luo et. al.[3] carried out pyrolysis and gasification of municipal solid waste (MSW) in a lab-scale fixed bed reactor in order to evaluate the effects of particle size at different bed temperatures on product yield and composition. The bed temperature was varied from 600 to 900 $^{\underline{o}}$C and the MSW was separated into three different size fractions (below 5 mm, 50–10 mm and above 10 mm). Particle size and temperature had integrated effects on product yield and composition: higher temperature resulted in higher gas yield with less tar and char, and, at the same temperature, dry gas yield increased with a decrease in particle size, and char and tar yield decreased. The differences due to particle sizes in pyrolysis and gasification performance practically disappeared at the highest temperatures tested. Smaller particle sizes resulted in higher H_2 and CO contents for both pyrolysis and gasification of MSW. Minimizing the size of raw materials is an alternative method to improve the gas quality of MSW pyrolysis and gasification.

Fig. 2.6 show the dry gas yield and the weight ratio of char and tar to the MSW obtained at different MSW particle size by steam gasification. The differences in product yield and composition with temperature are due first to the greater production of gas in the initial pyrolysis (faster at higher temperatures), second to the endothermic reactions of gasification of the char and third to the steam cracking and reforming of the tars. Table 2.1 shows the gas composition of MSW gasification by steam with different particle size at 900 ºC.

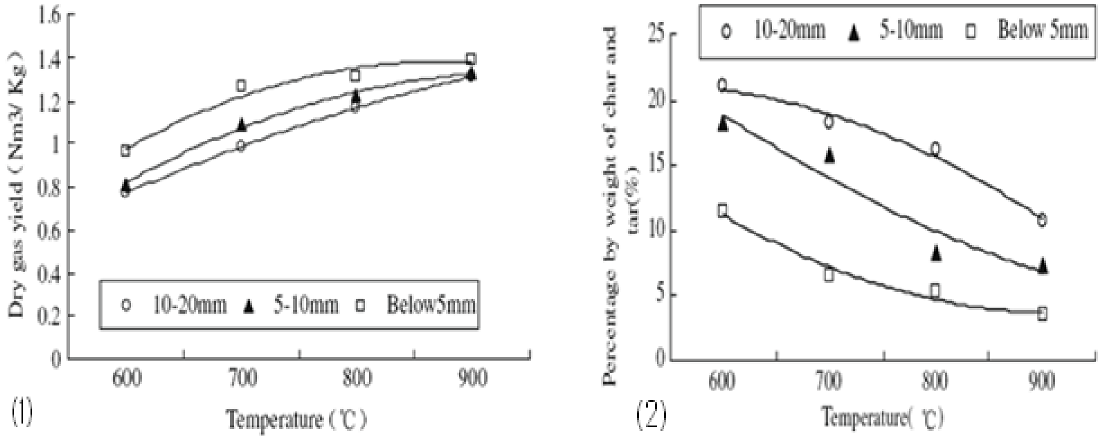


Figure 2.6: Experimental results of steam gasification of municipal solid waste (MSW) in a lab-scale fixed bed reactor [3]
(1) Dry gas yield of MSW as a function of particle size and bed temperature
(2) Percentage by weight of char and tar as a function of particle size and bed temperature

Table 2.1: Gas composition of MSW gasification by steam with different particle size at 900 °C [3]

Particle size d (mm)	d < 5	5 < d < 10	10 < d < 20
H_2	22.4	20.6	18.3
CO	1.5	24.7	22
CO_2	34.2	37.1	43.2
CH_4	10.1	12.6	11.5
C_2H_4	5.3	3.3	4.3
C_2H_6	1.5	1.7	0.7

Francisco Tinaut et. al.[4] presented a one-dimensional stationary model of biomass gasification in a fixed bed downdraft gasifier. The model was validated experimentally in a small-scale gasifier by comparing the experimental temperature fields, biomass burning rates and fuel/air equivalence ratios with predicted results. A good agreement between experimental and estimated results was achieved. The model can be used as a tool to study the influence of process parameters, such as biomass particle mean diameter, air flow velocity, gasifier geometry, composition and inlet temperature of the gasifying agent and biomass type, on the process propagation velocity (flame front velocity) and its efficiency. The maximum efficiency was obtained with the smaller particle size and lower air velocity. It was a consequence of the higher fuel/air ratio in the gasifier and so the production of a gas with a higher calorific value.

Zainal et. al.[5] is carried an experimental investigation of a downdraft biomass gasifier using furniture wood and wood chips. The effect of equivalence ratio on the gas composition, calorific value and the gas production rate is presented. The calorific value of the producer gas increases with equivalence ratio initially, attains a peak and then decreases with the increase in equivalence ratio. The gas flow rate per unit weight of the fuel increases linearly with equivalence ratio. It is also observed that complete conversion of carbon to gaseous fuel has not taken place even for the optimum equivalence ratio.

Patel S.R. et. al.[6] installed one unit of Sardar Patel Renewable Energy Research Institute (SPRERI's) 1.25 GJ h^{-1} capacity open core down draft gasifier burner system, suitable for thermal application at M/s Dinesh Pharmaceutical Pvt. Ltd., Nandesari, for steam generation. Producer gas burner was used in dual fuel mode (60% LDO (light diesel oil)+40% producer gas). Gasifier consumed 78–80 kg/h of wood, and replaced 40% (20 l/h) LDO. The system was tested for a cumulative period of 600 h using sawmill woody waste as feedstock in test runs of 15–18 h. Financial analysis of the gasifier system showed that user could save about Rs. 221.8 per hour by using dual fuel (60% LDO+40% producer gas) for steam generation. Economic analysis of the system tested in the field indicated the viability of the gasifier-based operation.

Erlich et. al.[7] studying the impact of the char bed properties such as char bed porosity and pressure drop on the gasification performance as well as the impact of fuel particle size and composition on the gasification process in one and the same gasifier. In addition, there is very little gasification data available in literature of "before disregarded" fuels such as sugar cane bagasse from sugar/alcohol production and empty fruit bunch (EFB) from the palm-oil production. By pelletizing these residues, it is possible to introduce them into downdraft gasification technology. The results show that one and the same reactor can be used for a variety of fuels in pellet form, but at varying air–fuel ratios, temperature levels, gas compositions and lower heating values. Gasification of wood pellets results in a richer producer gas while EFB pellets give a poorer one with higher contents of non-combustible compounds. In this gasification study, there is almost linear relation between the air–fuel ratio and the cold-gas efficiency for the studied fuels: Higher air–fuel ratios result in better efficiency. The pressure drop in the char bed is higher for more reactive fuels, which in turn is caused by low porosity char beds.

Ratnadhariya and Channiwala [8] proposed three zone equilibrium and kinetic free model of biomass gasifier. In this three zone: first zone of the model is drying and pyrolysis zone combined together; second zone is oxidation zone; and the third zone is the reduction zone. Each zone has been formulated with: (i) reaction stoichiometry (ii) constituent balance; and (iii) energy balance along with a few justifying assumptions. This model clearly provides an operating range of equivalence ratio and moisture content for the woody biomass materials. Further, this model facilitates the prediction of the maximum temperature in the oxidation zone of gasifier, which provides useful information for the design of the gasifier and selection of the material for the construction. The merits of the model lies in the fact that it is capable of handling predictions for all category of biomass materials with a wide operating range of equivalence ratio and moisture content in all of the three principal zones of the gasifier.

Gokhale et. al.[9] set up a fixed-bed coal gasification reactor which specifically simulated the devolatilization zone in a gasifier. Samples (100 g) of lignite coal in three size ranges were devolatilized in the temperature range 350–550 °C with a steam-oxygen mixture, at 1 atm. The effect of these operating variables on tar yield and composition, melting point, viscosity, specific gravity, and molecular weight distribution was determined. A first-order reaction model was fitted to the experimentally observed total loss in weight of the lignite.

Prins et. al.[10] studied the effect of fuel composition on the thermodynamic efficiency of gasifiers and gasification systems. A chemical equilibrium model is used to describe the gasifier. It is shown that the equilibrium model presents the highest gasification efficiency that can be possibly attained for a given fuel. Gasification of fuels with varying composition of organic matter, in terms of O/C and H/C ratio as illustrated in a Van Krevelen diagram, is compared. It was found that energy losses in gasifying wood (O/C ratio around 0.6) are larger than those for coal (O/C ratio around 0.2). At a gasification temperature of 927 °C, a fuel with O/C ratio below 0.4 is recommended, which corresponds to a lower heating value above 23 MJ/kg. For gasification at 1227 °C, a fuel with O/C ratio below 0.3 and lower heating value above 26 MJ/kg is preferred. It could thus be attractive to modify the properties of highly oxygenated biofuels prior to gasification, e.g. by separation of wood into its components and gasification of the lignin component, thermal pre-treatment, and/or mixing with coal in order to enhance the heating value of the gasifier fuel.

Bhattacharya et. al.[11] obtained the gas composition and temperature profiles for charcoal, gasified in the down-draft mode, from theoretical considerations. The prediction is based on kinetics and the heat and mass transfer mechanisms in an air-blown gasifier at atmospheric pressure. The charcoal has been assumed to be pure carbon, i.e. free from volatile matter and ash. Parametric studies were made on solid and gas flow rates, char reactivity and particle size, both with dry air and with steam in the system. The rate parameters used were those for anthracite coke and were taken from published literature, with appropriate reactivity corrections. The results showed the O_2 consumption took place very rapidly, in a distance of about 10–15 cm from the level at which air entered; the CO_2 concentration dropped after increasing to a maximum; the CO and H_2 concentrations continually increased from zero. The model predictions agreed reasonably with experimental results.

2.8 Producer gas

Producer gas is the mixture of combustible and non-combustible gases as shown in Table 2.2. The quantity of gases constituents of producer gas depends upon the type of fuel and operating condition.

Table 2.2: Producer Gas and its Constituents for Coal [16]

Constituents	%
CO	5-20
CO_2	5-15
H_2	8-18
CH_4	2-5
N_2	45-60
H_2O	6-8

Table 2.3: Density and Heating value of different gases [16]

Gas Type	Density	Heating value
	Kg/m ^{3}	MJ/m^3
Carbon monoxide	1.2	13
Carbon dioxide	2.0	0
Hydrogen	0.1	11
Methane	0.8	35
Nitrogen	1.3	0
Producer gas	1.2	5

The heating value of producer gas vary from 4.5 to 6 MJ/m^3. Heating value of producer gas is depends on heating value and density of its constituent as shown in Table 2.3. Carbon monoxide is produced from the reduction of carbon dioxide and it´s quantity varies from 10 to 30 % by volume basis. Although carbon monoxide posses higher octane number of 106, it´s ignition speed is low. This gas is toxic in nature. Hence, human operator need to careful while handling gas.

Hydrogen is also a product of reduction process in the gasifier. Hydrogen posses the octane number of 60-66 and it increases the ignition ability of producer gas. Methane and hydrogen are responsible for higher heating value of producer gas. Amount of methane present in producer gas is very less (up to 5 %). Carbon dioxide and nitrogen are non-combustible gases present in the producer gas. Compared to

Table 2.4: Composition of Producer Gas from various fuels [18]

Fuel	Gasification method	Volume Percentage					Calorific value MJ/m^3
		CO	H_2	CH_4	CO_2	N_2	
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65
Wood with 12-20% moisture content	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.86
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50
Coconut husks	Downdraft	16-20	17-19	-	10-15	-	5.80
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20
Pressed Sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30
Charcoal	Updraft	30	19.7	-	3.6	46	5.98
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29
Rice hulls pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32

other gas constituents, producer gas contains highest amount (45-60 %) of nitrogen. The amount of carbon dioxide varies from 5 to 15 %. Higher percentage of carbon dioxide indicates incomplete reduction. Water vapors in the producer gas occur due to moisture content of air introduced during oxidation process, injection of steam in gasifier or moisture content of biomass fuels.

Table 2.4 shows the percentage of composition of producer gas and heating value of producer gas from different biomass fuel and gasification method.

Chapter 3

Materials and Methods

Towards achieving the objective the experiments were performed on 10 kWe downdraft gasifier. The methods and equipment used in the experiments have been discussed in following section.

3.1 Experimental procedure

It always ensures that the gasifier system (gasifier, cyclone and surge tank) is clean before starting any new experiment. It also ensure that there is no choking within the system through the pressure drop across cyclone, orifice and surge tank. The prepared char is fed into the gasifier up to air tuyeres then fuel (lignite) is fed into the gasifier and the top cover is closed. All the air tuyeres are closed except the firing nozzle. Fuel is fired with the help of mashal from the firing nozzle when the inner part seems to be red hot mashal removed. Then firing nozzle is closed and air tuyeres are opened. Flow rate is maintained with the help of U-tube manometer at design level and temperature along the length of gasifier is recorded. Thereafter the flow rate and temperature is recorded in regular interval. Meanwhile material is fed up to have continuous operation. Gas is collected for analysis in gas balloon from one of pet cock.

The procedure is repeated by changing fuel (lignite) particle size.

The position of ball valve and opening of air tuyeres are kept same throughout experiment and for all the experiment with different lignite size.

3.2 Experimental set-up

The schematic diagram of downdraft gasifier system is as shown in Fig. 3.2, and Fig. 3.1 shows the actual experimental set-up. The components of gasifier system are as below:

- Gasifier
- Cyclone
- Orifice meter
- Surge tank
- Ball valve
- Blower
- Burner

In order to measure the pressure drop across each element the pet cock are inserted at 50mm of distance on inlet and outlet respectively. The temperature in gasifier is measure with eight thermocouples at regular distance. Orifice is installed at 10 times the diameter of pipe after cyclone. 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. At end the burner is placed where the producer gas is burnt. The flow line of system is explained as under.

Gas is generated in gasifier 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. Before the surge tank gas is passed through orifice plate. After surge tank it goes to the burner via blower where it burned.

Figure 3.1: Experimental set-up

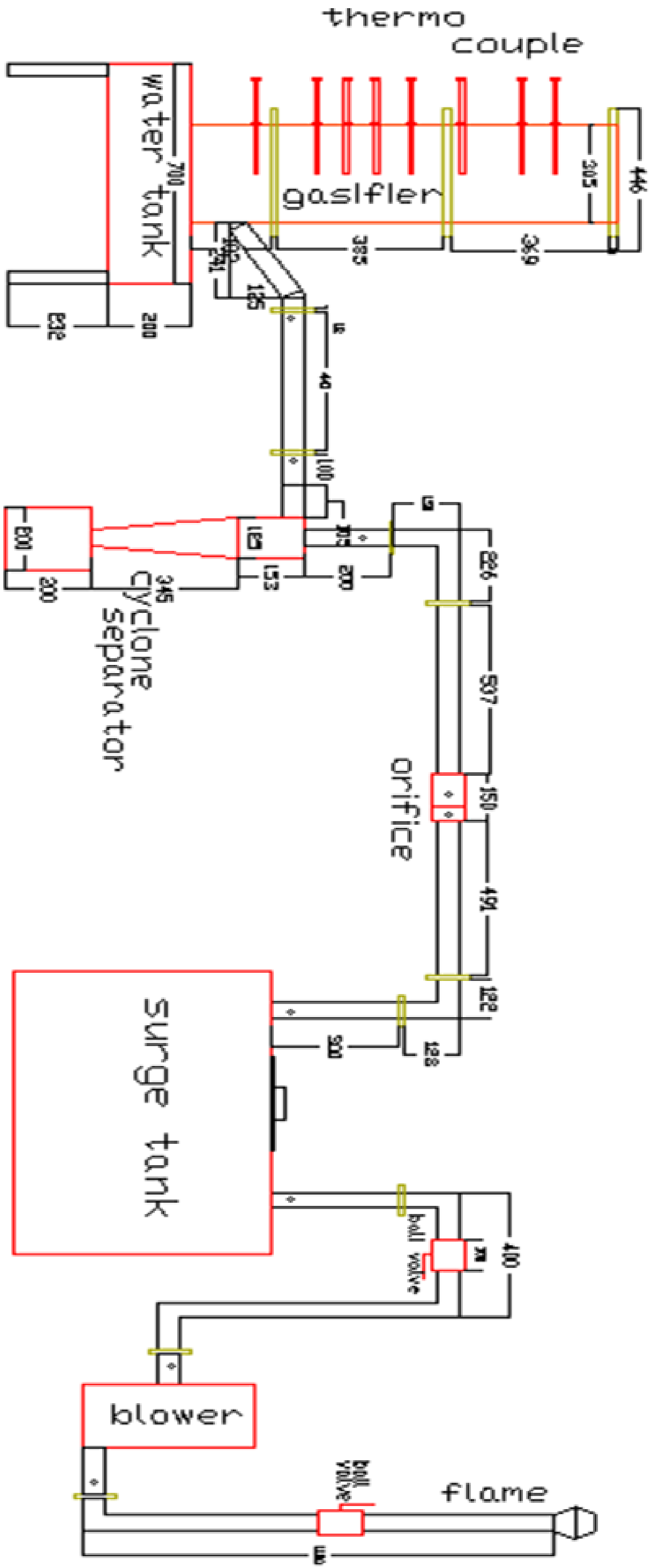


Figure 3.2: Schematic diagram of downdraft gasifier system

3.3 Sample Preparation

3.3.1 Lignite sizing

Cold flow studies suggest that the ratio of choke plate (throat) diameter and particle size diameter is greater than 5

$$\text{Throat diameter of experimental gasifier} = D_{th} = 121 \text{ mm}$$

$$\text{Particle size diameter} = D_p$$

$$\frac{D_{th}}{D_p} = 6 \tag{3.1}$$

$$D_p = 20mm$$

Aim of experiment is to check the effect of size of lignite on gasifier parameter hence three different particle size will selected.

(1) 17 mm

(2) 20 mm

(3) 23 mm

Lignite is available in the rock form as shown in Fig. 3.3, so it is required to break the lignite in the desired size. It is impossible to have the exact size of lignite because of its volatile matter its turns out to be in a powder form while breaking.

Figure 3.3: Lignite

Therefore experiment were planned with following particle size:

1. 16mm to 19mm
2. 19mm to 22mm
3. 22mm to 25mm

Fig. 3.4 show the image of sieve and Table 3.1 shows the dimension of sieve.

Figure 3.4: Sieve

Table 3.1: Selection of Particle Size

Actual Particle size (mm)	Selected particle range (mm)		Sieve hole dia.(mm)	
	max	min	Upper layer	Bottom layer
17	19	16	19	16
20	22	19	22	19
23	25	22	25	22

3.3.2 Char preparation

Char is a material of fuel being used for reduction material. For experiment of gasifier on Lignite it is advisable to prepared char from wood.

Take require quantity (as per experimental) of wood. Fire the wood with the help of diesel and allow it to burn for 20minuts. When observe that it catches fire all over, cover it with suitable vessel and kept it for almost 2.5 hour.

The char is blackish in color and it shine.

3.4 Proximate analysis

The proximate analysis done by using simple test methods, estimating the main constituents of fuel which have a direct influence on the combustion characteristics e.g. the moisture content of fuel, the amount of volatile matter, fixed carbon and the amount of ash. All these component of proximate analysis are related to some way to the combustion characteristics of the fuel.

3.4.1 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 (shown in Fig. 3.5), 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:

$$m = \frac{m_i - m_f}{m_i} \times 100\ \% \tag{3.2}$$

Figure 3.5: Hot Air Oven

3.4.2 Ash content

Ash is non-combustible components of the fuel. The calorific 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 (shown in Fig. 3.6), 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. Put sample in desiccator and cool at atmospheric temperature, then again measure the weight of sample.

$$a = \frac{m_i}{m_f} \times 100\ \% \tag{3.3}$$

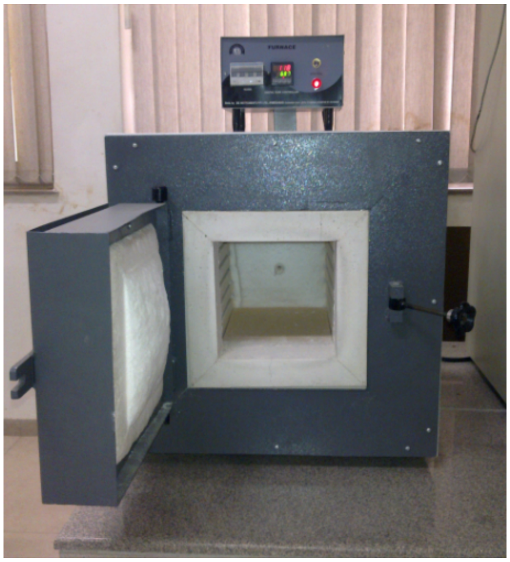


Figure 3.6: Muffle Furnace

3.4.3 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 and cooled in desiccator 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 Put sample in desiccator and cool at atmospheric temperature, and again measure 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 formulae.

$$Vm = \frac{m_i - m_f}{m_i} \times 100\ \% \tag{3.4}$$

3.4.4 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 %

$$Fc = 100\% - (m + a + Vm)\% \tag{3.5}$$

3.5 Calorific value of fuel

The Calorific 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 calorific value is determined by bomb calorimeter (as shown in Fig. 3.7). 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 polised outer vessel containing a known weight of water with is known temperature. The combustion products CO_2 and H_2O 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 calorific value so estimated is the gross calorific value. The detail calculation to calculate the calorific value of lignite is shown in appendix C.

Figure 3.7: Bomb Calorimeter

3.6 Temperature profile

Calibrated 8 nos. K-type thermocouple probe is use for measurement of temperature along the length of gasifier (shown in Fig. 3.8). 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 profile of gasifier is prepared by taking temperature at different zone at regular time interval. There are mainly four processes in gasifier. The Temperature should be taken in drying zone, Pyrolysis zone, Oxidation zone and reduction zone at seven different places along the length of gasifier. The gas outlet Temperature below grate is also taken.

Figure 3.8: Thermocouple across the length of gasifier

3.7 Pressure drop

U-tube manometer with least count of 1 mm (as shown in Fig. 3.9)is used to measure the pressure drop across the three main components in the system, viz., the gasifier, cyclone separator and surge tank.

Figure 3.9: U-tube manometer

3.8 Gas generation rate

Gas flow rate (Gas generation rate) measured from the gas temperature at orifice and pressure drop at the orifice. Gas flow rate calculated through orifice plate for producer gas.

Gas flow rate is measured with the help calibrated orifice meter, which has been kept in main flow line and with differential U- tube manometer.The orifice is having 2inch inlet diameter and 1inch throat or orifice plate diameter. The equation is derived to compute the gas generation is:

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

3.9 Fuel consumption

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

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

3.10 Calorific value of producer gas

An ultimate analysis of gas is required to make overall material, energy balance and calorific value calculation of gasification process. The composition of producer gas is measured by the producer gas analyzer (as shown in Fig.3.10). Here the concentration of carbon monoxide, hydrogen, methane, carbon dioxide and oxygen in producer gas is measured. Calorific value of the producer gas on the basis of the above mentioned gases is also evaluated. The calorific value of producer gas is mainly depend on carbon monoxide, hydrogen, methane and is calculated from higher heating value and concentration of these components. The calculation is as below:

$$CO + \tfrac{1}{2}O_2 = CO_2 + 3015\,kcal/m^3$$

$$H_2 + \tfrac{1}{2}O_2 = H_2O + 2579\,kcal/m^3$$

$$CH_4 + 2O_2 = CO_2 + H_2O + 8570\,kcal/m^3$$

$$CV\ of\ Producer\ gas = (3015 \times CO + 2579 \times H_2 + 8570 \times CH_4) kcal/m^3 \tag{3.8}$$

Figure 3.10: Producer Gas Analyzer

3.11 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 calorific value of gas and gas generation rate of producer gas by following equation:

$$HGR = CV\ of\ producer\ gas\ kcal/nm^3 \times GGR\ in\ nm^3/hr \tag{3.9}$$

3.12 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 Calorific value of Lignite, Fuel consumption, Calorific value of producer gas and Gas flow rate. The efficiency is calculated by,

$$\eta_g = \frac{CV\ of\ Lignite\ in\ kcal/kg \times FC\ in\ kg/hr}{CV\ of\ gas\ in\ kcal/nm^3 \times GGR\, in\ nm^3/hr} \tag{3.10}$$

Chapter 4

Results and Discussion

Experiments were conducted on 10kWe downdraft gasifier with three different size of lignite to check the effect of size of lignite on Gas generation rate, Calorific value of producer gas and gasifier efficiency. The methods and equipments used to measure different parameters are discussed in chapter 3.

Effect of size of lignite on temperature profile, producer gas temperature, calorific value of producer gas and gasifier efficiency is discussed in following sections.

4.1 Temperature profile

As discussed in earlier section temperature across the length of gasifier were taken at interval of 15 minutes for every sample.

Figs. 4.1 to 4.4 indicate the temperature at said location at different time respectively.

As anticipated the temperature at pyrolysis zone, oxidation zone, and reduction zone were observed in the range of $600^\circ C$ to $800^\circ C$, $800^\circ C$ to $1000^\circ C$ and $500^\circ C$ to $700^\circ C$ respectively as reported in literature.

It is observed from the temperature profile at different section across the gasifier at different time interval after firing the gasifier for different size of lignite feedstock that the temperature for lignite having size 19mm to 22mm is the lowest and lignite having size 16mm to 19mm is the highest. It also is observed that the highest temperature in oxidation zone is reported for lignite having size 16mm to 19mm in all time intervals.

Fig. 4.5 shows the temperature profile across the length of gasifier for different size of lignite at time when the temperature is maximum.

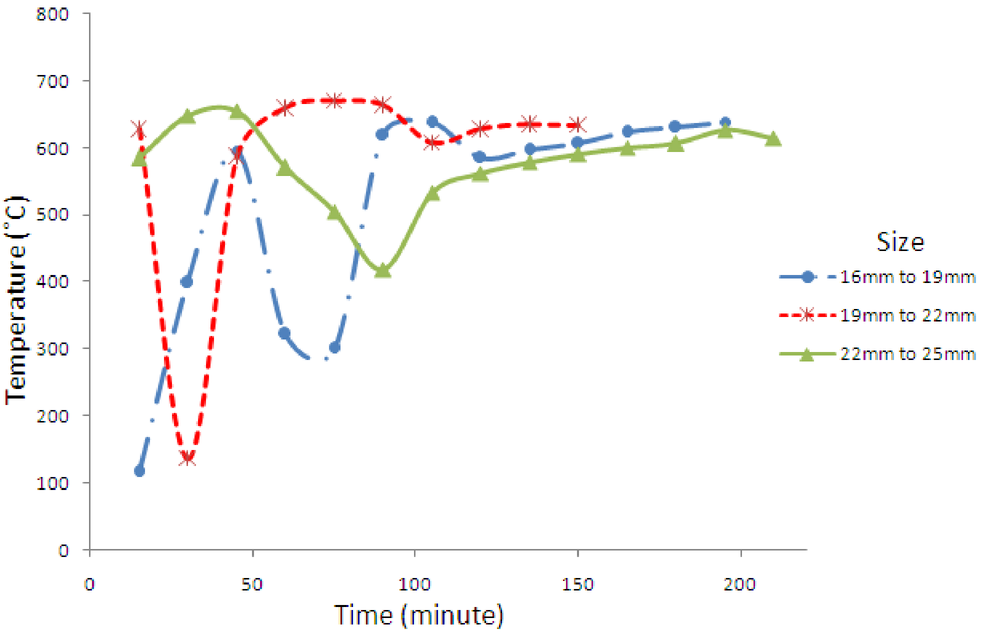


Figure 4.1: Temperature profile at Reduction zone

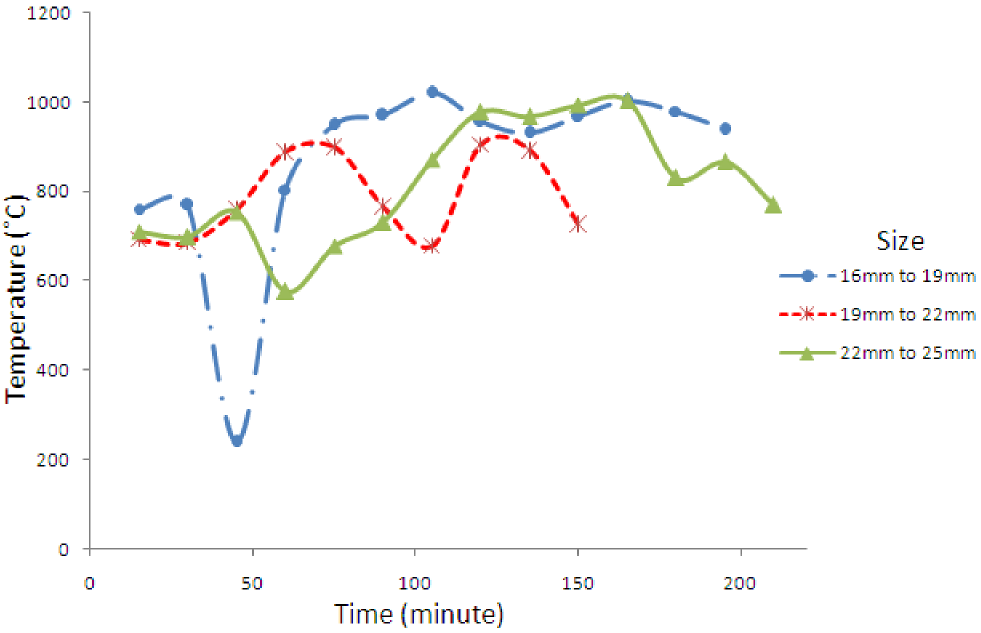


Figure 4.2: Temperature profile at Oxidation zone

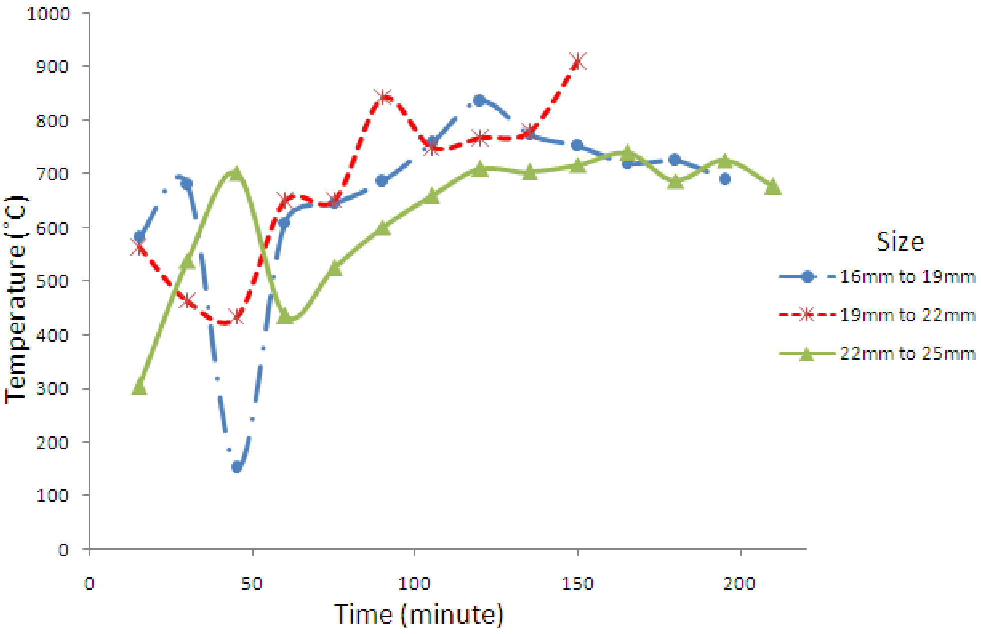


Figure 4.3: Temperature profile at Pyrolysis zone

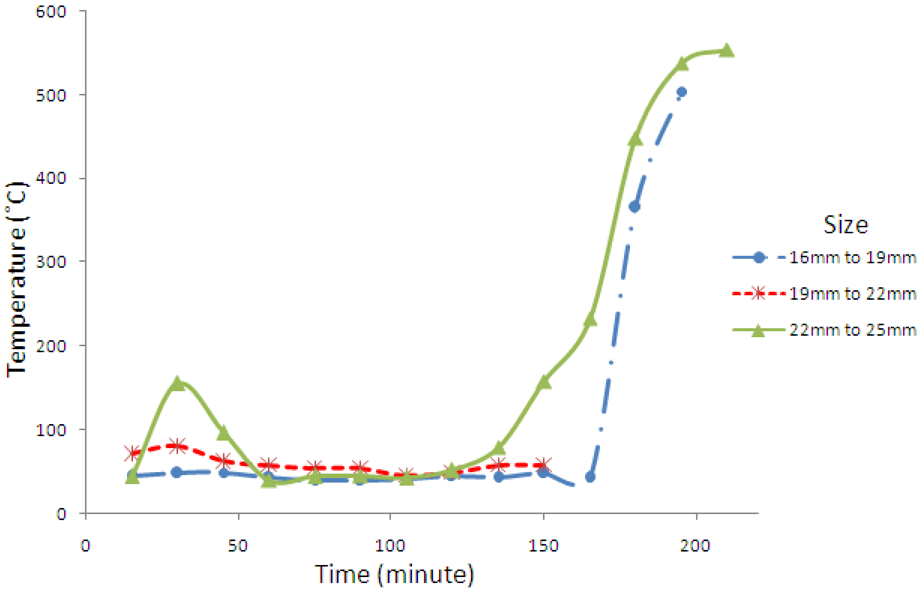


Figure 4.4: Temperature profile at Drying zone

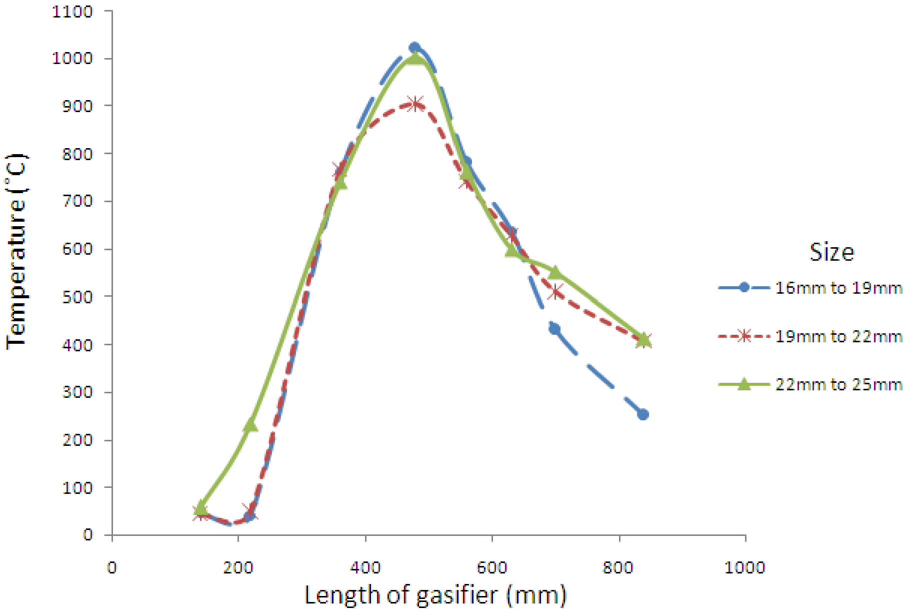


Figure 4.5: Temperature profile across the length of gasifier

4.2 Producer gas temperature

Producer gas temperature is measured at gas outlet of gasifier below grate at an interval of 15 minute.

Fig. 4.2 indicates the gas temperature.

It is observed that the gas temperature is proportional to size of lignite. For large lignite size 22mm to 25mm diameter temperature is highest while small lignite size 16mm to 19mm diameter gas temperature is lowest. The Producer gas temperature is in the range of 250 ° C to 450 ° C.

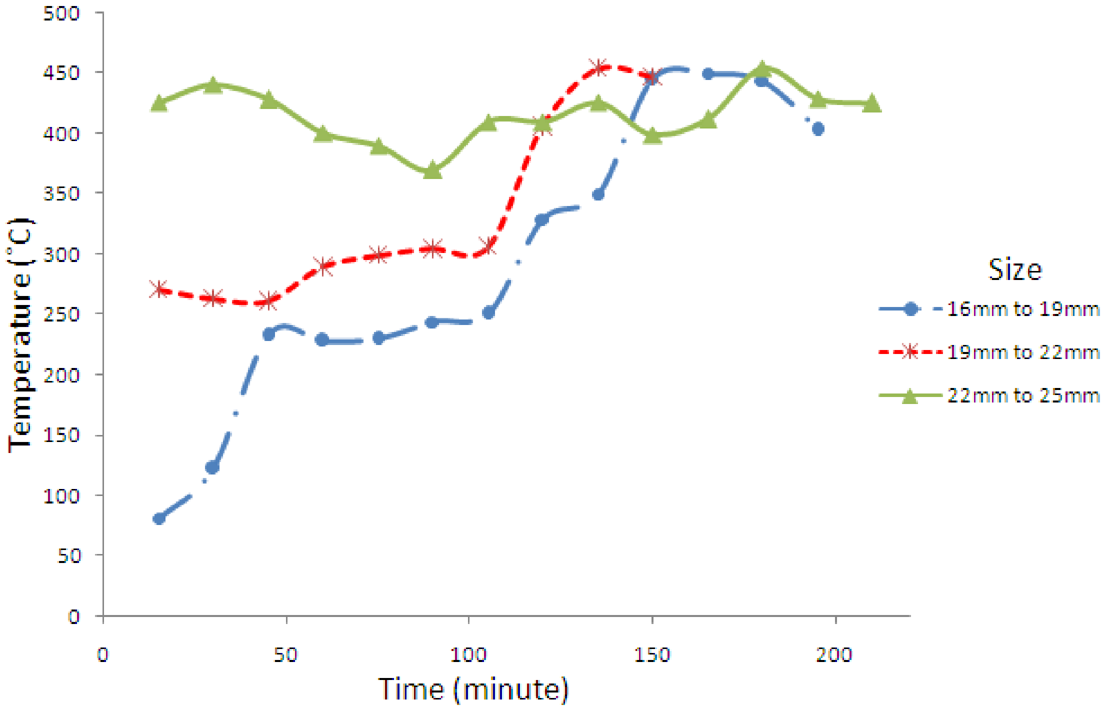


Figure 4.6: Producer gas Temperature at different time interval

4.3 Fuel consumption

Experiments were performed on 10 kWe downdraft gasifier. Literature suggests that the fuel consumption for 10kWe gasifier is typically 10kg/h. Fig. 4.7 indicates the fuel consumption rate in gasifier after firing.

It has been observed that the fuel consumption is of the range of 10 to 11 kg/h.

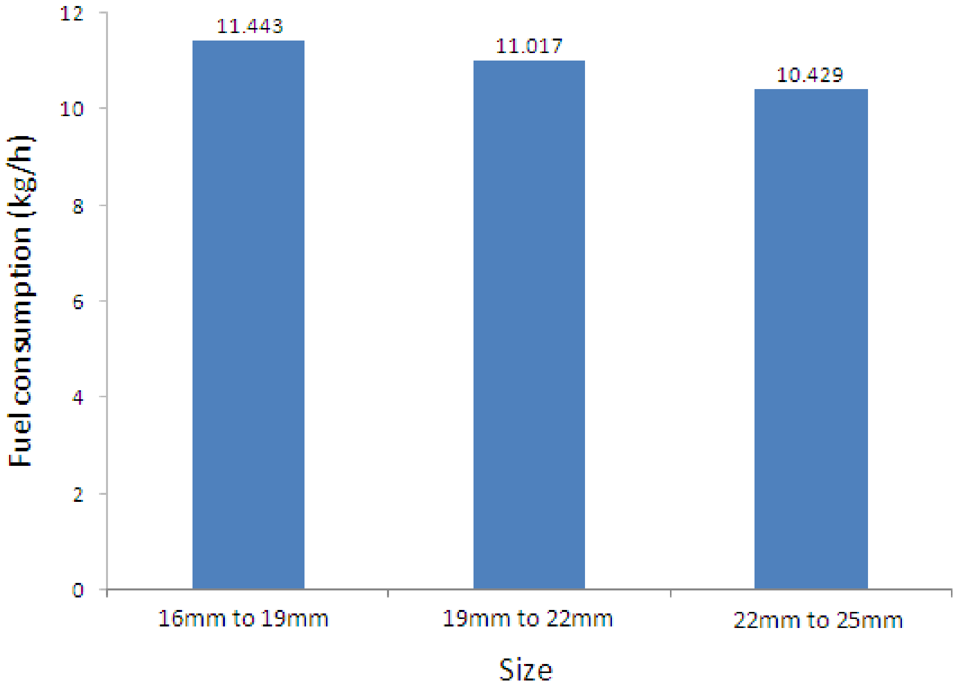


Figure 4.7: Fuel Consumption

4.4 Producer gas generation rate

Producer gas flow rate measured as explain in section 3.2.6 for all three size of lignite.

Fig. 4.8 indicates the flow rate of producer gas for all three size of lignite. From figure it is very clear that the gas generation rate is remaining constant irrespectively of lignite size.

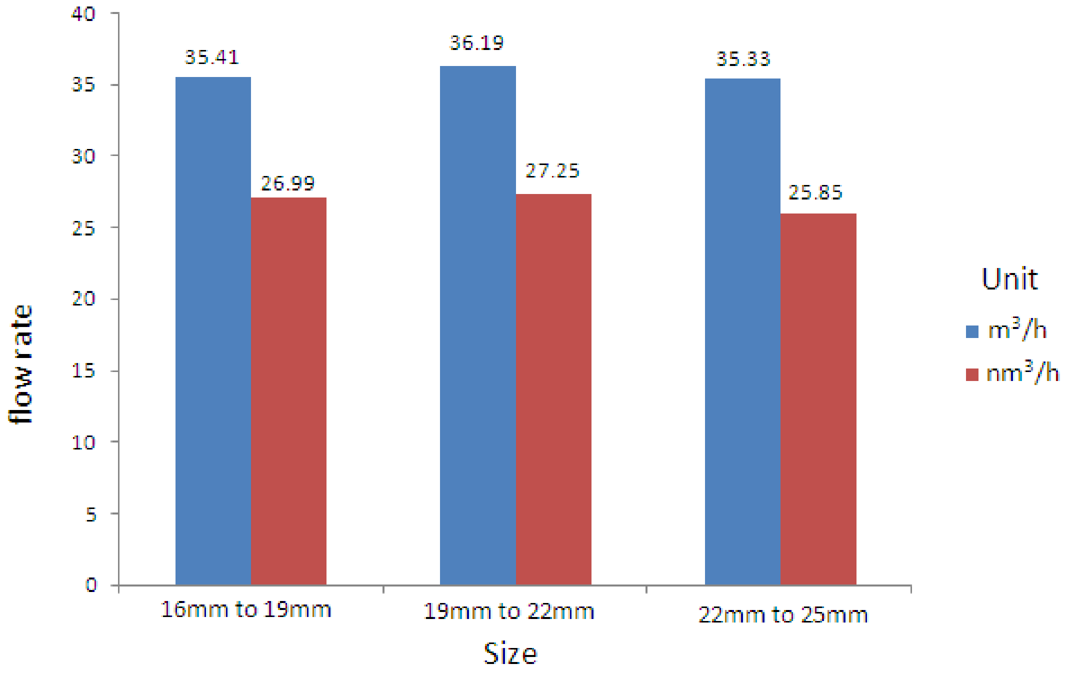


Figure 4.8: Producer gas generation rate

4.5 Calorific value of producer gas

Gas sample were collected at interval of 30 minutes after firing of gasifier. These samples were analyzed for gas composition as discussed earlier. The percentage of CO, CO_2, H_2, CH_4, and O_2 in producer gas was observed in producer gas analyzer and from the same calorific value of producer gas was calculated. The calorific value of gas with lignite sample 22mm to 25mm is observed to be the highest.

It was also observed from Fig. 4.9 that as the size of lignite increase calorific value of the gas is increase.

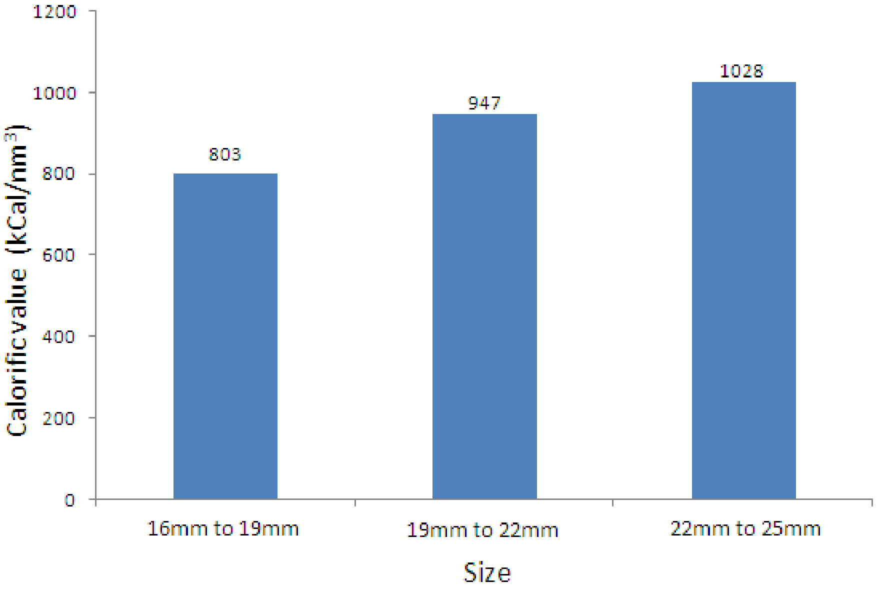


Figure 4.9: Calorific value of producer gas

4.6 Efficiency of gasifier

It is observed from Fig. 4.10 that better efficiency obtain with the fuel having size 22mm to 25mm diameter.

The poor efficiency with smaller size of lignite is attributed to higher fuel consumption and lower calorific value of producer gas.

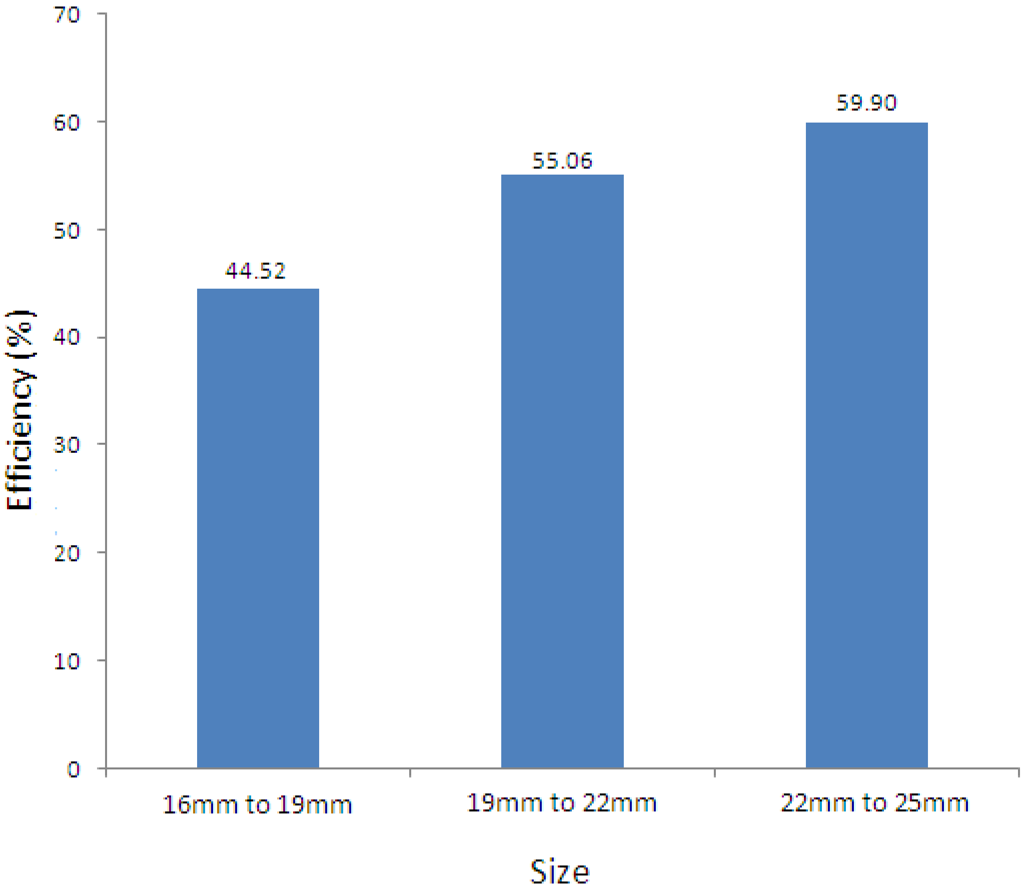


Figure 4.10: Gasifier efficiency

Table 4.1 gives the summary of experimental results. It compares the value of maximum temperature, pressure drop, gas generation rate, calorific value of producer gas and efficiency of gasifier for three different size of lignite.

Table 4.1: Summary

		Lignite 16mm to 19mm	Lignite 19mm to 22mm	Lignite 22mm to 25mm
Maximum temperature	$^\circ$C	1020	903	1003
Pressure drop at orifice	mm of water	45.6	47.2	45.57
Producer gas flow rate	nm^3/h	26.99	27.25	25.85
Producer gas flow rate	m^3/h	35.41	36.19	35.33
CV of producer gas	kcal/m^3	803	947	1028
Fuel consumption	kg/h	11.443	11.017	10.429
efficiency	%	44.52	55.06	59.90

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

Following are the major conclusions on the basis of above study.

- Typical fuel consumption for 10kWe downdraft gasifier is approximate in the range of 10 to 11 kg/h for all three size of lignite.
- Gas analysis of producer gas with different lignite size indicates that calorific value of producer gas varies between 803kcal/m^3 to 1028kcal/m^3.
- Calorific value was observed the highest with feedstock of 22mm to 25mm diameter lignite and is decrease with decrease in size.
- The flow rate of the producer gas at orifice was observed almost constant 36m^3/h and 27nm^3/h.
- Efficiency of gasifier is much dependent on size of lignite. There is large variation in efficiency by varying lignite size. The efficiency of gasifier is increase with increasing lignite size.
- The general conclusion from the above study is that the larger size of lignite having 22mm to 25 mm diameter is the best feedstock for present study.

5.2 Future Scope

Following are the work that can be done in future.

- The effect of lignite size on Moisture, Tar and SPM are to be investigated.
- The effect of particle size of lignite on the performance of SIPGE (Spark Ignition Producer Gas Engine) may also be studied.
- In the presence study three size of lignite (16mm to 19mm, 19mm to 22mm and 22mm to 25mm) were consider. The experimental results show that the lignite with the highest particle size which is 22mm to 25mm gives best performance. However it may happens that still better performance is possible with higher lignite size. Experiment with lignite size more than 25mm may be performed.

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Appendix A

Bulk Density

Table A.1: Bulk Density of Lignite with size 16mm to 19mm

Sr. No.		Size of Box (m) (L×B×H)	Volume of Box (m^3)	Weight of empty Box (kg)	Weight of Box + Lignite (kg)	Weight of Lignite (kg)	Density (kg/m^3)
1	I	0.352×0.354 ×0.322	0.040124	5.959	27.794	21.835	544.18
	ii				27.641	21.682	540.37
2	I	0.338×0.173 ×0.325	0.019	2.243	12.531	10.288	541.47
	ii				12.571	10.328	543.58
AVERAGE							542.35

Table A.2: Bulk Density of Lignite with size 19mm to 22mm

Sr. No.		Size of Box (m) (L×B×H)	Volume of Box (m^3)	Weight of empty Box (kg)	Weight of Box + Lignite (kg)	Weight of Lignite (kg)	Density (kg/m^3)
1	i	0.352×0.354 ×0.322	0.040124	5.959	27.581	21.622	538.90
	ii				27.548	21.589	538.07
2	I	0.338×0.173 ×0.325	0.019	2.243	12.471	10.228	538.32
	ii				12.479	10.236	538.74
AVERAGE							538.51

Table A.3: Bulk Density of Lignite with size 22mm to 25mm

Sr. No.		Size of Box (m) (L×B×H)	Volume of Box (m^3)	Weight of empty Box (kg)	Weight of Box + Lignite (kg)	Weight of Lignite (kg)	Density (kg/m^3)
1	i	0.352×0.354 ×0.322	0.040124	5.959	28.866	22.907	570.91
	ii				28.769	22.810	568.49
2	i	0.338×0.173 ×0.325	0.019	2.243	13.005	10.762	566.42
	ii				12.961	10.718	564.11
AVERAGE							567.48

Table A.4: Wood pieces of 35mm to 45mm length and Quadra Cylindrical shape

Sr. No.		Size of Box (m) (L×B×H)	Volume of Box (m^3)	Weight of empty Box (kg)	Weight of Box + Wood (kg)	Weight of Wood (kg)	Density (kg/m^3)
1	i	0.352×0.354 ×0.322	0.040124	5.959	23.70	17.741	442.15
	ii				23.765	17.806	443.77
2	I	0.338×0.173 ×0.325	0.019	2.243	10.701	8.458	445.15
	ii				10.738	8.495	447.10
AVERAGE							444.54

Appendix B

Proximate Analysis

B.1 Moisture Content

Table B.1: Moisture Content in Lignite

Sr. No.		W (Crucible) g	W (Crucible + Lignite) g	W (Lignite) g	W (Crucible + Lignite) g	W (Lignite) g	W (Moisture) g	Moisture Content %
			Initial		Final			
1	i	34.029	36.329	2.300	35.866	1.837	0.463	20.12
	ii		36.120	2.091	35.735	1.706	0.385	18.39
2	i	16.341	18.340	1.999	17.95	1.609	0.390	19.52
	ii		18.660	2.319	18.199	1.858	0.461	19.89
AVERAGE								19.48

Table B.2: Moisture Content in Wood

Sr. No.	W (Petridish) g	W (Petridish + wood) g	W (wood) g	W (Petridish + wood) g	W (wood) g	W (moisture) g	Moisture Content %
		Initial		Final			
1	78.825	95.01	16.185	94.157	15.332	0.853	5.27
2		95.163	16.338	94.284	15.459	0.879	5.38
3		99.613	20.788	98.590	19.765	1.023	4.92
4		97.53	18.705	96.479	17.654	1.051	5.62
AVERAGE							5.30

B.2 Ash Content

Table B.3: Ash Content in Lignite

Sr. No.		W (Crucible) g	W (Crucible + Lignite) g	W (Lignite) g	W (Crucible + Lignite) g	W (Lignite) g	W (Ash) g	Ash Content %
			Initial		Final			
1	i	34.029	36.485	2.456	34.229	0.200	0.200	8.18
	ii		36.351	2.322	34.216	0.187	0.187	8.06
2	i	16.341	18.530	2.189	16.515	0.174	0.174	7.96
	ii		18.350	2.009	16.504	0.163	0.163	8.09
AVERAGE								8.07

Table B.4: Ash Content in Wood

Sr. No.		W (Crucible) g	W (Crucible + Wood) g	W (Wood) g	W (Crucible + Wood) g	W (Wood) g	W (Ash) g	Ash Content %
			Initial		Final			
1	i	34.029	36.207	2.178	36.092	0.115	0.115	5.44
	ii		36.804	2.775	36.655	0.149	0.149	5.02
2	i	16.341	18.343	2.002	18.245	0.098	0.098	5.21
	ii		18.253	1.912	18.146	0.107	0.107	4.96
AVERAGE								5.16

B.3 Volatile Matter & Fixed Carbon

Table B.5: Volatile Matter & Fixed Carbon in Lignite

Sr. No.		W (Crucible) g	W (Crucible + Lignite) g	W (Lignite) g	W (Crucible + Lignite) g	W (Lignite) g	W (Volatile Matter) g	Volatile Matter %
			Initial		Final			
1	I	34.029	35.857	1.828	35.281	1.252	0.576	32.78
	ii		36.156	2. 127	35.369	1.340	0.787	37.62
2	I	16.341	19.172	2.831	18.233	1.892	0.939	33.78
	ii		18.861	2.520	17.973	1.632	0.888	35.22
Average								34.23
Fixed Carbon			100 – Volatile matter – Ash content – Moisture					38.22

Table B.6: Volatile Matter & Fixed Carbon in Wood

Sr. No.		W (Crucible) g	W (Crucible + Wood) g	W (Wood) g	W (Crucible + Wood) g	W (Wood) g	W (Volatile Matter) g	Volatile Matter %
			Initial		Final			
1	I	34.029	36.618	2.589	34.759	0.730	1.859	71.82
	ii		36.152	2.123	34.671	0.642	1.481	69.78
2	I	16.341	18.238	1.897	16.872	0.531	1.366	72.03
	ii		19.321	2.98	17.321	0.980	2.000	67.12
Average								70.19
Fixed Carbon			100 – Volatile matter – Ash content – Moisture					19.35

Appendix C

Calorific Value

Table C.1: Calorific Value of fuel

Name of sample		Lignite			Wood
Weight of sample	g	0.932	0.835	0.906	0.945
Weight of Nicrome wire	g	0.029	0.028	0.029	0.030
Weight of thread	g	0.092	0.096	0.089	0.094
Weight of water	g	2000			
CV of Nicrome wire	cal/g	3350			
CV of thread	cal/g	4180			
Specific heat of water	cal/g	1			
Heat release through Nicrome Wire	cal	97.15	93.8	97.15	100.5
Heat release through thread	cal	384.56	401.28	372.02	392.92
Bomb fire Temperature	°C	27.82	29.35	28.45	27.09
Final Temperature	°C	30.12	31.25	30.66	29.27
Temp. rise of water	°C	2.30	1.90	2.21	2.18
Heat gain by water	cal	4605.81	3808.36	4429.3	4360.36
Heat liberated by sample	cal	4124.1	3313.28	3960.13	3866.94
Calorific Value of sample	cal/g	4425	3968	4371	4092
Calorific Value of sample	kcal/kg	4254			4092

Appendix D

Temperature Profile

Table D.1: Temperature Profile of Lignite with size 16mm to 19mm

Length in mm	140	220	360	480	560	630	700	840
Time in min	Drying zone		Pyrolysis zone	Oxidation zone		Reduction zone		Exhaust Gas
15	43	44	581	761	798	116	89	81
30	45	48	680	769	751	399	113	122
45	46	49	152	240	158	596	277	233
60	43	43	610	804	715	322	386	228
75	40	40	645	950	770	300	361	230
90	45	40	686	970	790	619	397	244
105	47	41	758	1020	780	637	430	251
120	44	44	837	957	772	585	493	329
135	44	43	773	931	784	597	492	350
150	44	48	752	968	782	606	495	445
165	44	43	721	1003	817	623	496	450
180	55	365	725	980	820	630	509	444
195	123	504	689	939	919	639	509	403

Table D.2: Temperature Profile of Lignite with size 19mm to 22mm

Length in mm	140	220	360	480	560	630	700	840
Time in min	Drying zone		Pyrolysis zone	Oxidation zone		Reduction zone		Exhaust Gas
15	53	71	564	692	580	628	517	271
30	52	80	464	684	493	136	425	263
45	49	62	434	761	655	587	333	261
60	53	57	650	888	706	659	486	289
75	54	54	652	898	697	670	520	299
90	60	54	842	766	679	664	549	304
105	46	45	749	677	555	608	532	306
120	44	49	767	903	740	628	509	406
135	48	57	779	891	730	635	537	454
150	66	57	910	727	728	634	540	447

Table D.3: Temperature Profile of Lignite with size 22mm to 25mm

Length in mm	140	220	360	480	560	630	700	840
Time in min	Drying zone		Pyrolysis zone	Oxidation zone		Reduction zone		Exhaust Gas
15	40	44	303	711	796	585	561	426
30	38	155	538	698	709	648	536	441
45	48	96	702	754	708	655	543	428
60	40	39	435	576	333	570	552	401
75	42	44	525	678	605	505	525	390
90	46	45	600	730	706	419	469	370
105	42	42	659	872	698	534	508	410
120	44	51	710	977	713	562	542	410
135	50	79	704	967	723	578	569	426
150	54	158	718	993	787	591	546	399
165	58	233	740	1003	762	600	551	412
180	72	448	688	830	767	606	569	454
195	123	538	727	866	772	626	561	429
210	181	554	677	769	777	615	544	425

Appendix E

Pressure Drop

Table E.1: Pressure Drop in Lignite with size 22mm to 25mm

Time min	Pressure drop mm of water			Pressure at blower mm of water	
	orifice	cyclone	tank	Before	after
Before fire	60	20	6	210	-15
25	55	30	7	152	-22
50	70	32	7	153	-20
75	38	29	8	150	-21
100	36	27	8	151	-20
125	39	27	8	149	-17
150	41	33	9	150	-18
175	40	35	9	147	-19

Table E.2: Pressure Drop in Lignite with size 19mm to 22mm

Time min	Pressure drop mm of water			Pressure at blower mm of water	
	orifice	cyclone	tank	Before	after
Before fire	49	21	6	205	-16
25	45	23	8	131	-18
50	52	30	8	148	-19
75	50	32	9	155	-18
100	43	33	7	158	-19
125	46	35	8	153	-18

Table E.3: Pressure Drop in Lignite with size 16mm to 19mm

Time min	Pressure drop mm of water			Pressure at blower mm of water	
	orifice	cyclone	tank	Before	after
Before fire	40	20	6	200	-15
25	42	30	7	155	-24
50	44	31	7	154	-22
75	47	30	8	152	-22
100	48	31	9	154	-22
125	46	31	8	155	-22
150	45	32	7	159	-17
175	44	33	7	159	-19

Appendix F

Fuel consumption

Table F.1: Fuel Consumption

		Lignite 16mm to 19mm	Lignite 19mm to 22mm	Lignite 22mm to 25mm
Gasifier working Duration	min	210	157	213
Total fuel used	kg	40.051	28.829	37.023
Fuel Consumption	kg/h	11.443	11.017	10.429

Appendix G

Flow Rate of Producer gas

Table G.1: Gas generation rate of Lignite with size 16mm to 19mm

Sr. No.	Exhaust Gas Temp.	Orifice pressure Drop	Flow rate of producer Gas	
	°C	mm of water	m^3/h	nm^3/h
1	122	42	34.16	31.40
2	233	44	34.97	28.10
3	230	47	36.14	29.14
4	251	48	36.52	28.76
5	329	46	35.75	25.91
6	445	45	35.36	22.91
7	444	44	34.97	22.68
Average			35.41	26.99

Table G.2: Gas generation rate of Lignite with size 19mm to 22mm

Sr. No.	Exhaust Gas Temp.	Orifice pressure Drop	Flow rate of producer Gas	
	°C	mm of water	m^3/h	nm^3/h
1	263	45	35.36	27.86
2	275	52	38.01	29.58
3	299	50	37.27	28.29
4	306	43	34.57	26.052
5	406	46	35.75	24.47
Average			36.19	27.25

Table G.3: Gas generation rate of Lignite with size 22mm to 25mm

Sr. No.	Exhaust Gas Temp.	Orifice pressure Drop	Flow rate of producer Gas	
	°C	mm of water	m^3/h	nm^3/h
1	441	55	39.09	28.13
2	428	70	44.10	32.06
3	390	38	32.49	24.34
4	410	36	31.63	23.32
5	410	39	32.92	24.27
6	399	41	33.75	25.10
7	454	40	33.34	23.75
Average			35.33	25.85

Appendix H

Calorific Value of Producer Gas

Table H.1: Calorific Value of Producer Gas

		Lignite 16mm to 19mm	Lignite 19mm to 22mm	Lignite 22mm to 25mm
Producer Gas Composition (%)	CO	7.59	9.93	9.98
	CO_2	8.21	6.91	8.08
	CH_4	4.01	3.85	4.97
	H_2	9.03	12.38	11.74
	O_2	6.02	6.03	6.99
CV (kcal/Nm^3)		803	947	1028

Appendix I

Heat Generation Rate of Gasifier

Table I.1: Heat Generation Rate of Gasifier

		Lignite 16mm to 19mm	Lignite 19mm to 22mm	Lignite 22mm to 25mm
CV of Producer gas	kcal/nm^3	803	947	1028
Producer gas flow rate	nm^3/h	26.99	27.25	25.85
Heat Generated	kcal/h	21672.97	25805.75	26573.8
	kW	25.21	30.01	30.91

Appendix J

Gasifier Efficiency

Table J.1: Gasifier Efficiency

		Lignite 16mm to 19mm	Lignite 19mm to 22mm	Lignite 22mm to 25mm
CV of Fuel	kcal/kg	4254		
Fuel consumption	kg/h	11.443	11.017	10.429
CV of Producer gas	kcal/nm^3	803	947	1028
Producer gas flow rate	nm^3/h	26.99	27.25	25.85
Gasifier Efficiency	%	44.52	55.06	59.90