EXPERIMENTAL STUDIES ON DOWN DRAFT BIOMASS GASIFIER BASED POWER GENERATING UNIT

By

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Pankaj Kumar Sharma

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Date: September 2012 (Pankaj Kumar Sharma)

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **“Experimental studies on down draft biomass gasifier based power generating unit”** by **Pankaj Kumar Sharma** in partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Engineering) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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Executive Summary

Electric power is the main source of energy to turn the wheels of growth and prosperity of any nation these days. In developing counties like India there are many areas especially remote rural parts where electricity is yet a distant dream. Extending grid power to these areas is uneconomical and at times not possible because of inaccessible terrain. For electric power generation at large and small scale, combustion of fossil fuels is very common. But their limited resources and impact on environment forces the researchers, world over to explore new frontiers of alternate energy sources. For the new and alternative sources, the essential condition is that, they must be renewable and also support sustainable development.

Out of these alternate energy sources, biomass gasification is an age old technology that was taken off around Second World War. The interest in this technology is renewed because of soaring fuel prices. In today's energy scenario, biomass gasification can give a ready solution for power crisis in rural areas and make them energy independent. For power generation using producer gas requires a prime mover. Reciprocating internal combustion engine and gas turbine are the two feasible prime mover options. As the present work is focused on development of rural technology, therefore using gas turbine is not a viable option because of complicated technology involved and high initial capital cost of gas turbine. The second option of prime mover is then opted for the present work because reciprocating internal combustion engine are easily available in market and their capital cost is very low.

It is reported that in past decade, negative impact on forest ecosystems of India has been posed by several invasive species, lantana being one of them. Out of many weeds lantana has spread more and posing even higher degree problems. The massive growth of lantana may be dedicated to large number of fruits per plant and its ability to grow under wide climatic conditions. It is already mentioned that lantana is a weed and posing serious problems but every negative thing has some positive aspects as well. This work tries to explore the positive aspect of lantana by exploring it as a biomass gasifier feed.

Biomass gasification is the process of conversion of solid carbonaceous biomass into combustible gas by partial combustion. Producer gas is the result of gasification process; it is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. This resultant gas is more versatile than the original solid biomass. For gasification of biomass three types of gasifiers are used and reported in the literature namely updraft, down draft and fludized bed biomass gasifiers. Out of these, down draft biomass gasifiers are used for power generation application because of low tar production during gasification.

In the present work, a downdraft biomass gasifier was designed and developed for lantana gasification. Producer gas coming out of gasifier contained particulate matter, tar oils and moisture and hence was inappropriate for engine operation; which is one of the main objectives of this work. To eradicate these impurities a series of gas cleaning systems were developed. In the series of equipment a cyclone separator was designed to separate particulate matter from the hot gas coming out from the gasifier outlet. To separate tar oil vapours, gas was allowed to cool in a cooler below 200^{o}C and then the liquid vapours were separate out by using sand bed filter and wood wool. Further the gas was cooled below 100^{o}C to condense water vapour and then again allowed it to pass through bed of glass wool and wire mesh so that fine water droplets were absorbed.

The suitability of producer gas for engine operation was yet to be established. For establishing the producer gas as engine fuel the first step was to find out its composition. Therefore, gas was analyzed in a gas chromatograph. The composition of the gas was found to be approximately 20% carbon monoxide, 20% hydrogen, 3-5% carbon dioxide, 1-3 % methane and remaining nitrogen. The resulting gas composition and calorific value was in line with the reported literature.

The clean engine grade gas was to be used for engine operation to generate electrical energy. But the existing engine was designed and manufactured for commercial petrol fuel operation, so the first modification required in the existing petrol engine was in carburetion. Petrol carburetor was designed for approximately 16:1 air/fuel ratio. And the required air fuel ratio for producer gas operation was 1.1:1 to 1.5:1. For that purpose a gas carburetor was designed for producer gas operation. Secondly, existing petrol engine was having a compression ratio of eight which was found to be insufficient for producer gas. So the compression ratio was then changed to 11 for producer gas operation; which found to be sufficient.

Once the setup was complete and ready for experimentation, an electric load panel was fabricated and some thermocouples were put at different locations of gasifier to gather temperature readings. Exhaustive experimentation was carried out on the setup. Gasifier readings were taken at different sets of equivalence ratio and corresponding gasifier temperatures and gas compositions were noted down. Then using empirical relations gas high and low heating values, gas yield and gasifier thermal efficiency was calculated. After these experiments optimum equivalence ratio was obtained in terms of gas composition and calorific value. Now, the gasifier was run with this equivalence ratio and engine was tested with producer gas. The engine was already tested on petrol for baseline data. Furthermore two other gaseous fuels were also tested on the same engine so that comparison can be carried out with producer gas. The engine output was found to be 2.5 kW with petrol, LPG and enriched biogas, as the calorific values of all the three fuels was same, while with producer gas engine output was found to be 2.0 kW i.e. 20% de-rating of the engine. Several runs of engine testing were carried out for reliability of data taken and then 20% de-rating of engine was established with producer gas. Engine performance and emission test were carried out with all the fuels available. And then the performance & emission characteristics of the engine were compared with different fuels. On the performance part, graphs for brake thermal efficiency, relative air fuel ratio (λ), exhaust gas temperature were plotted and compared with other fuels. For emission characteristics, % of carbon monoxide, carbon dioxide, nitrogen oxides, unburned hydrocarbons were recorded with the help of gas analyser. The results were plotted and compared with petrol and other gaseous fuels.

To summarize, physico-mechanical, physico-chemical and physico-thermal characteristics of lantana were found to be suitable for gasification. Behavior of lantana chips was normal during gasification. Thermal efficiency of the developed downdraft biomass gasifier for lantana was found to be almost same as reported in the literature. The producer gas generated by the gasifier was of high quality in terms of composition and calorific value. The carbon dioxide was low and percentage of carbon monoxide and hydrogen was found in line of the reported literature. However, much data was not available on lantana gasification for comparison of obtained results. Gasifier was able to supply constant and reliable engine quality producer gas.

The engine was found to be power de-rated by 20% with producer gas. The brake thermal efficiency of the engine with producer gas was found to be 27% while that with petrol was about 28%. In the engine exhaust the carbon monoxide, nitrogen oxides, carbon dioxide and unburned hydrocarbons were found to be low with operation on producer gas when compared with petrol, LPG & enriched biogas.

From the present work some important conclusions can be drawn such as: the problem of lantana, as a weed can be solved by using the same for biomass gasification, lantana is a good feed for downdraft biomass gasifier; producer gas from lantana biomass and downdraft biomass gasifier is a good fuel for engine operation, small petrol run generator set can be modified and run with producer gas with little de-rating in power; the emission from the engine was found to be very low implying that producer gas a cleaner fuel, the developed technology i.e. downdraft biomass gasifier with small power generating unit can give a sustainable development option in remote rural areas and make them energy independent.

LIST OF SYMBOLS

%	per cent
ρ	Density
°C	degree Celsius
cm	centimeter
g	grams
h	hour
kJ	Kilo joule
kg	kilogram
kW	kilowatt
m	meter
min	minutes
MJ	mega joule
ml	milliliters
N	Newton
s	seconds
m^3	cubic meter
Nm^3	Normal cubic meter
MC	moisture content of fuel on wet basis (decimal)
Y	Latent Heat of vaporization for water, ($MJkg^{-1}$)
H	hydrogen content of the fuel on the weight basis

LIST OF ABBREVIATIONS

A/F	air fuel ratio
B T E	brake thermal efficiency
BSFC	brake specific fuel consumption
BHP	brake horse power
CO	carbon monoxide
CRT	char reaction time
ER	equivalence ratio
HC	hydrocarbon; various hydrocarbons
LPG	liquid petroleum gas
NO_x	nitrogen oxides
ppm	parts per millions
RPM	revolution per minute
SBFR	Specific biomass feed rate
SI	spark ignition
STP	Standard Temperature Pressure

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CHAPTER 1

INTRODUCTION

In today's world, society is dependent on fossil fuels for their domestic and industrial energy needs weather it is transportation, power generation, heat application or agriculture irrigation. On earth the fossil fuel reserves are not only exhaustible but also their use adds green house gases to the environment. All the nations, developed or developing understand this hard truth and therefore a visible shift at policy level is observed in the last decade. Sustainable development is the mantra for all governments across the globe. Research institutes, labs and researchers are getting encouragement from the governments to explore new avenues of sustainable energy source.

Many new and renewable energy sources are successfully tried by the researchers in the past. These renewable energy sources are not only offering an opportunity for sustainable development but also, giving an edge over conventional energy sources in terms of very low greenhouse gas addition to the environment. But, the challenges are not less because the alternate energy sources have to compete with the conventional sources of energy which is very flexible in use. In order to replace the convention fuels these alternate energy sources have to convert into a more flexible source i.e. electric power economically.

In India, electricity is reaching in urban or rural areas through central grid. In present times, there is an electrical energy crisis in the country because of high prices and less availability of conventional fuel and very less use of renewable energy sources. This problem is even more acute in rural parts of the country. To add further, there are some remote parts in the country which don't even come in the reach of central grid. This is because, their tough and inaccessible terrain make grid extension uneconomical to these areas. The only visible solution for this problem is to generate standalone power by tapping local resources. In mountainous regions small hydro and biomass are promising energy resources.

In the present work, biomass gasification is explored to meet the above needs. This energy source is not new; traditionally people are dependent on biomass for their different energy needs, but the problem lies with its inefficient use in developing countries. The bad effects of inefficiency in the use of biomass are very much visible in the society on health, environment and social well-being.

Energy from biomass can be tapped by direct combustion, anaerobic digestion, fermentation and gasification. Biomass gasification is not a new technology but, because of soaring fuel prices and environmental concerns, the interest in this technology is renewed.

Biomass gasification means converting biomass material into combustible gases consisting of nitrogen (N_2), carbon monoxide (CO), hydrogen (H_2) and traces of methane (CH_4). This mixture is called producer gas. Producer gas can be used in internal combustion engines (both compression and spark ignition), and can be seen as a potential substitute for furnace oil in direct heat applications. If the biomass gasification can be done in the presence of oxygen in place of air the resultant gas is known as syngas and can be used to produce, in an economically viable way, methanol – an extremely attractive chemical which is useful both as fuel for heat engines as well as chemical feedstock for industries (1). Since any biomass material can undergo gasification, this process is much more attractive than ethanol production or biogas generation from biomass where only selected biomass materials can produce the fuel.

However under present conditions, economic factors seem to provide the strongest argument of considering biomass gasification (2), (3) in many situations where the price of petroleum fuels is high or where supplies are unreliable.

1.1 ENERGY CONVERSION TECHNOLOGIES FOR BIOMASS

The conversion of biomass into more valuable and cleaner gaseous form is normally achieved through two entirely different processes, namely, biochemical processes and thermo chemical process.

The biochemical processes include anaerobic digestion and alcoholic fermentation. Anaerobic decomposition of biomass yields methane through bacterial fermentation or ethanol from yeast fermentation. Biomass is a mixture of three main components namely, cellulose, hemicelluloses and lignin and some other minor components like inorganic compounds. Complete biomass con version to energy is possible only through thermo chemical processes like paralysis, gasification or combustion.

In the thermo-chemical conversion processes, biomass is subjected to high temperatures and depending on the quantity of oxygen supplied, the processes such as pyrolysis, gasification and combustion occurs.

Pyrolysis is the thermal decomposition of biomass without oxygen at temperatures about 200 to 450^{o}C to yield energetically dense products like, charcoal, tar oils and gaseous products. Pyrolysis is an intermediate step in the gasification or combustion process.

Combustion is defined as series chemical reactions in which combustible components of biomass such as carbon, hydrogen react with oxygen present in atmospheric air to form carbon dioxide and water with the liberation of heat. Complete combustion ensures minimum production of carbon monoxide and maximizes the heat release. Direct combustion of biomass, is as old as human mankind and still in rural parts of developing countries people are dependent on it. But direct combustion of biomass has poor thermal efficiency.

Thermal gasification is the process of converting biomass into a gaseous fuel by means of partial oxidation at high temperature (between 700 to 850°C). In this process, a combustible gas is obtained from a biomass by the reaction of the fuel with a gasifying medium, usually air (4). The gas so obtained is generally called producer gas and is mainly composed of carbon monoxide and hydrogen. It also contains carbon dioxide, water vapour, nitrogen and small amounts of hydrocarbons along with tars and ash. The quality of the gas depends much on the gasification medium and the type of the gasifier employed.

1.2 BIOMASS GASIFIERS

Equipments used for biomass gasification is known as gasifier and is available in four designs. All four designs have their respective merits and demerits. Different biomass gasifiers are used for different applications and depend on the relative merits of particular design. For example for engine application very clean gas (tar less) is required and downdraft biomass gasifiers are known to have this quality. In the subsequent subsection different biomass gasifier designs are explained in detail.

(i) Downdraft gasifier

In a downdraft gasifier, the feedstock and gasifying agent both move in the same direction. The gases have to pass through the high-temperature so amount of tar is significantly lower than that in an updraft gasifier. The particulate content is however higher for downdraft gasifier and the thermal efficiency is lower since producer gas draws an appreciable amount of energy while passing through the high-temperature zone inside the gasifier.

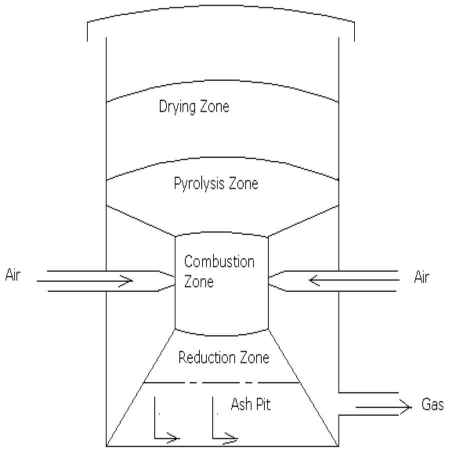


Figure 1.1: Different zones in a Down draft Biomass Gasifier

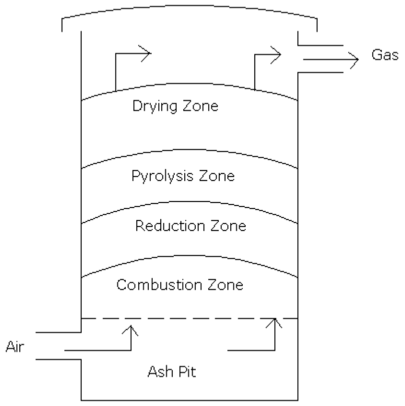


Figure 1.2: Different zones in an updraft biomass gasifier

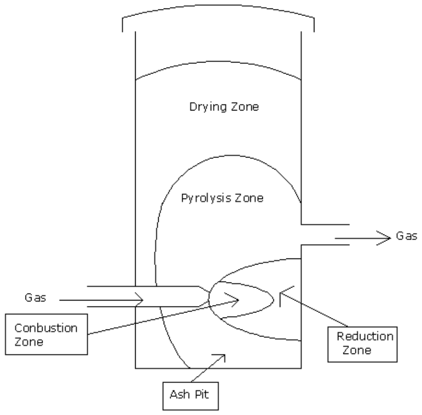


Figure 1.3: Cross draft biomass gasifier

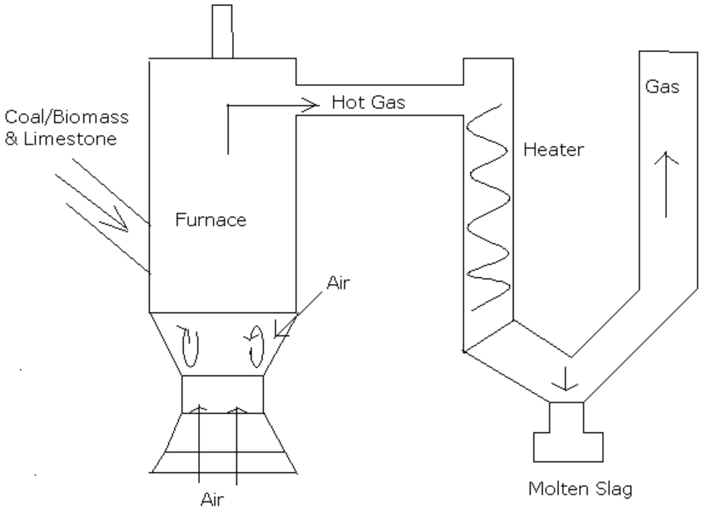


Figure 1.4: Fluidized bed gasifier

(ii) Updraft gasifier

The movement of the feedstock and the gasifying agent are in opposite directions in this kind of gasifier (also called a counter-current gasifier). Since the producer gas formed is not forced to pass through the hot high temperature zone, the tar content is high in the producer gas from this gasifier. On the other hand, the temperature of producer gas exiting from this gasifier is lower around and hence the thermal efficiency of this kind of gasifier is high. Due to high tar content in the producer gas, a subsequent tar cleaning system is needed, which can become a major investment if the end-process requires tar-free producer gas.

(iii) Cross draft gasifier

The movement of feed stock and the gasifying agent is perpendicular to one another. Air enters at high velocity through a single nozzle, induces substantial circulation and flows across the bed of fuel and char. This produces very high temperatures in small volume and hence the producer gas produced is of low tar content, which permits it for rapid load changes.

(iv) Fluidized gasifier

In fluidized bed gasifiers, feedstock is fluidized with some bed material like sand/silica with a gasifying medium which can be air or steam. Fluidized bed gasifiers can further be classified into two types: bubbling and circulating. Circulating fluidized bed adds one more feature to bubbling bed such that solid material trapped in the gas phase is trapped and re-circulated back to the gasification bed. This provides the significant advantages over the bubbling bed gasifier in terms of mass conversion efficiency and reduces particulate content in the producer gas output (5).

The table 1.1 gives the relative advantages and disadvantages of different biomass gasifier design (6).

Table 1.1: Advantages and disadvantages of different gasifiers

Sr. No.	Gasifier Type	Advantage	Disadvantage
1.	Updraft	Small pressure drop Good thermal efficiency Little tendency towards slag formation	Great sensitivity towards tar and moisture content of fuel Relatively long time is required for the start up of IC engine Poor reaction capability with heavy gas load.
2.	Downdraft	Flexible adaptation of gas production to load Low sensitivity towards 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	High sensitivity to slag formation High pressure drop

1.3 APPLICATION OF GASIFICATION SYSTEMS

The combustible gases from the gasifier can be used a) in internal combustion engines, b) for direct heat applications and c) to run gas turbines.

(i) Shaft power systems

The biggest application of producer gas has been in driving IC engines. Both spark ignition and compression ignition engines have been driven by it. In principle any IC engine can be converted to run completely or partly on the gas.

(ii) Direct heat systems

Direct heat systems are those in which the producer gas is burnt directly in stove, furnace or boiler. The advantage of this as compared to direct combustion of biomass is in obtaining controlled heating and higher flame temperatures than those obtainable otherwise. Because of direct burning, the gas quality is less critical than in shaft power systems and consequently they are less demanding on cooling and cleaning equipment and have more versatility as far as fuels are concerned (2).

End applications of the producer gas as listed above are numerous. Ranges from electricity generation to running irrigation pump to liquid hydrocarbon to simply cooking and space heating. But, the present work is a step in the direction of making rural households energy independent using the biomass gasification technology.

For understanding the existing technologies and practices exhaustive literature review was done. In the next chapter the detailed literature review is discussed.

CHAPTER 2

LITERATURE REVIEW

Biomass is the term used to describe all biologically produced matter and it is the name given to all earth’s living matter (7). Biomass energy is derived from the plant sources, such as wood from natural forests, waste from agricultural and forestry processes and industrial, human or animal wastes. It is natural process that all biomass ultimately decomposes to its molecules with release of heat. And the combustion of biomass imitates the natural process. So the energy obtained from biomass is a form of renewable energy and it does not add carbon dioxide to the environment in contrast to the fossil fuels (8). Out of various renewable energy sources, biomass is unique in that it effectively stores solar energy inherently. Furthermore, it is the only renewable energy source of carbon and is able to convert into convenient solid, liquid and gaseous fuels. Because of this, biomass has evolved as one of the most promising sources of fuel for the future. This has spurred the growth of research and development efforts in both government and private sectors (9). This impetus is motivated by several factors; dwindling fossil fuels and thus an increase need of energy security, environmental concerns and promotion of socioeconomic benefits to rural areas. Another important fact is somewhat, uniformly distributed nature of biomass worldwide which means it is available locally and is helpful in reducing the dependence upon the fossil fuel (10). The energy derived from biomass is significant and accounts for more than half of all the renewable energy generation among which, two-thirds is used for heat, power or Combined Heat and Power (CHP) (11).

The end-use of products from biomass conversion can be mainly in any one of heat and power applications, transportation fuels (biodiesel, bio-ethanol) and chemicals for subsequent processing (12). Up to present, the only long-term solution for the carbon based fuels and chemical is biomass and can be effectively converted into solid, liquid and gas (13) (14). Biomass can be converted into bio-fuels using either thermal or chemical processes. Among thermal conversion processes, gasification has received the most attention. This is due to the higher efficiency compared to processes such as direct combustion, pyrolysis and liquefaction (15) (16).This industrial rate of power generation using gasification process can be expected to rise with advances in clean coal technologies and more economically feasible techniques for biomass gasification.

The selection of the biomass for gasification should be such that it does not affect the ecosystem i.e. biomass should be selected properly, such as growing weeds in the forest which not only effects the growth of trees but also harmful for animals. There are many unwanted weeds growing around such as lantana, mungi plants and the yhidzon vines. Lantana is one such weed which is posing threat to forest ecosystem

2.1 BIOMASS FEEDSTOCK FOR GASIFICATION PROCESS

During the past few decades, India has witnessed negative impact on forest ecosystems posed by invasive species. Among them, the lantana (Verbeinaceae) is one of the most serious invasive plant species and has colonized large areas of forest in the Himalayan foothills (Shivalik range), particularly the Dudhwa, Corbett and Rajaji National Parks (17). Rawat et al (18) recorded the highest average density of lantana bushes (i.e. 18 per 100 m^2) in Doon valley followed by Shivaliks (9.2 per 100 m^2) and the outer Himalayas (7 per 100 m^2) fig 2.1.

Figure 2.1: Photograph of Lantana bush with flowers

The success of lantana may be attributed to large number of fruits per plant (19) (20), its ability to grow under a wide range of climatic conditions (21), allelo-chemicals released by roots in the soil inhibiting the growth of neighboring plants (22) (23) and the possession of some feeding deterrents that probably render them less acceptable to generalist herbivores than non-invasive plants (24) (25). Its dominance in invaded areas and possession of poisonous components like triterpenes leads to forage scarcity and bad health or deaths of animal (25) (26) (27). This species also possess ability to change socioeconomic scenario of invaded regions. In India, its invasion is associated with estimated loss of US$ 924 million per year (28).

Dobhal et al. (29) concluded that, lantana poses a threat to local flora. The number, density and frequency and overall health of species were remarkably poor in invaded areas. Further, due to its inflammable nature and dominance in regional flora, lantana is a potential threat to riparian zones that can act as a buffer against fire and act as a refuge for fire sensitive species. Beside individual species and life forms such as trees and herbs, the entire forest ecosystem itself is under threat due to lantana invasion. It requires the immediate committed attention of ecologists, conservationists and policy makers.

Lantana is of no use and is a weed which destroys the vegetation but it acts as very beneficial biomass for gasification. In the present work gasification of lantana is to be done to produce heat and electricity.

2.2 BIOMASS GASIFICATION

The conversion technologies for utilizing biomass can be separated into four basic categories; direct combustion processes, thermo chemical processes (pyrolysis, gasification), biochemical processes and agro-chemical processes (30). In the last decade, biomass gasification had drawn large attention of researchers for upgrading the energy into more convenient fuels such as gases, liquids and charcoal. This is because the biomass gasification offers higher efficiencies compared to combustion and pyrolysis.

Gasification is a process of conversion of solid carbonaceous fuel into combustible gas by partial combustion (31). Producer gas is the result of gasification process, which is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. This resultant gas is more versatile than the original solid biomass. Producer gas is burnt to produce electricity and heat. The detailed chemical process is described with the help of chemical equations and is given in the following section.

2.2.1 Gasification Process

A gasification process normally follows the steps as shown in fig 2.2 (32). The sequences of steps are frequently modeled in the same way as given in the figure 2.2, but there is no clear boundary between them, and they often overlap. In the following sections discuss these steps of biomass gasification in detail.

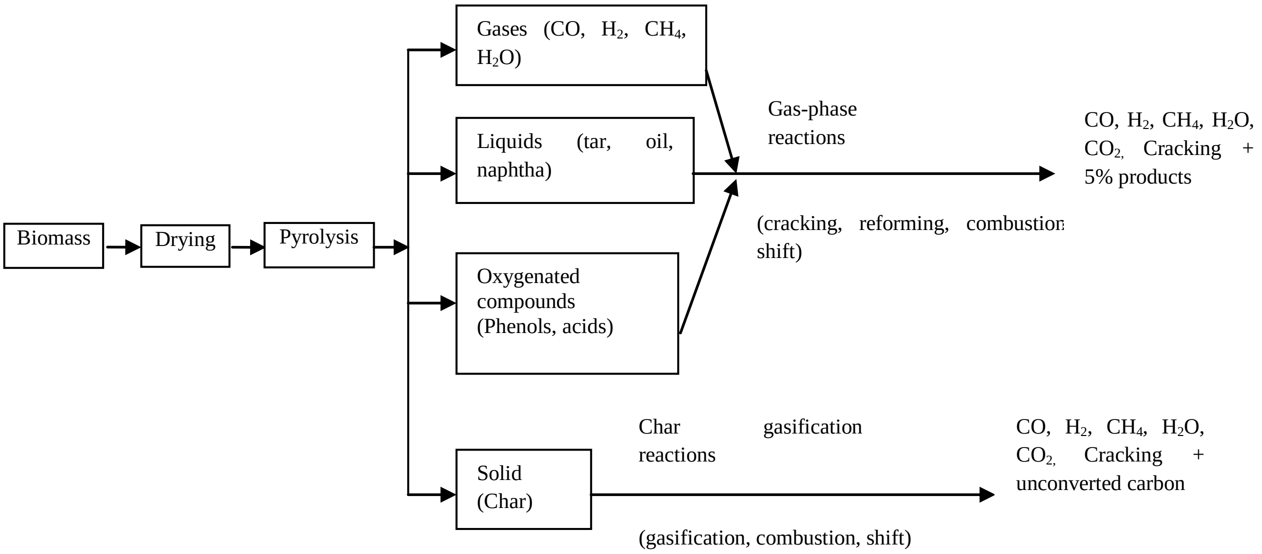


Figure 2.2: Potential paths for biomass gasification

2.2.1.1 Biomass drying

Most of the gasifiers use dry biomass with a moisture content of 10-20%, to produce fuel gas with a reasonably high heating value. Green wood typically contains around 30 – 50% moisture and pre-drying of biomass is therefore essential before feeding it into gasifiers. The final drying takes place after the biomass enters the gasifier, as it receives heat from the hot pyrolysis zone. This heat dries the feed, which releases water. Above 100 ^{o}C, the loosely bound water that is in the biomass is irreversibly removed. As the temperature rises, the low- molecular-weight extractives start volatilizing. This process continues until a temperature of approximately 200 ^{o}C is reached (32).

2.2.1.2 Pyrolysis

Pyrolysis, which precedes gasification, involves the thermal breakdown of larger hydrocarbon molecules of biomass into smaller gas molecules (condensable and non-condensable) with no major chemical reaction with air, gas, or, any other gasifying medium. Tar is one of the important products of pyrolysis that is formed through condensation of the condensable vapour produced in the process. Tar, a sticky liquid creates a great deal of difficulty in industrial use of the biomass gasification product (32).

Table: 2.1: Gasification Reactions at 25 ^{o}C

Typical Gasification Reactions at 25^{o}C	**Equation number**
Reaction Type and Reaction	
Carbon Reactions	
	2.1 (Boudouard)
	2.2(water-gas or steam)
	2.3 (hydrogasification)
	2.4
Oxidation Reactions	
	2.5
	2.6
	2.7
	2.8
Shift Reactions	
	2.9
Methanation Reactions	
	2.10
	2.11
	2.12
Steam-Reforming Reactions	
	2.13
	2.14

2.2.1.3 Char Gasification Reactions

After pyrolysis gasification step comes that involves chemical reactions among the hydrocarbons in fuel, steam, carbon dioxide, oxygen, and hydrogen in the reactor, as well as chemical reactions among the evolved gases. Out of these char gasification is the most important. Bio char (char product of biomass pyrolysis) is not necessarily pure carbon. Bio char contains a certain amount of hydrocarbon comprising hydrogen and oxygen.

Gasification of biomass char involves several reactions between the char and the gasifying mediums.

2.15

2.16

2.17

2.18

Equations 2.15 to 2.18 shows the reactions of gasifying agents like oxygen, carbon dioxide, and steam react with solid char (carbon) to convert it into lower molecular- weight gases like carbon dioxide, carbon monoxide and hydrogen. Some of these reactions are known by names as listed in table 2.1.

Gasification reactions are generally endothermic, but some of them can be exothermic as well. For example, those of carbon with oxygen and hydrogen (equation 2.3, 2.4 and 2.5 in table 2.1) are exothermic, whereas those with carbon dioxide and steam (reactions 2.1 and 2.2 in table 2.1) are endothermic. The heat of reaction given in table 2.1 for various reactions refers to a temperature of 25 ^{o}C (32).

(i) Speed of Char Reactions

Bio char gasification rate depends primarily on its reactivity and gasifying medium reaction potential. For example, oxygen is the most active gasifying medium, followed by steam and carbon dioxide. Char–oxygen reaction rate (eq. 2.4) is the fastest among the four in Table 2.1 (eq. 2.1, 2.2, 2.3, 2.4). It is so fast that it quickly consumes the oxygen, leaving hardly any free oxygen for any other reactions.

Char–steam reaction rate (eq. 2.3) is three to five orders of magnitude slower than that of the char–oxygen reaction. The Boudouard, or char–carbon dioxide, reaction (eq. 2.1) is six to seven orders of magnitude slower (33). The water–gas or water–steam gasification reaction (eq. 2.2) is about two to five times faster than that of the Boudouard reaction (eq. 2.1) (34).

The methane forming char- hydrogen reaction (eq. 2.3) is the slowest of all. Walker et al. (1959) (35) estimated the relative rates of the four reactions, at 800 °C temperature and 10 kPa pressure, as 10^5 for oxygen, 10^3 for steam, 10^1

for carbon dioxide, and 3 × 10^{-3} for hydrogen. The relative rates, *R*, may be shown as

2.19

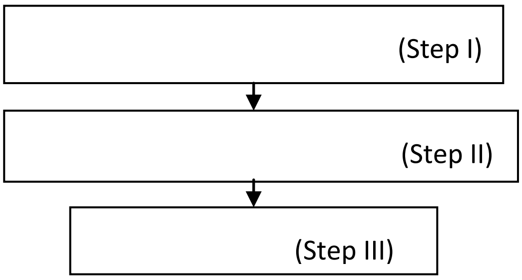
When steam reacts with carbon it can produce CO and H_2. Under certain conditions the steam and carbon reaction can also produce CH_4 and CO_2.

(ii) Boudouard Reaction Model

Boudouard reaction is popularly known as the char gasification in carbon dioxide.

(2.1 in Table 2.1) 2.20

Blasi (2009) (34) describes the Boudouard reaction with the help of following steps. CO_2 dissociates in the first step at a carbon-free active site (C_{fas}), releasing carbon monoxide to form a carbon–oxygen surface complex, C(O). This reaction can move in the opposite direction as well, forming a carbon active site and CO_2 in the second step. In the third step, the carbon–oxygen complex produces a molecule of CO.



2.21

2.22

2.23

where k_i is the rate of the i_{th} reaction.

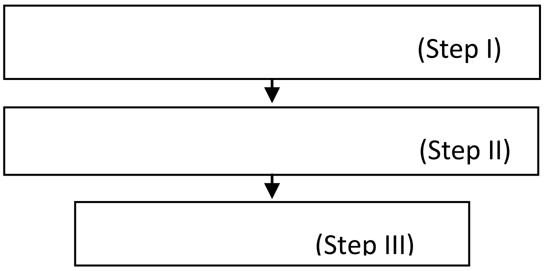
The rate of the char gasification reaction in CO2 is insignificant: below1000 K.

(iii) Water–Gas Reaction Model

The gasification of char in steam, known as the water–gas reaction, is perhaps the most important gasification reaction.

(2.2 of table 2.1) 2.24

The reaction starts with the dissociation of H_2O in the first step on a free active site of carbon (C_{fas}), releasing hydrogen and forming a surface oxide complex of carbon C(O). In the second and third steps, the surface oxide complex produces a new free active site and a molecule of CO.



2.25

2.26

2.27

Some models (Blasi, 2009) (34) also include the possibility of hydrogen inhibition by C(H) or $C(H)_2$ complexes as here:

2.28

2.29

The presence of hydrogen has a strong inhibiting effect on the char gasification rate in H_2O. For example, 30% hydrogen in the gasification atmosphere can reduce the gasification rate by a factor as high as 15 (36). So an effective means of accelerating the water–gas reaction is continuous removal of hydrogen from the reaction site.

(iv) Shift Reaction Model

In biomass gasification the shift reaction is an important gas-phase reaction. Because of this reaction the hydrogen content within the gasification product increases at the cost of carbon monoxide. In some literature this reaction is also called as “water–gas shift reaction” (37), but it is different from the water–gas reaction (eq 2.2).

(eq. 2.9 in table 2.1) 2.30

This is a pre-step in syngas production in the downstream of a gasifier, where the ratio of hydrogen and carbon monoxide in the product gas is critical.

(v) Hydro gasification Reaction Model

Char gasification reaction in a hydrogen environment, leads to the production of methane and commonly known as hydro gasification reaction.

(Equation 2.3 in table 2.1) 2.31

The reaction rate of this reaction is comparatively slower than the other reactions, and so this is not discussed in detail. This is important only when the production of synthetic natural gas (SNG) is desired (32).

2.2.1.4 Char Combustion Reactions

Mostly gasification reactions are endothermic by nature and therefore require heat not only for reaction but also for heating, drying, and pyrolysis. For that, a certain amount of exothermic combustion reaction is allowed in a gasifier. Oxidation of biomass (bio char) ($C + O2 \rightarrow CO2$) eq. 2.5 is the best in this regard as it gives the highest amount of heat (394 kJ) per k.mol of carbon consumed. The next best is eq. 2.4 ($C + 1/2O2 \rightarrow CO$), which also produces the fuel gas CO, but produces only 111 kJ/mol of heat. The speed of eq. 2.4 is relatively slow.

When carbon comes in contact with oxygen, both eq. 2.4 and 2.5 can take place, but their extent depends on temperature. A partition coefficient, β, may be defined to determine how oxygen will partition itself between the two. Eq. 2.4 and 2.5 may be combined and written as

2.32

The value of the partition coefficient β lies between 1 and 2 and depends on temperature. One of the commonly used expressions (38) for β is

$$\qquad 2.33$$

where *T* is the surface temperature of the char.

Combustion reactions are generally faster than gasification reactions under similar conditions. The combustion rates are at least one order of magnitude faster than the gasification reaction rate. Owing to pore diffusion resistance, finer char particles have a much higher reaction rate.

2.3 PARAMETERS IN THE GASIFICATION PROCESS

Producer gas composition varies widely and mostly depends upon the gasifier type, feedstock, feedstock pre-treatment, gasifying medium and operating parameters like temperature, pressure, and nature of interaction between reactants in the gasification process (39). The effects of major parameters affecting the quality of producer gas are discussed in the sections below.

2.3.1 Moisture content

Biomass contains moisture in both ways: intrinsically by its nature, and extrinsically wherein moisture is absorbed from the surrounding atmosphere (40). Moisture content in the biomass, during gasification, increases CO_2 concentration by the water-shift reaction (which consumes CO and liberates H_2) (41) (42). While the equilibrium constant for water-shift reaction varies little over a wide range of temperatures, the direction tends to reverse at higher temperature. Since more heat is required for moisture evaporation than the small amount of heat gained due to the exothermic behavior of the water-shift reaction, thermal energy inside the gasifier reduces when gasifying biomass with higher moisture content (43). Thus, the decrease in temperature further exacerbates the scenario and forms more CO_2 since the water-shift reaction is improved at lower temperature. The overall effect is the reduction in calorific value of producer gas because, the small increase in H_2 is not sufficient to compensate the loss of significant amount of CO with increase in moisture content (41) (42) (43). However, the negative effect of moisture content on the calorific value of producer gas is lower at lower equivalence ratio (ER). The ER is the ratio of actual air fuel ratio to the stoichiometric air fuel ratio which provides the basis for evaluating the amount of air supplied for the gasification with respect to the amount of air required for the complete combustion of the feedstock. Roy et al. (41) have observed that, in a downdraft gasifier, when the moisture content is increased from 0 to 40%, heating value of producer gas decreases by 8.72% at ER of 0.45 while the decrease was of 4.7% when the ER used was 0.29. This result was reported from their equilibrium model and thus is applicable to any gasification process. Table 2.2 (9) (10) (23) summarizes the effect of moisture content in three common gasifier types.

A limiting condition called auto-thermal limit is reported as 65% moisture content in literature beyond which self-sustaining gasification is not possible due to an enthalpy deficiency for vaporization. In fact, supplemental fuel is required for most of the combustor when the moisture content is greater than 50% on a wet basis (44) (45). Moisture content up to 30% (wet basis) can be used for downdraft gasifier (46) (47). When air is used as the gasification agent, the amount of methane produced is small and stays almost constant with change in moisture content (42) (48). Thus the temperature decrease inside the gasifier due to moisture also results lower mass conversion efficiency and increases tar content (43) (49) (50). Sheth et al. (51) report the decrease in biomass consumption rate with increase in moisture content which is due to the higher amount of heat necessary for drying those wood chips inside the reactor before they can be pyrolyzed. However, some moisture content is always desirable since it enhances steam reforming and helps to crack tar, and at higher temperature, also enhances other reactions such as char gasification (52) (53). Steam injection is widely used in industrial applications to adjust producer gas composition in the gasification process but often, in the presence of higher temperature provided by some external source (54).

2.3.2 Equivalence ratio

Equivalence ratio (ER) is the most influential parameter in any gasification process and often has significant impact on producer gas composition.

Increase in ER increases the temperature inside the gasifier while ER decrease increases char formation inside the gasifier. As can be seen from figure all combustible products reduce with an increase in ER with the formation of higher amount of CO_2 as well as total gas yield greatly diminishing the heating value of the final producer gas (55) (56) (57). Zainal et. al. (58) compared the best optimal value for the downdraft gasifier with respect to equivalence ratio using furniture wood and wood chips as feedstock. The effect of equivalence ratio for each producer gas component was analyzed with the conclusion of an optimal equivalence ratio of 0.38 for the gasifier performance for that particular feedstock. At this equivalence ratio, CO, CH_4 and calorific value each attain their maximum outputs while CO_2 reaches its minimum.

Heat conduction inside the gasifier is often limited by the thermal diffusivity of charcoal particles- 0.7 ×10-7 m^2/s which is lower than that of wood (59). The optimum equivalence ratio is necessary for accelerating pyrolysis and drying rate due to conduction and convection process which also increases the biomass consumption rate (60) it has been reported that an optimal equivalence ratio of 0.2 for downdraft gasification of olive kernels and olive tree cutting and furniture wood (60). The optimum equivalence ratio varies for different biomass due to the amount of oxygen elementally present in the biomass as well as the ash content. For example, coal requires far more oxygen than common biomass materials for gasification due to its lower oxygen content. The existing literature shows that equivalence ratio should be around 0.3-0.4 for the successful gasification.

Table 2.2: Effect of moisture content on producer gas composition

Parameter	**Gasifier Type**	**CO**	**CO_2**	**H_2**	**CH_4**	**Maximum Limit (% w.b)**
Moisture content (M.C)	Updraft	Decreases with increase in M.C	Increases with increase in M.C	Increases with increase in M.C	No significant change	<50
	Downdraft	Decreases with increase	Increases with increase	Increases with increase	No significant change	< 40

		in M.C	in M.C	in M.C		
	Fluidized	Decreases with increase in M.C	Increases with increase in M.C	Increases with increase in M.C	No significant change	<10

Any compound with molecular weight greater than that of benzene is called tar (61). Tar decreases with increase in ER. This is mainly due to two reasons: (a) higher temperature as a result of higher ER increases reaction rates of the chemical products; and (b) high ER supplies additional oxygen for cracking of tar into lower hydrocarbons, CO_2 and H_2O. Thus, at some point between the applicable ranges (0.15-0.4), a shift between types of tar is also reported. Light tar increases while heavy tar decreases (56) (62). Corella et al. (63) suggests an equivalence ratio above 0.36 for pine wood in a fluidized bed to reduce the tar content below 2 g/m^3, a level below which coke formation does not exceeds its removal rate.

2.3.3 Temperature

Increase in temperature reduces the tar content as well as decreases char inside the gasifier (56) (64). Gas yield increases due to higher tar cracking. One of the means of increasing temperature is by internal recirculation of producer gas (65). Tar cracking temperatures are often reported to be around 1000-1100^{o}C with some dependency on gasifier design (46) (61). Other methods of tar cracking are also employed such as multi-stage gasifiers (66) (67) (68). Multi-stage gasifiers , have separated pyrolysis and gasification zones and make use of partial oxidation of pyrolysis gas obtained in the pyrolysis zone for tar cracking and thus, tar content can be reduced as low as 15mg/Nm^3 (Nm^3–volume at NTP) (66). CO content increases with increase in temperature because endothermic reactions are more favored at higher temperature (69). Mass conversion efficiency decreases with decrease in temperature (65). An oxidation zone below a temperature of 725^{o}C gives significantly lower mass conversion efficiency (70). Generally, less than 100^{o}C difference in total rise of height is acceptable (53). Heating value as well as producer gas yield is found to increase due to increase in combustibles, particularly at temperatures above 800^{o}C with an increase in operating temperature driven by an external supply of heat in the gasifier for constant ER (53) (55) (57). However, this is different when the temperature is increased due to increase in ER inside the reactor which actually reduces the combustibles (57). Temperature control cannot be independent in any gasification process and is an output variable, with the exception of small lab-scale or pilot plants which can be heated with external heat. The temperature of the reactor is dependent on various factors such as moisture content of the fuel, ER, heat losses from the system, and amount of steam added (63) (71) (72). Thus, the temperature inside the gasifier should represent an optimal compromise with ER. The best approach is the proper insulation of the reactor and using waste heat. Higher temperature also reduces tar content significantly due to thermal cracking (53) (60) (55) (57) (73) (74). In addition, Cao et al. (73) report higher reduction in tar with same increase in top part of reactor than in bottom section. However, (62) suggest that the tar that is cracked due to temperature is mostly the heavy tar while light tar is not decomposed. Heavy tars are the product of pyrolysis process which has not gone through cracking while light tars are the cracking products of heavy tar. In certain cases, light tar seems to increase due to the subsequent breakdown of heavy tar into light tar and other compounds. Typical temperatures suggested for biomass gasification in a fluidized bed are around 800-900^{o}C by various studies (75) (76).

2.3.4 Particle size

Fixed bed gasifiers have lower biomass feedstock size restrictions compared to fluidized bed gasifiers. Usually, feed size less than 51 mm and 6 mm is recommended for fixed bed and fluidized bed, respectively. Saravana kumar et al. (77)], have successfully gasified long sticks with length of 68 cm and diameter of 6 cm successfully in a top-lit updraft gasifier. The maximum particle size suggested for a conventional downdraft gasifier with throated design is one-eighth of the reactor throat diameter (78). The larger particles form bridges preventing the efficient flow of biomass inside a gasifier while smaller particles interferes with the air/gasifying agent passage creating high pressure drop and consequently can result in gasifier shut-down.

Sharma (79) reports increase in the temperature of oxidation and reduction zone with decrease in particle size of the biomass feedstock in a downdraft gasifier. Decrease in particle size reduces the heat loss due to radiation and enhances the thermal conductivity in the oxidation and reduction zones. On the other hand, decrease in particle size increases pressure drop inside the gasifier. Burning rate and thus the char oxidation period of fuel particles decrease with increase in bulk density and particle size (80) (81). Biomass consumption rate is inversely related to particle size (82). In other words, higher residence time is recommended for larger biomass particle size. Decrease in CO with increase in CO_2 concentration is observed. Ryu et al. (81) report decrease from 18% to 13.5% CO when the size of wood cubes used in the experiments were increased from 10 mm to 35 mm. Their model predicts a decrease in CH_4 and an increase in H_2 with increase in size of biomass particles. Also, the temperature gradient decreases thus increasing time taken for diffusion of heat. This will result in poor temperature distribution which is also one of the reasons for the increase in CO_2 concentration with increase in particle size.

Carbon conversion efficiency is not strongly affected by particle size except the lower biomass size increases tar concentration because of high entrainment susceptibility during fluidization (83). This is because particles can be easily transported to the upper part of the reactor, leaving little time for tar cracking. Multi-staging can prevent this as demonstrated the novel concept developed by (84) using a gasifier design consisting of several cone shaped structures welded together with the base of each connected to the next tubes of equal diameters. The design makes it possible to maintain numerous fluidized sections in one reactor, and thus effectively control back-mixing of solids and gases. On the other hand, the axial temperature drop increases significantly with decrease in size. This is due to the easy passage of feed particles from the feed point and thus little or no reaction taking place below the feed point. Thus, the homogeneity of the bed material cannot be maintained throughout the reactor (62) (72).

2.3.5 Dust content

All gasifier fuels produce dust. This dust is a nuisance since it can clog the internal combustion engine and hence has to be removed. The gasifier design should be such that it should not produce more than 2-6 g/m^3 of dust (5). Figure shows dust produced as a function of gas production for wood generators used during World War II (7). The higher the dust produced, more load is put on filters necessitating their frequent flushing and increased maintenance.

2.3.6 Tar content

Tar is one of the most unpleasant constituents of the gas as it tends to deposit in the carburetor and intake valves causing sticking and troublesome operations (85). It is a product of highly irreversible process taking place in the pyrolysis zone. The physical property of tar depends upon temperature and heat rate and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water) (5). There are approximately 200 chemical constituents that have been identified in tar so far.

Very little research work has been done in the area of removing or burning tar in the gasifier so that relatively tar free gas comes out. Thus the major effort has been devoted to cleaning this tar by filters and coolers. A well-designed gasifier should put out less than 1 g/m^3 of tar (7). Usually it is assumed that a downdraft gasifier produces less tar than other gasifiers. However because of localized inefficient processes taking place in the throat of the downdraft gasifier it does not allow the complete dissociation of tar (5). More research effort is therefore needed in exploring the breakdown of tar in downdraft gasifiers.

2.3.7 Ash slagging characteristics

The mineral content in the fuel that remains in oxidized form after complete combustion is usually called ash. The ash content of a fuel and the ash composition has major impact on trouble free operation of gasifier.
Ash basically interferes with the gasification process in two ways:

a) It fuses together to form slag and this clinker stops or inhibits the downward flow of biomass feed.
b) Even if it does not fuse together it shelters the points in fuel where ignition is initiated and thus lowers the fuel's reaction response.

Ash and tar removal are the two most important processes in gasification system for its smooth running. Various systems have been devised for ash removal. In fact some fuels with high ash content can be easily gasified if elaborate ash removal system is installed in the gasifier (7).

Ash slagging, however, can be overcome by operating the gasifier with methods given below (86):

a) Low temperature operation that keeps the temperature well below the flow temperature of the ash.
b) High temperature operation that keeps the temperature above the melting point of ash.

The first method is usually accomplished by steam or water injection while the latter method requires provisions for tapping the molten slag out of the oxidation zone. Each method has its advantages and disadvantages and depends on specific fuel and gasifier design.

Keeping in mind the above characteristics of fuel, only two fuels have been thoroughly tested and proven to be reliable. They are charcoal and wood. They were the principal fuels during World War II and the European countries had developed elaborate mechanisms of ensuring strict quality control on them (87).

Charcoal, specifically, because of being tar free and having relatively low ash content property was the preferred fuel during World War II and still remains so (2). However there is a major disadvantage of charcoal in terms of energy. Charcoal is mostly produced from wood and in conversion of wood to charcoal about 50% of original energy is lost (88). When made by pit method (as is normally made in most developing countries) the losses can be as high as 80% (89). Besides with the present energy crisis where most countries do not have enough supply of wood it is advantageous and attractive to use agricultural residues. For the agricultural sector this is an extremely attractive alternative.

Many agricultural residues and fuels have, therefore, been gasified. However the operating experience is very limited and most of the work has been on laboratory scale (1) (90). More research needs to be done in order to make gasification systems running on these fuels on a large scale.

2.4 PROPERTIES OF PRODUCER GAS

The producer gas is affected by various processes as outlined above hence one can expect variations in the gas produced from various biomass sources. Table 2.3 (7) (91) fuels lists the composition of gas produced from various sources. The gas composition is also a function of gasifier design and thus, the same fuel may give different calorific value as when used in two different gasifiers.

The maximum dilution of gas takes place because of presence of nitrogen. Almost 50-60% of gas is composed of noncombustible nitrogen. Thus it may be beneficial to use oxygen instead of air for gasification. However the cost and availability of oxygen may be a limiting factor in this regard. Nevertheless where the end product is methanol – a high energy quality item, then the cost and use of oxygen can be justified (92).

Table 2.3: Composition of Producer Gas from different biomass

Fuel	**Gasification Method**	**Volume Percentage**					**Gross 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	Downdraft	17-22	16-20	2-3	10-15	55-60	5.00-5.86

content							
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50
Coconut husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20
Pressed sugar cane	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 pellets	Downdraft	16.1	9.6	0.95	-	-	3.25
Cotton stalks cubed	Downdraft	15.7	11.6	3.4	-	-	4.32

On an average 1 kg of biomass produces about 2.5 m^3 of producer gas at S.T.P. In this process it consumes about 1.5 m^3 of air for combustion (7). For complete combustion of wood about 4.5 m^3 of air is required. Thus biomass gasification consumes about 33% of theoretical stoichiometric ratio for wood burning.

The producer gas generated from the gasifier can be used,

a) In internal combustion engines,
b) For direct heat applications.

However in order for the gas to be used for any of the above applications it should be of fuel grade quality and also free from tar and dust and be cooled. The failure or the success of producer gas units depends completely on their ability to provide a clean and cool fuel grade gas to the engines or for burners. Table 2.4 summarizes the properties of producer gas which are important for establishing it as a fuel grade gas which can be used in IC engines. Thus the importance of cleaning and cooling systems cannot be overemphasized.

Table 2.4: Properties of producer gas

Gas Name	**Flammability Limit in air, Percent**		**GCV MJ/Nm^3**	**Wobbe Index MJ/Nm^3**
	Lower	**Higher**		

Producer Gas	17	20-35	4.21	5.23

2.5 PRODUCER GAS CLEANING

The temperature of gas coming out of gasifier is normally within 300-500°C and is of dirty nature. It carries particulate matter, tar oil vapour and moisture. All the three components are supposed to remove from the gas. For removal of tar and moisture gas has to cool below their dew point temperature i.e. 350^{o}C is for tar and 100^{o}C is for water. So for cleaning, gas has to cool below 100^{o}C. But if it is done in one step then particulate matter and tar oil will form a sticky material, which is difficult to remove. So the cleaning has to be done in steps. First particulate matter is removed, then tar oil and in last stage the moisture content.

For gas cooling various types of cooling equipment have been used (87). Most coolers are gas to air heat exchangers where the cooling is done by free convection of air on the outside surface of heat exchanger. Since the gas also contains moisture and tar, some heat exchangers provide partial scrubbing of gas (85). Thus ideally the gas going to an internal combustion engine should be cooled to nearly ambient temperature. Gas quality requirements for the power generation are very strict as in Table 2.5 (89).

Cleaning of the gas is trickier and is very critical. Normally three types of filters are used in this process. They are classified as dry, moist and wet (85). In the dry category are cyclone filters. They are designed according to the rate of gas production and its dust content. The cyclone filters are useful for particle size of 5 μm and greater. Since 60-65% of the producer gas contains particles above 60 μm in size the cyclone filter is an excellent cleaning device (87).

Table 2.5: Gas quality requirements for power generators

Parameters	IC Engine	Gas Turbine

Particles, mg/Nm^3	< 50	<30
Particle size, µm	< 10	<5
Tar, mg/Nm^3	< 100	
Alkali metals, mg/Nm^3		0.24

Table 2.6: Gas quality of raw producer gas from atmospheric air blown biomass gasifier.

Pollutants	Fixed bed co-current Gasifier	Fixed bed counter-current gasifier	CFB gasifier
Particles, mg/Nm^3	100-8000	100-3000	8000-100,000
Tar, mg/Nm^3	10-6000	10,000-150,000	2000-30,000

Even after passing through cyclone filter the gas still contains fine dust, particles and tar. It is further cleaned by passing through either a wet scrubber or dry cloth filter. In the wet scrubber the gas is washed by water in countercurrent mode. The scrubber also acts like a cooler, from where the gas goes to cloth or cork filter for final cleaning.

Since cloth filter is a fine filter, any condensation of water on it stops the gas flow because of increase in pressure drop across it. Since the gases are still above dew point, condensation takes place in filter.

The gas quality requirement for the power generators is very strict. Gas cleaning systems are expected to reduce particles and tar content from the raw producer gas to the postulated levels. Typical values of particulates and tar content are given in Table 2.6 (2). Table shows that the amount of tar is much higher in countercurrent than concurrent gasifiers.

2.6 PRODUCER GAS ENGINE

Literature survey in the field of producer gas based engines reveals modest research work to have been carried out since the inception of biomass/charcoal gasification systems. This could be attributed to two reasons, namely non-availability of standard gasification system that could generate consistent quality producer gas and the other relating to misconceptions about producer gas fuel.

Anon (93) has reported extensive work on the design and development of closed top charcoal and wood gasifiers for use with the reciprocating engines. These engines were however in the lower compression ratio (CR<10), either adapted from petrol engines or modified diesel engine. Martin et al., (94) reported work using charcoal gas and biomass based producer gas on a SI engine with a de-rating of 50% and 40% respectively at CR 7. They also claimed 20% de-rating when worked with producer gas at CR 11. They indicate an upper limit of CR of 14 and 11 for charcoal and biomass based producer gas, respectively.

In the Indian sub-continent, work in the area of producer gas engine has been reported by the biomass gasification group of Indian Institute of Technology, Mumbai. They have reported work on a gas engine converted from a naturally aspirated diesel engine at CR 11.5 (95) (96). The reason given for limiting the CR was knocking tendency. However, no experimental evidence was provided in support of it. If one were to summarize the findings of earlier studies (prior to 2000), it becomes evident that no systematic investigation had been attempted in identifying the existence of knock limitation, if any, with producer gas operation at CR comparable to that of diesel engine operation. On the contrary producer gas with large fraction of inert (> 50%) and with laminar burning velocity being high (due to the presence of H2), smooth operation at higher CR must be definitely possible. A systematic investigation on producer gas operation at CR comparable to that of diesel engine was carried out and reported by one of the present authors (97) (98). The source of producer gas fuel used was from an open top re-burn down draft gasifier system (99) (100) using casuarina wood pieces as the fuel. The compression ratio limits were tested up to 17:1 without any audible knocking. It was demonstrated that the comparable power to that of diesel engine (with a lesser extent of de-rating ~ 15-20%) could be achieved with producer gas by operating engine at higher CR.

Sridhar et. al. (97) summarized the overall development effort, performance of the engine at higher CR is smooth and it has been established that operating engines using producer gas in SI mode at CR up to 17 is feasible. They have conducted experiments on three engines of different makes, i.e., Kirloskar, RB-33 (E1), Greaves, TBDV12 (E2), and Cummins, G743G (E3). The specifications of the engines used in their experiments are given in table 2.7.

Table 2.7: Specifications of the engines used in experiments

Parameter	**Engine 1 (E1)**	**Engine 2 (E2)**	**Engine 3 (E3)**
Make and Model	Kirloskar, RB-33	Greaves, TBDV12	Cummins, G743G
Engine Type	In-Line, 3 Cylinder, Naturally Aspirated Diesel Engine	'V' Configuration, 12 Cylinder, Turbo-Charged with After Cooler Gas Engine	In-line, 6 cylinder, 4-stroke, Naturally Aspirated Gas Engine
Rated Output - 1500 Rev/Min @ sea level	28 kW, with diesel fuel	290 – 310 kW (Estimated) Using Diesel	101 kW with natural gas
Net Output* - @ Bangalore ~ 1000m above sea level	24 kW, with diesel fuel	240 - 258kW, with diluted natural gas	84 kW, with natural gas
Bore x Stroke, mm Total Displacement, L	110 x 116 3.3	128 x 140 21.6	130 x 152 12.1
Specific Power, kW/L	8.5 (with diesel)	13.4 – 14.4 (with diesel)	7.0 (with NG)
Compression Ratio (CR)	17	12	10
Bumping Clearance, mm	1.5	1.6	11
Combustion Chamber	Flat Cylinder Head and Hemispherical Bowl-in Piston Type	Flat Cylinder Head and Cylindrical Bowl-in Piston	Flat cylinder head and a Shallow Bowl-in piston type
Squish Area	70%	68%	35%
Spark Plug Type & Location - Gas Mode	Cold, Offset from the Axis of Cylinder by 8mm	Cold, Offset – Located in the Vertical Plane Close to the Outer Edge of the Bowl	Central
Conversion/ modification, if	Converted to SI engine	Producer Gas Carburetor adapted	Producer Gas Carburetor

any			adapted

Table 2.8 gives the summary of their results for all three engines used. The results suggests that the performance of the engine at higher CR is smooth and it has been established that operating engines using producer gas in SI mode at CR up to 17 is feasible.

Table 2.8: Maximum net engine output on different engines

Engine	CR	IGN, BTC	Φ	Net Elec. Power, kWe	Net Brake Power (BP Net), kW	Mixture Energy Density, MJ/kg	Efficiency : Gas-to-Shaft, %
E1	17.0	06	1.10	17.5	20.0	2.20	30.7
	14.5	10	1.10	16.4	18.8	2.20	29.0
	13.5	14	1.06	16.2	18.6	2.10	29.3
	11.5	15, 17	1.07	15.3	17.6	2.20	27.5
E2	12	12, 14	0.94	165	182	1.90	28.3
E3	10	22, 24	1.01	55	60	2.15	27.4

Prior to (97) work, there was some misconceptions regarding producer gas fuel and they were identified as follows: (1) auto-ignition tendency at higher CR when used in reciprocating engine, (2) large de-rating in power due to calorific value of the fuel being low.

As producer gas is being a mixture of many inert gas species like CO_2 and N_2 accounting to 12–15% and 48–50% and therefore has high octane rating when compared to natural gas and biogas and these gas species act as knock suppressors. However, so far there has not been any research of octane rating test conducted on producer gas fuel. Moreover, it is not clear if any established test procedure exists for producer gas like the Methane number test for natural gas and biogas. One crude way of assessment is to test the fuel gas in standard engines and place them accordingly in the octane rating table.

As producer gas being a lower calorific fuel, the extent of de-rating would be large when compared to high calorific value fuels like natural gas and liquefied petroleum gas (LPG). The de-rating if any could be due to two possible reasons. Firstly, with the lower energy density fuels there is a net decrease in number of molecules when compared to high-energy fuels like diesel, gasoline, natural gas or LPG. This contributes to some de-rating in case of low energy density fuels (11). De-rating of power on account of calorific value will be small because of marginal differences in the energy release per unit mixture (air + fuel gas) (12). This can be explained as follows. The calorific value of producer gas varies between 4.7 and 5.0 MJ/Nm^3 as against 30 MJ/Nm^3 for natural gas. The energy density per unit (producer gas + air) mixture is only 15–20% lower than natural gas and air mixture even though the calorific value of producer gas is one-eighth of natural gas. This is because the stoichiometric air-fuel ratio for producer gas is 1.2 as compared to 17 for natural gas. Hence the extent of de-rating with producer gas would not be marginal compared to natural gas fuelled operation at comparable operating conditions.

This gap could be nullified by working producer gas at higher CR when compared to natural gas. The upper limit of CR for natural gas has been identified to be around 15.8: 1 based on a recent work (11).

2.7 CONCLUSION FROM LITERATURE REVIEW

After exhaustive literature review it is concluded that, there is a possibility of fossil fuel replacement of biomass gasification for meeting energy demands (heat and power) in remote rural areas. Down draft biomass gasifiers are the best option among other gasifiers like updraft and fluidized flow for IC engine application as they produce very less tar.

As lantana and some other weeds are posing serious threat for forests and require immediate action to eradicate the same. No work has been done on lantana as a feed stock for gasification process.

A little work has been done in developing bigger IC engines for power generation using producer gas as a result of biomass gasification. Portable IC engine based electric generators are not used in the literature.

2.8 MOTIVATION

About 70% of the Indians live in rural areas and use animal dung, agricultural waste and fuel wood as fuel for cooking. About 87% of the schools in the country are located in the rural areas. About 25.81 million or (61.3%) of the enterprises in India are located in the rural areas (Economic Census 2005). The energy need in the rural areas is growing very fast. The search for alternate energy sources are going on globally.

The above requirement motivates the work to follow biomass gasification route, which is turning out to be a ready solution to the small energy needs of the sparsely populated rural households located away from the hustle and bustle of big cities and towns.

As lantana and some other weeds are posing huge threat for forests and require immediate action to eradicate the same. But still not much work has been done on lantana or other weeds gasification.

Bigger IC engines were developed and used for power generation using producer gas from biomass gasifiers. Portable IC engine based electric generators are not used till date. Bigger IC engines are useful for power generation for a community rather than a single house hold. Experience tells us that, in India most of the community biomass gasifier plants are not working properly as no one is taking ownership for maintenance and caretaking of the plant. That’s why development of a small IC engine based portable generator set is taken up as objective in the present work.

The present work is a step in the direction of making rural households energy independent using the biomass gasification technology and making it more rural friendly and also tries to fill these gaps found during literature review.

2.9 OBJECTIVES OF PRESENT INVESTIGATIONS

1. Study on feasibility of production of producer gas from lantana biomass as feed stock.
2. Design, fabrication and performance evaluation of a portable down draft biomass gasifier.
3. Performance and emission analysis of an IC engine using conventional fuel and producer gas.

CHAPTER 3

METHODOLOGY

In order to achieve the objectives of the present investigations, experiments were conducted on an experimental setup which was designed, fabricated and installed in the Biofuels Research laboratory, University of Petroleum and Energy Studies, Dehradun, India. The integrated system was optimized to get maximum efficiency. A schematic of an overall system is depicted in Figure 3.1(a and b) .

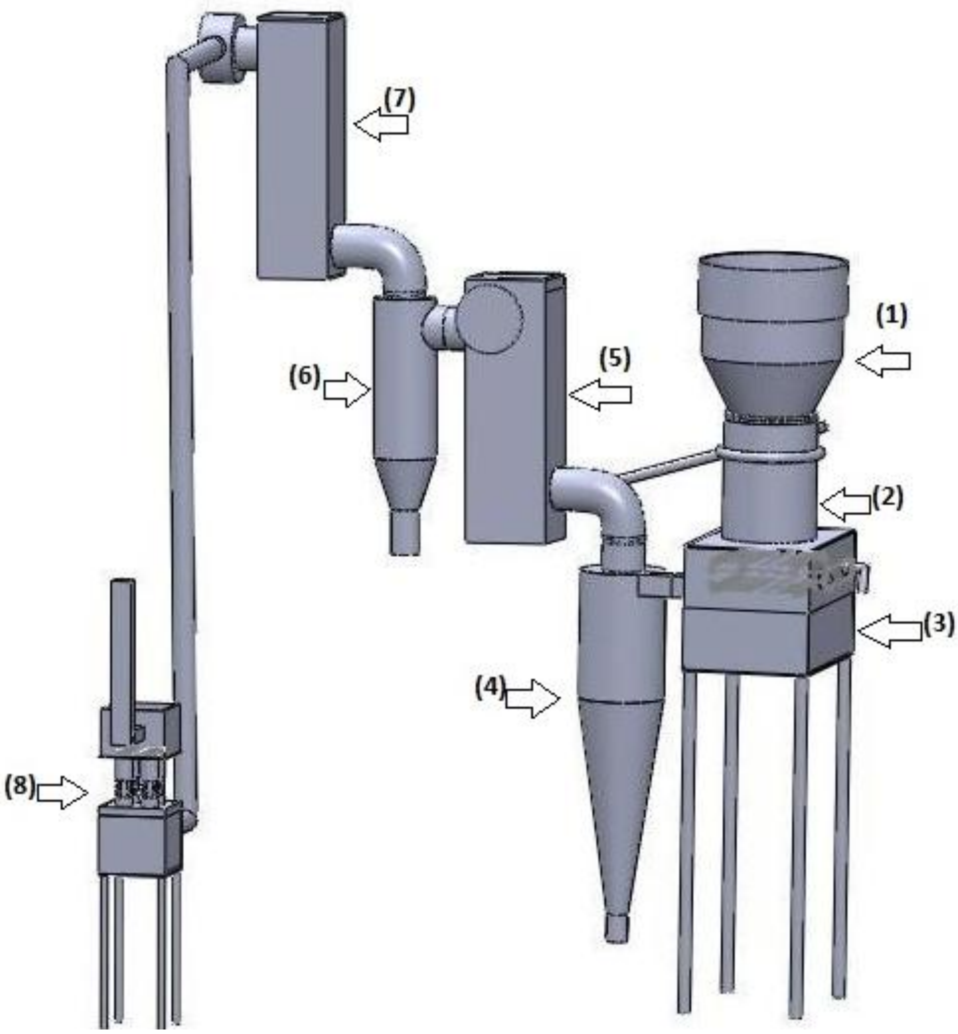
In the beginning of the research work, the analysis for identification potential biomass for gasification was carried out. A down draft biomass gasifier was designed based on the mechanical, chemical and thermal properties of the identified biomass. The design of different parts of the gasifier was optimized and the final setup was made ready for fabrication and installation. The integrated system consists of a downdraft gasification unit, heat exchanger, gas cleaning units like cyclone separator, sand bed filter and gas coolers.

The producer gas was produced and analyzed with the help of a gas chromatograph. The experimental runs were repeated for establishing the best conditions for gasification and obtaining good quality producer gas. The gas was then used in a modified petrol engine as a fuel to generate power. The emission and performance characteristics were determined at different loads. The detailed description about the work methodology and experimental setup is described in this chapter.

3.1. SELECTION OF BIOMASS MATERIALS AND COLLECTION

3.1.1 Selection of biomass materials

Lantana camara *L.* commonly known as lantana was selected for the gasification unit because of its availability in forest areas as well as in abandoned land of nearby villages. Lantana is posing serious problems for forest vegetation like bamboos and other grasses in Uttarakhand. The leaves of lantana are poisonous in nature and cannot be used for animal feed. The present work is a major step forward in direction of eradicating problems imposed by lantana.



1. Hooper	5. Heat Exchanger
2. Reaction Chamber	6.Moisture Condensor
3. Ash Extraction Unit	7.Sand Bed Filter
4.Cyclone Seperator	8. Cooking Stove Unit

Figure- 3.1a: Schematic diagram of gasifier experimental setup.

Figure -3.1b: Pictorial view of the integrated experimental setup.

3.1.2 Collection and storage of biomass materials

Lantana was collected from various locations of Uttarakhand by employing local rural people. The stems of lantana were chopped to smaller pieces of average size 2 cm. The chopped pieces were dried under the sun to reduce the moisture content less than 10% by weight. The pieces of lantana were stored in bins so that they were not exposed to moisture again.

3.2. PHYSICO-MECHANICAL CHARACTERISTICS

The Physico-mechanical properties such as bulk density, particle density, particle size, void fraction, and angle of repose were evaluated and analyzed in the subsequent sections.

3.2.1. Bulk Density

It is one of the most important physical characteristics of biomass. Bulk density of lantana was measured by weighing the loosely packed lantana chips in a container with respect to the volume of container as per the standard procedure prescribed by ASTM standard (E 873-83).

3.2.2. Biomass particle density

Density of lantana was determined by evaluating the weight of the lantana chips and volume of the same quantity of chips. This procedure was repeated for 20 numbers of chips of different volumes and the average value was taken as density of lantana biomass.

3.2.3. Void fraction

Void fraction is defined as the ratio of volume of void space in the box when the biomass is loosely filled and the volume of solid biomass materials loosely filled in the box. The value of void fraction of biomass material was evaluated from the empirical formula by using the values of particle density, bulk density and the volume of a rectangular vessel filled with a known mass of the biomass.

3.2.4. Particle size and shape

From the discussion about particle size in chapter review of literature, it was concluded that the optimum size of biomass chips will give good results during gasification of lantana. The lantana chips were in cylindrical shape with average diameter of about 1.32 cm and length of about 2 cm.

3.2.5. Angle of repose

Angle of repose for each of the biomass materials was determined by measuring the dimensions of the conical heap formed due to the free fall of lantana through a vertically held circular tube. The height and the base diameter of the heap were measured accurately. Angle of repose was calculated from the following equation 3.1.

$$— \qquad 3.1$$

= angle of repose, degree

Height of the heap, mm

Width of the heap, mm

3.3. PHYSICO AND THERMO CHEMICAL CHARACTERISTICS

The physico-chemical properties, such as volatile matter, moisture, ash content, elemental composition and the chemical composition of the lantana were necessary for the proper design and operation of a downdraft biomass gasifier. Thermo-chemical properties such as higher and lower heating values influence conversion process directly.

Property like moisture content of the biomass fuel affects the quality of the gas. Water requires about 2300 kJ/kg to vaporize and 1500 kJ/kg to raise the temperature from atmospheric to 700^0C during pyrolysis/gasification. Therefore, this energy must be subtracted from the heat budget of the gasifier. Lantana has 35-40% moisture content by weight, while <15% moisture is desired for biomass gasification.

ASTM standard methods for solid fuels such as coal and coke were adopted, in test procedures. Because of the absence of specified standard test and the presence of large quantities of volatiles in the biomass fuels in comparison to those in coal and coke, certain modifications were considered in the determination of physico-chemical properties in the present work. The standard procedures and methods are discussed in this section.

3.3.1. Proximate analysis

ASTM standard method for proximate analysis (D-3172-73 through D-3174-82 and D-3175-82) were followed to find out volatile matter and moisture content. One gram of lantana was finely chopped and taken for proximate analysis. The sample was divided into two portions and the first portion of the sample was placed in a silica crucible. The moisture content of the first sample was determined according to ASTM D 3173-73. The second portion of the sample was placed in a crucible and covered with a lid. It was then heated in the furnace at a temperature of 400^oC for duration of six minutes. The crucible in desiccators was cooled and weighed to find out the difference in the weights. It is due to the loss of volatiles and moisture from the sample. The weight of volatile matter was found by subtracting the weight of corresponding moisture earlier determined from the first sample.

3.3.2. Ultimate analysis

The ultimate analysis was performed on finely ground and dried lantana samples to determine the weight fractions of carbon, hydrogen, nitrogen and oxygen. The weight fractions of carbon, hydrogen and nitrogen were determined using CHNS Elemental Analyzer at ShriRam Institute for Industrial Research, New Delhi. The ash content was determined separately following the standard method IS: 1350 (Pt-1). There is no direct method available for the determination of oxygen in biomass fuels and therefore its percentage was estimated by subtracting the sum of carbon, hydrogen, nitrogen, and ash percentages from the numerical value of 100.

3.3.3. Heating values

The higher heating value of a lantana sample was determined in a standard bomb calorimeter as per ASTM-D2015-17. The biomass samples were meshed to 250µm (60 mesh). One gram of each of the powdered biomass samples was converted to pellet form. The pellets were burned in the bomb in presence of oxygen at the pressure of 30 atmospheric. The higher heating values were determined from the temperature rise of the surrounding water bath and the heat capacity of the system. The lower heating values were then calculated using the relation given by (101).

3.4 DESIGN AND FABRICATION OF DOWNDRAFT GASIFIER

3.4.1. Theoretical consideration for design of downdraft gasifier

Design of gasifier was carried out by using empirical relations and experimental data. The principal design parameters are specific biomass feed rate (SBFR), char reaction time (CRT), diameter of reaction chamber, and biomass fuel characteristics. The derived parameters are total length of pyrolysis zone, reduction char zone, fuel velocity and reaction time in pyrolysis zone. The complete design of gasifier with different parameters relevant to design is discussed in this section.

3.4.1.1. Equivalence ratio

Equivalence ratio is defined as the ratio air supplied per kg wood to the stoichiometric requirement of air per kg of wood. Equivalence ratio fixes the amount of air supplied for gasification. The downdraft biomass gasifier was designed for 0.25 equivalence ratio. As the equivalence ratio value approaches 1.0 combustion reaction is predominant and as it tends to zero, pyrolysis is the major process. For a given biomass consumption rate, the volumetric rate of air can be calculated from equivalence ratio value (102).

3.4.1.2. Specific biomass feed rate (SBGR)

SBGR is a derived parameter obtained from feed rate in kilogram per hour and cross sectional area of gasifier reaction chamber.

3.4.1.3. Char reaction time

Char reaction time is also termed as retention or residence time of producer gas in the char zone of gasifier. It is defined as the average time spent by the gas phase in reaction zone. Char bed thickness and the residence time has linear relationship i.e., higher the residence time, bigger the char zone thickness and vice-versa. From the reported literature it was found that, residence time has a positive effect on the gas yield. Along with gas yield, high residence time also leads to higher gasifier efficiencies. In the present work during gasifier design, a higher value of residence time i.e. 400 seconds was assumed.

3.4.2. Design of pyrolysis and char zone

3.4.2.1. Pyrolysis zone design

In pyrolysis zone design the main parameters are reaction time (t_p), fuel velocity (v_f), and pyrolysis length (l_p). Main considerations in governing the reaction time are, heat of pyrolysis (h_p), heat to vaporize water to 600°C (h_w), and the biomass properties like average volume of chips (V), fuel density (ρ), surface area of biomass chips (A), and the heat transfer rate between fuel chips and the hot gases (q). Time of pyrolysis in seconds was calculated with the help of equation from 3.2 to 3.5.

3.2

Fuel velocity in cm/s was calculated with the help of equation 3.3.

3.3

Where, D_m is the diameter of the gasifier reaction chamber, and F_v is the void fraction. The pyrolysis zone length was calculated in centimeters with the equation 3.4:

3.4

3.4.2.2. Char zone design:

After designing the pyrolysis zone parameters, char zone was designed. For estimating the char zone length (l_c) the char reaction time (t_c, in seconds) was assumed to be 400 seconds. The equation used for calculating the char zone length is

3.5

The design parameters used in designing the gasifier and the estimated values of gasifier dimensions are given in the Table 3.1

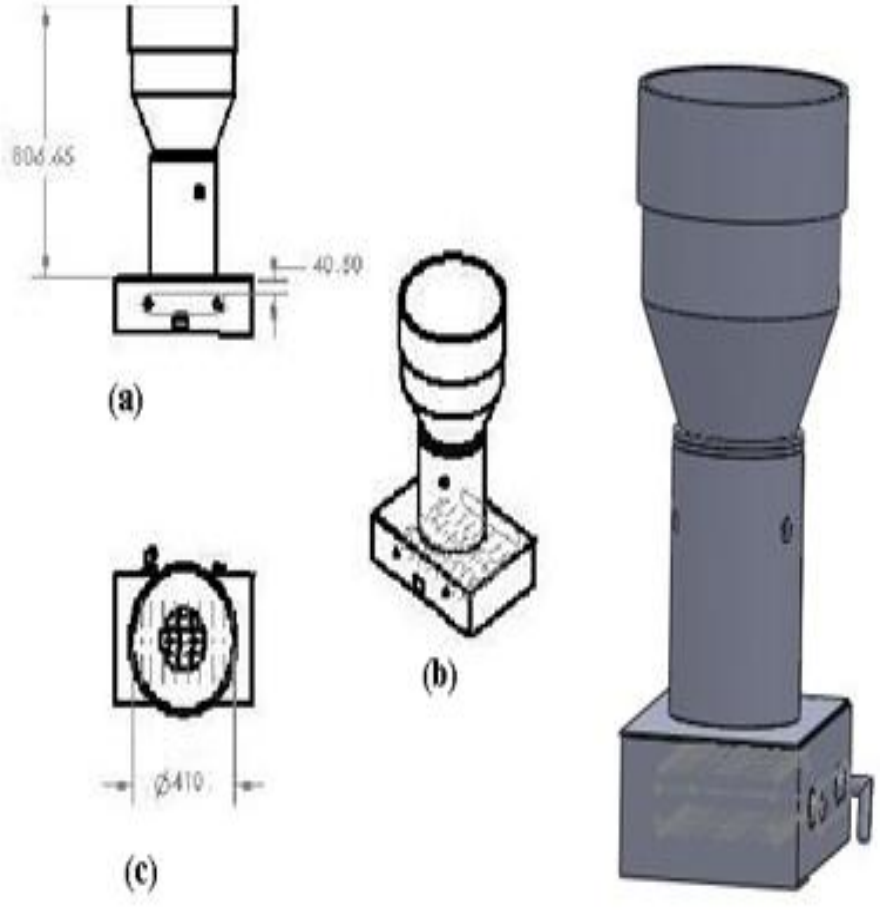


Figure 3.2: Complete assembly down draft gasifier

Table 3.1: Design of Pyrolysis and Char Reaction Zone

Gasifier Inputs	Symbols	Units	Numerical values	
Proximate Analysis of lantana (Dry Basis)				
Volatile			0.518	
Fixed carbon			0.375	
Ash			0.035	
Water	F_w		0.072	
Physical Properties of Fuel				
Density	P	g/cm^3	0.7	
Bulk Density		g/cm^3	0.43	
Void Fraction	F_v		0.67	
Average Diameter		cm	1.32	
Volume	V	cm^3	2.78	
Surface Area	A	cm^2	5.57	
length		cm	2.03	
Gasifier Conditions				
Diameter	D_g	cm	18 (assumed)	
Heat Transfer (between fuel and hot gases)	Q	W/cm^2	2(assumed)	
Biomass Feed Rate	M	g/s	0.8333333	
Cross Sectional area	A_g	cm^2	254.47	
Specificbiomass feed rate	M	g/cm^2s	0.0033	
Gasifier Design Parameters				
Pyrolysis Zone:			**Designed values**	**Actual values**
Residence Time	t_p	s	409.48	
Fuel Velocity	v_f	cm/s	0.0143	0.014653
Length of Pyrolysis zone	l_p	cm	**5.855564**	**6**
Reduction Zone:				
Residence Time	t_c	s	400	409.48
Length of reduction zone	l_c	cm	**5.72**	**6**

3.4.2.3. Down draft gasifier reaction chamber

The reaction chamber is a cylindrical chamber which housed the pyrolysis zone, reactive char zone, non reactive char zone, and biomass drying zone. Total length of the reaction chamber includes the estimated lengths of pyrolysis zone and char zone obtained after design calculations. The dimensions of the reaction chamber were, inner diameter of 180 mm (D_g), intermediate diameter of 240mm, and outer diameter of 270mm. Total length of the reaction chamber was 380mm as shown in Figure 3.3a. The reaction chamber was having an intermediate and outer Mild steel casing of 5mm thickness. Two layers of insulation were filled between inner and intermediate and intermediate and outer concentric cylindrical shells. A feed hopper is fitted at the top of the reaction chamber with flanges and gaskets. The bottom of the reaction chamber opens into stoker based ash extraction system for controlled extraction based on the ash content in the feed stock. The gas outlet is provided at the other end of the ash extraction system. The ash/char outlet is provided at the bottom in a water bath it also acts as water seal for escaping gas. The reactor is instrumented to measure temperatures at 5 different locations in the reaction chamber and gas exit temperature.

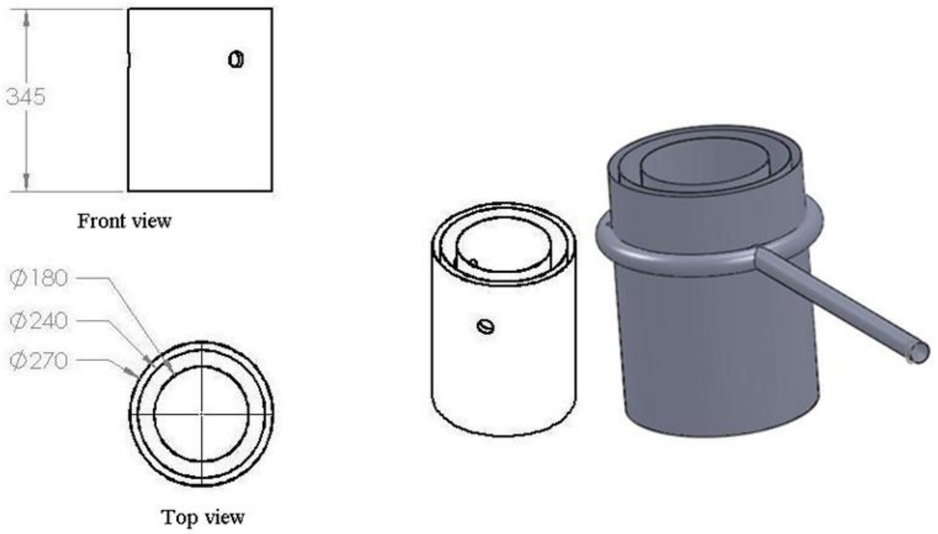


Figure 3.3: Design details of reaction chamber and reaction chamber

3.4.2.4. Air draught system

The atmospheric air was used as the gasifying agent for the biomass gasification process. The designed downdraft gasifier works under balanced draft. Two blowers, a forced blower for supplying air to the reaction chamber and one induction blower for sucking gas from the gasifier were used. Both the blowers were driven by AC single-phase motors consuming 100W powers running at 2500rpm.

The forced blower was capable of supplying air at 0.064 m^3/minute flow rate. The air was passed through a 20mm pipe. Air from the forced blower was initially pre heated in a heat exchanger (shell and tube type) through hot gas from the gasifier. The pre heated air was fed into the reaction chamber through three nozzles equally spaced on the circumference of reaction chamber.

The induction blower was capable of creating a suction head of the order of 100mm water column. This blower was fitted on exit pipe of sand bed filter. In the gas circuit after gasifier a series of gas cleaning equipments like cyclone separator, a heat exchanger, and a sand bed filter was attached. A pipe of 12.5cm diameter connects all the gas cleaning equipments with the gasifier and at last the blower was also attached on the same diameter pipe. A 6cm pipes connects the blower with the cooking stove and a 10mm valve was fitted in between for the gas for IC engine. The clean gas was either flared in the cooking stove or used for running IC engine for experimental runs.

3.4.2.5. Hopper design and fabrication

On the top of the reaction chamber a truncated cone type hopper was fitted and designed for batch feeding of biomass. Main parameters to be designed were the diameter and the height of the hopper. The main considerations governing the diameter of the hopper were, storage requirements, the reaction chamber diameter (D_g), size of the biomass particle, and the angle of repose of the fuel (θ). The bigger and smaller diameter of the hopper was 50cm and 18cm (diameter of reaction chamber) respectively with the length of 44cm. it was single walled and made up of 2mm thick plate of mild steel. The capacity of the hopper was about 8kg of loosely packed biomass. Hopper was closed at the top with a lid and a 100mm water seal was provided to avoid any leakage. This water seal was for two purposes one to avoid leakage and second was to ensure that the pressure in the system should not exceed 100mm of water column. If the pressure inside the gasifier exceeds 100mm of water column then this lid would go off and acts as safety valve. In Figure 3.4 the detail drawings of the hopper are given.

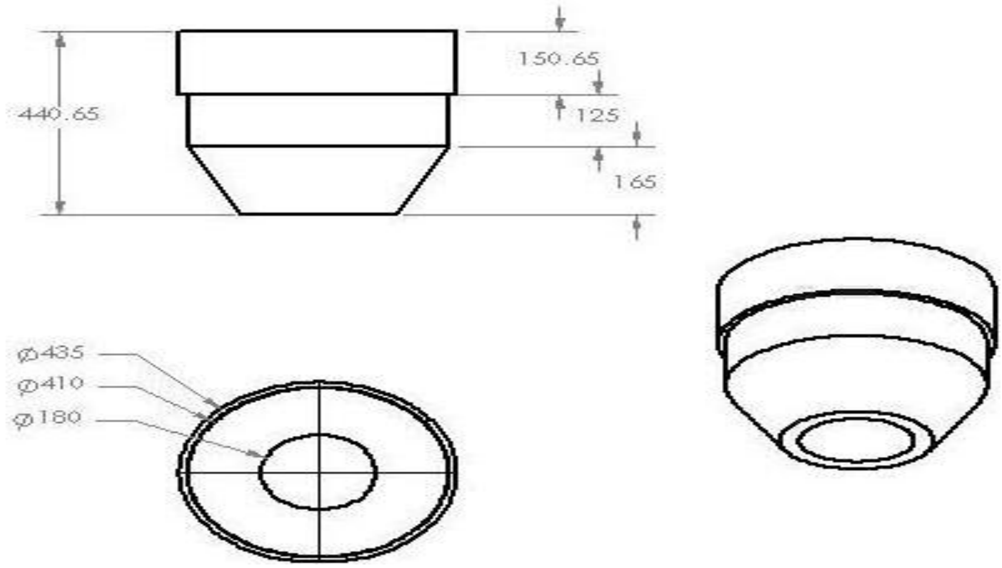


Figure 3.4: Hooper Design Details with complete dimensions

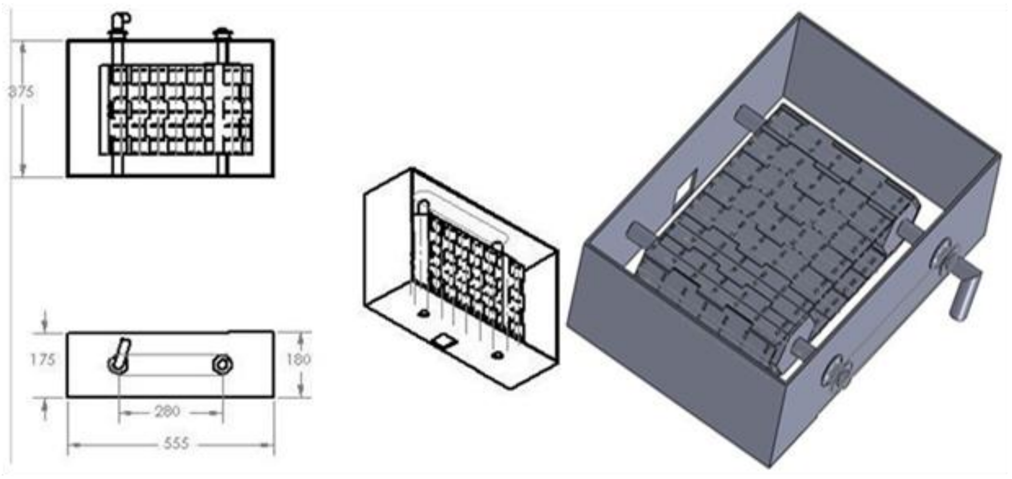
3.4.2.6. Ash extraction system

The reaction chamber was attached with the ash extraction cum moving bed unit by circular flanges. A rectangular box of 55.5cm x 37.5cm x 18 cm housed the ash extraction unit. This unit comprised of two regular hexagonal drums of face width 5cm and length 24.5cm. The two drums were kept at center to center distance of 28cm. A continuous belt, hinged assembly of the 18 pieces of stainless steel plate of thickness 0.5mm was running over the two drums. The width and length of the belt was kept equal to the face width and length of drums. On each piece of the belt 28 holes were provided for gas flow across the bed. This assembly of belt and drums was connected by a chain-sprocket and a handle fitted outside the box housing for giving rotation to the bed. The rotation frequency of the bed was around one rotation in one hour. This frequency was established after several runs of gasifier. The bottom part of the housing box opened into a water tank which acted as a water seal to prevent the gases from escaping from the bottom and also cooled and chars ash for safe handling. The detailed drawing of ash extraction unit is given in the figure 3.5.

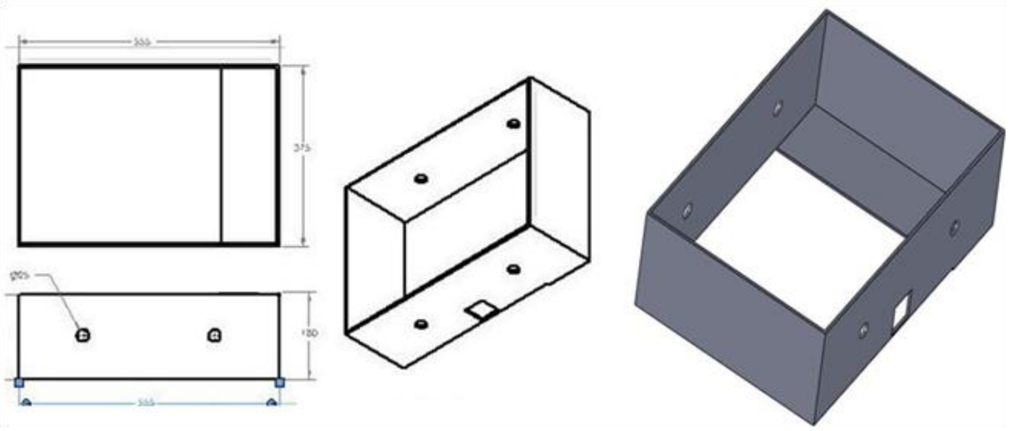
3.4.2.7. Heat exchanger unit

The air required for gasification was supplied by a forced blower as explained in section 4.4.2. Instead of supplying ambient air in the gasifier, it was preheated in a heat exchanger placed after cyclone separator. Heat exchanger received hot gas from the gasifier after cyclone separator and cold air from the forced blower. Heat was exchanged between the two fluids i.e. hot gases and cold air in this shell and tube type heat exchanger. The shell of heat exchanger for the hot gases was a square box of 25cm x 25cm x 75cm made of mild steel plates of thickness 1.5mm. The tubes for cold air were made of mild steel pipe of cross section 2cm. Three bents were provided in the pipe of 25cm x 25cm x 25cm. The total surface area available for heat transfer was about 550cm^2. The detailed drawing of heat exchanger is given in the figure 3.6.

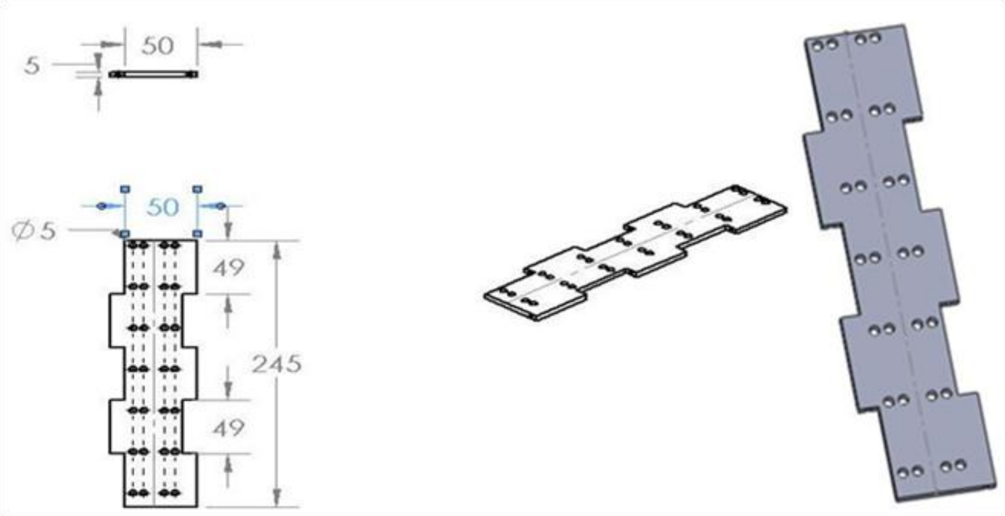
Along with heat exchanger circuit this equipment also acts as tar removal unit. The temperature of gas at the inlet was about 100^{o}C (dew point of tar mist). For capturing tar mist a sand bed along with wood wool was filled in the box. The entire system including gas inlet pipe, heat exchanger unit and gas outlet pipe were insulated by glass wool blanket and then covered by aluminum sheet of 1mm thickness.



(a) Drum-chain assembly unit



(b) Ash extracting unit housing



(c) Chain design details

Figure 3.5: Design details of Ash extraction system unit

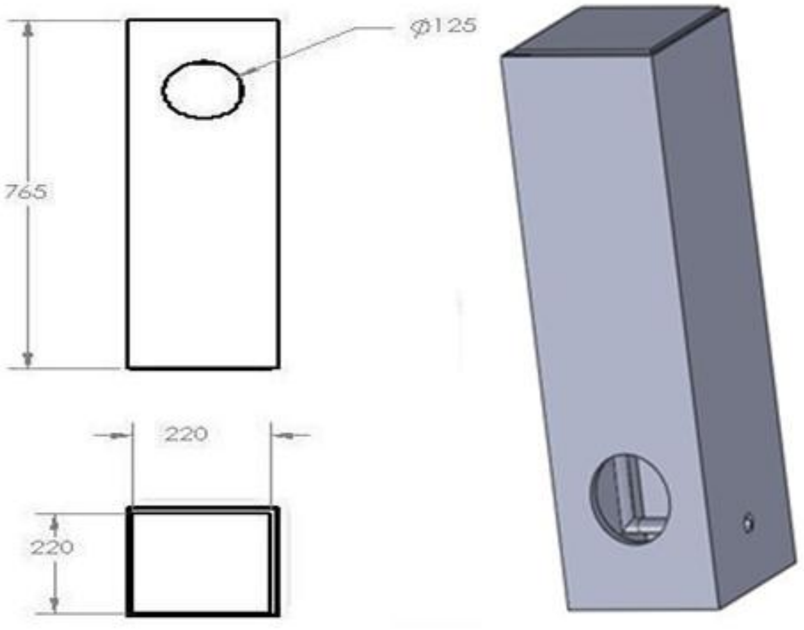


Figure 3.6: Heat exchanger assembly design

3.4.3. Gas cleaning units

Gas coming out of gasifier was very dirty and contained impurities like suspended ash particles, tars and moisture. If the gas was to be used in a burner no cleanup cleaning was required. This gas cannot be used for engine application directly. Solids can be quite abrasive, and the tar mist can cause the inlet valves, rings, throttle shafts, and other moving parts of engine to block by sticking. Therefore, the contaminants must be removed completely before feeding it to the engine for power generation. Successful gasifier-engine systems requires clean gas of the order of 10mg/m^3 to less than 1mg/m^3. Historically, downdraft gasifiers are known for producing less tar. In the present work a downdraft gasifier was used. However, a gas cleaning system was designed with the capability of cleaning very dirty gas that was occasionally produced by the gasifier, especially during startup, idling, and when wet fuels were used.

The present gas cleaning system was designed based on, the order of removal, temperature, and the intended deposit site for collected materials, and ease of equipment servicing and cleaning. The logical sequence of gas cleaning is to remove suspended particles first at above 300^{o}C (above dew point temperature of tar), tars are removed next at intermediate temperatures (above 100^{o}C), and water is removed last at 30^{o}-60^{o}C.

In the present work the gas cleaning system consisted of cyclone separator just after the gasifier for particulate particles removal, then a heat exchanger cum tar removal system followed by a cooler and then at last a sand bed filter to capture any liquid droplets of water and tar if any.

3.4.3.1. Cyclone separator

A high efficiency cyclone separator was attached to the exit pipe of gas from the downdraft biomass gasifier char bed cum ash extraction system. The cyclone was made of 1.5mm thick mild steel sheet with a body of 250mm diameter and 375mm height. The cyclone dimensions are given in the figure 3.7

The cyclone outlet was connected to a horizontal pipe, which connects to the heat exchanger cum tar removal unit. The cyclone separator together with the gas inlet pipe, and gas exit pipe was insulated with glass wool blanket.

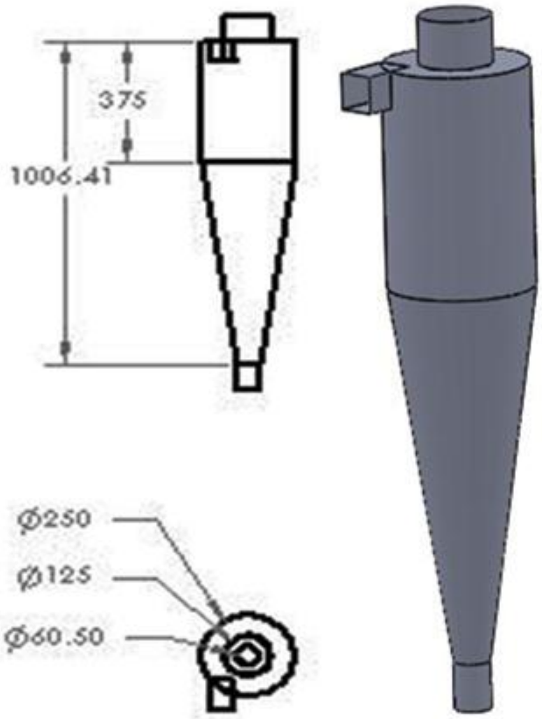


Figure 3.7: Design of cyclone separator

3.4.3.2. Gas cooler

A moisture condenser (gas cooler) was attached to the exit pipe of heat exchanger unit. The temperature of gas in this unit was about 60^{o}C. The moisture present in the gas was condensed in this chamber and taken out from the bottom of the chamber. The detailed dimensions of the condensing unit are given in the figure 3.8

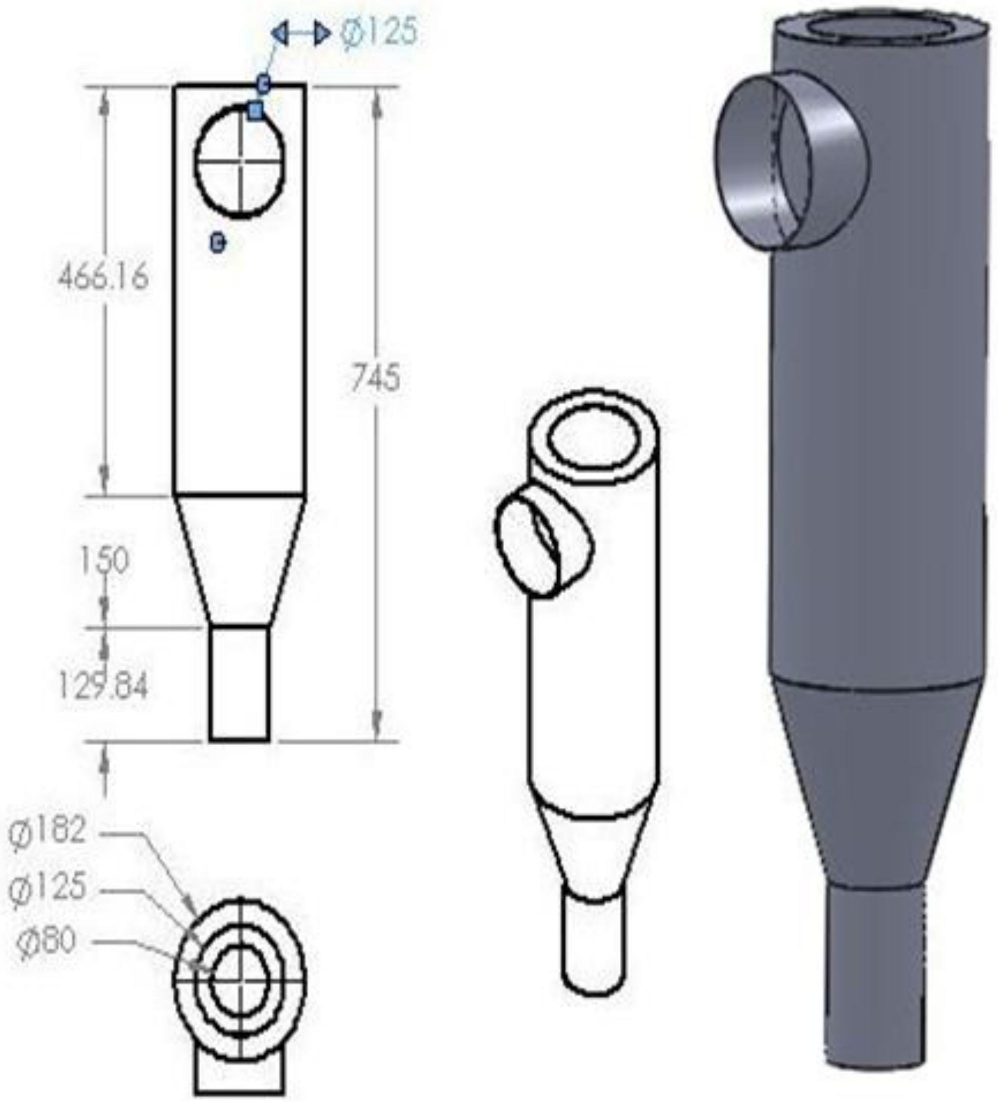


Figure 3.8: Moisture condensers

3.4.3.3. Sand bed filter

A san bed filter was attached to the exit pipe of moisture condenser unit. The bed was designed to capture any liquid droplet of water or tar being carried away by the gas. Three sand beds with 10mm thickness were put inside the chamber along with sand used to capture water droplet from the outgoing gas. The chamber had a 20cm x 20cm square cross section with 90cm height. This chamber was attached vertically to arrest the heavier water droplets by gravity. The sand beds were equally spaced in the chamber. The detailed design of the chamber is given in the figure 3.9

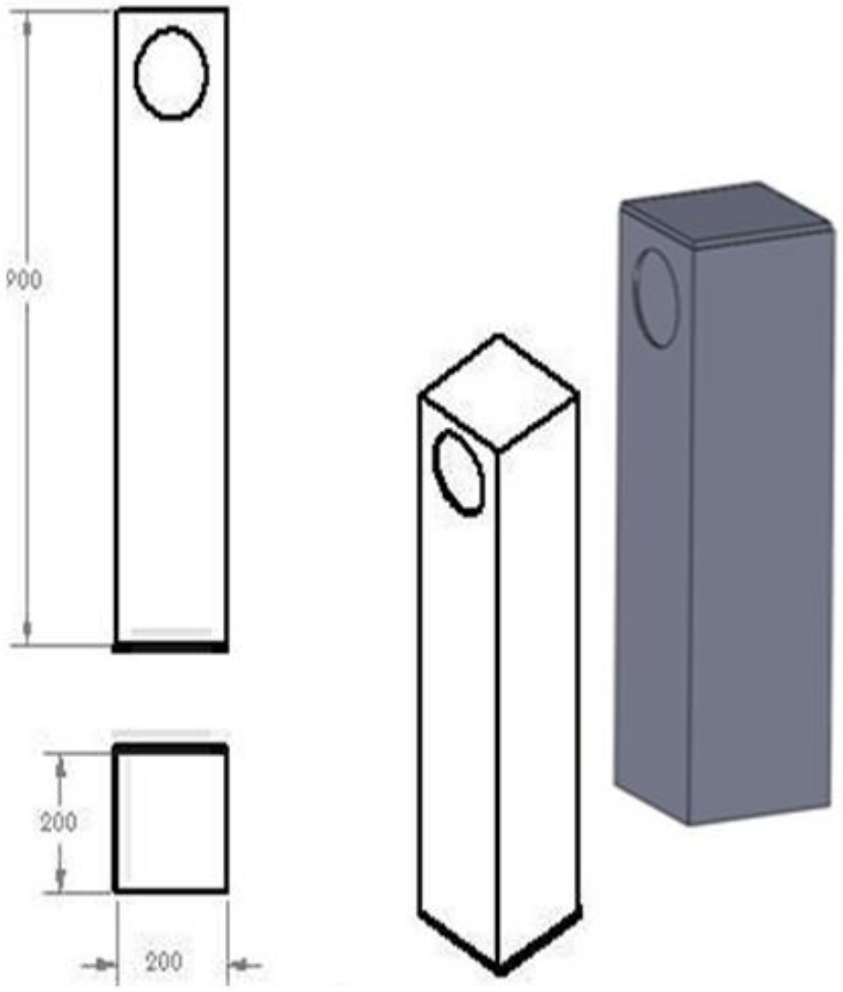


Figure 3.9: Sand bed filters

3.5. SELECTION AND MODIFICATION OF SPARK IGNITION PORTABLE GENERATOR SET

A 2.3kW (Make: Gas Tech) spark ignition based portable generator set was selected for engine testing. It was a petrol engine with stoichiometric air fuel ratio of 16:1 and compression ratio of 8. As the producer gas is a low calorific value fuel compression ratio was modified to 11 and air to gas stoichiometric ratio was modified to 1:1. The carburetor system was developed keeping these features under consideration

a) Ability to maintain the required air-to-fuel ratio (1.1 to 1.2:1) with load or throttle variation
b) Smooth operation with minimal pressure loss
c) Shut off the fuel in case of engine tripping or shut-down

The gas carburetor was simple in design and did not have any moving components. It had a separate port for air and fuel, where the individual ports could be modified or tuned to achieve the required air-to-fuel ratio.

The modified IC engine was connected to the outlet of the gasifier. The gas was supplied to the IC engine through the modified carburetor for engine testing and experimentation.

3.6. EXPERIMENTAL SETUP FOR GASIFIER

For safe and efficient operation of the gasifier system, temperature and pressure measurement systems were employed in the system. In the present biomass gasifier unit thermocouples and orifice meter were used for better understanding the system and process as a whole.

3.6.1. Temperature measurement

K-type and J-type thermocouples were fixed at various points in the down draft gasifier. These were used in conjunction with digital temperature indictors to measure temperature. The thermocouples were sheathed in stainless steel tubes of 150mm length; 8mm outer diameter and 1.5mm wall thickness. They had special mounting nuts and sockets made of stainless steel with brass gland packing to avoid gas/air leakage. The mounting nuts facilitated easy mounting and withdrawal of the probes and allowed cleaning of the sensor tips accumulated with dust and tar after an experimental run. All the thermocouples were calibrated and checked for their accuracy. They were generally found to be correct within $\pm 5^0$C.

The thermocouples were inserted into the flow line to a sufficient extent to capture the temperature correctly. The suitable fabrication work was done to accommodate the thermocouples at desired locations. The wires communicating the signals from thermocouples to the digital indicators were connected to the appropriate terminals rigidly. The digital indicators of appropriate range were used with these thermocouples to indicate the temperatures on data display board.

Table 3.2: Thermocouple type and location in the gasifier

Thermocouple Type	**Temperature Range**	**Location in the gasifier set up**	**Number**
J Type	0-600	Hopper (storage Zone Temperature)	1
J Type	0-600	Drying Zone Temperature	1
K Type	0-1200	Pyrolysis zone	3
J Type	0-600	Reaction Char Zone Temperature	1
J Type	0-600	Non Reactive Char Zone Temperature	1
J Type	0-600	Gas Outlet Temperature (From Gasifier)	1

These indicators were connected to the sensors firmly with due care taken. The display board was mounted on steel stand at appropriate height so that the readings can be taken comfortably.

3.6.2. Pressure measurement

The pressure was noted during each experimental run at a point,

a) Across the orifice meter for air flow rate measurement at the inlet to the heat exchanger.
b) Across the orifice meter for measuring exit gas flow rate.

The accuracy of the pressure measurement was ±1mm of water column. Figure 3.10 shows the location of thermocouple probes fixed in the gasifier system.

The flow rate of the gasifying medium-air was measured by a calibrated orifice meter. The flow rate of the produced gas was also measured using another calibrated, but similar orifice meter and U tube water manometer.

3.7. EXPERIMENTAL PROCEDURE FOR GASIFIER TESTING

Each experimental run was comprised of three different parts namely, the gasifier operation, the sampling and analysis of the producer gas and the engine & generator operation. The gasifier operation included: start up of the gasifier, steady state operation, and shut down procedures. The gas sampling and analysis included compositional analysis of the gas. The engine and generator operation included the behavior of engine and generator on full load and part loads.

The gasification experiments were conducted to evaluate the performance of the down draft biomass gasifier at different equivalence ratios (0.20 to 0.34) with lantana as the biomass material. The amount of actual air needed for the complete combustion of the biomass was first calculated. The stoichiometric air for one kg of lantana was found to be 4.3kg. The desired value of equivalence ratio could be obtained by suitably adjusting the airflow, based on the air requirement for complete combustion. The operational data for the gasification experiments are given in Table 3.3 for lantana. Gasification experiments were performed at four equivalence ratios of 0.20, 0.25, 0.30 and 0.34. Experimental observations were noted under steady-state condition of gasification at several times-on-stream.

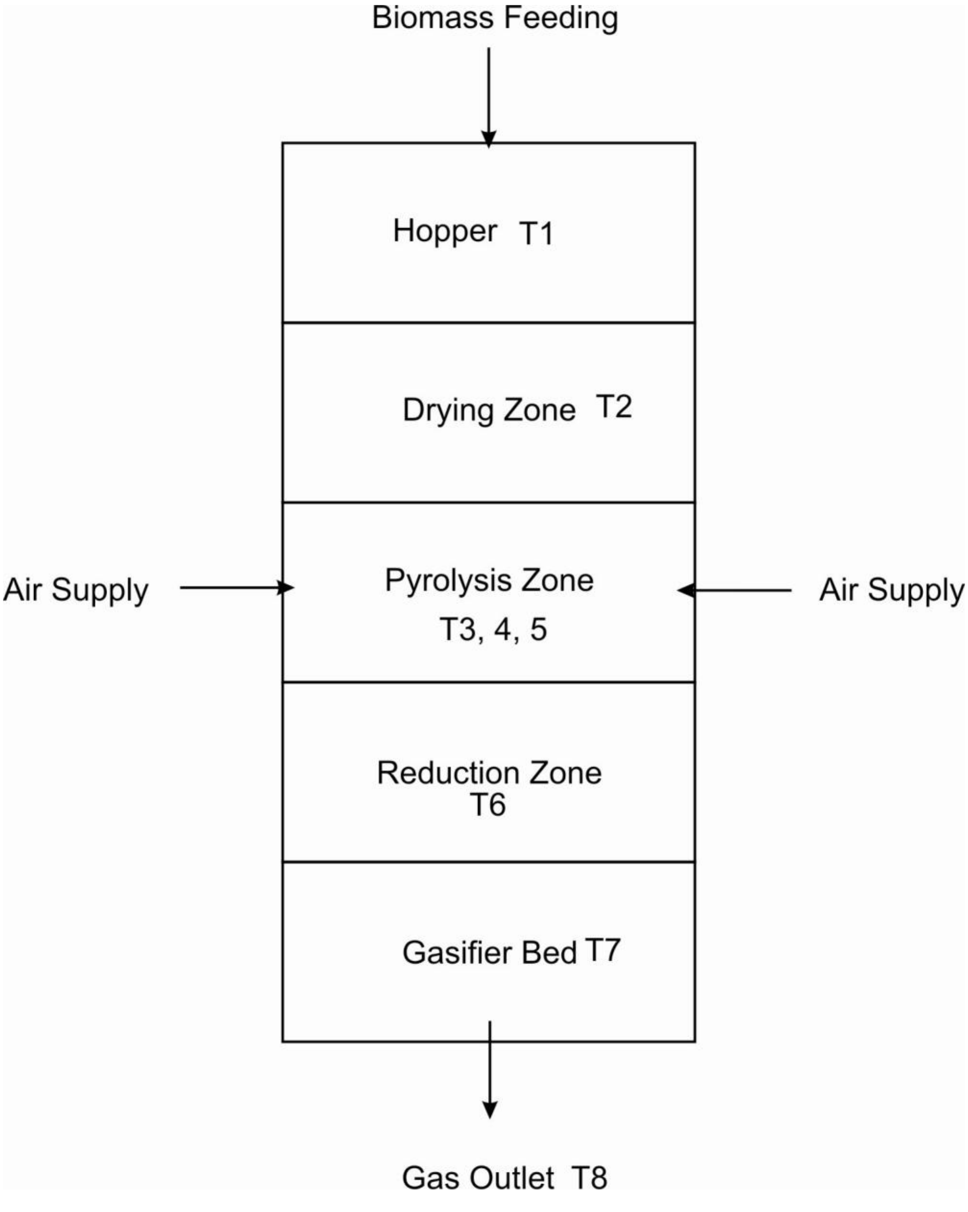


Figure 3.10: Thermocouple locations in down draft biomass gasifier

3.7.1. Start-up of the gasifier

A predetermined quantity of char pellets was loaded into the reaction chamber up to the height of air nozzles from the bed at the bottom of the reaction chamber. This char acted as char bed and reaction bed in the initial part of the gasifier operation. A small amount of kerosene oil was poured on the char bed igniting the char layer of the bed which initiated the combustion inside the reactor. Water sealing was done by filling the water in the water chamber at bottom of the gasifier. The forced blower was switched on and the airflow rate control valve was opened slowly to the maximum. Once the char became red hot the lantana pellets of suitable size was loaded into the reaction chamber through feeding hopper. This initial combustion of the biomass was continued till the bed temperature was found to be around 600^{o}C. Combustion for 15-20 minutes ensures the heating of the bed and the gasifier assembly.

3.7.2. Steady state operation of the gasifier

After the char bed reaches the temperature of about 600^{o}C the cover over the hopper was put on the hopper top and the airflow rate and the feed flow rate were adjusted such that a desired value of equivalence ratio was obtained. Thus the reactor was turned into gasification mode. The reaction zone temperature was found to drop immediately, but could be made stable within ±50^{o}C as the downdraft gasifiers are self regulating type.

The adjustment of air flow rate to obtain desired equivalence ratio was a tricky and complex as even a very slight variation in the airflow rate could turn the process into combustion (indicated by a sharp rise in temperature) or disturb the process (indicated by sharp downfall of the bed temperature). The gas from the induction blower outlet was flared at the exit end of the pipe in a gas burner. To the trained eyes, it was easy to recognize the gas of combustible quality.

All the temperatures and pressures were noted under steady-state operation at several times-on-stream. Gas sampling was also carried out under steady-state condition. The data was processed and the averaged values have been reported. The average temperature at reaction zone and the quality of the flare were the gross indicators of the process stability.

3.7.3. Shut down of the gasifier

When sampling of the gas and measurements of temperature and pressure were over, the blowers were continued to maintain air flow in the gasifier circuit for some more time, to burn off the residual biomass left in the bed. The dust collector was emptied and the char-ash mixture was consolidated and stored. The reactor cooled down slowly. The unit was completely shut off and the routine cleaning was initiated.

3.8. SAMPLING OF PRODUCER GAS

3.8.1. Gas sampling

Gas sampling was carried out using the plunger for taking samples through the sampling port in the gas exit pipe after the induction blower. The sampled gas was collected in the plunger after flushing the plunger with the gas by repeated cycles of filling and emptying. Samples were collected during an experimental run at 10minutes intervals.

3.8.2. Compositional analysis of gas

The gas sample taken in the plunger was analyzed in terms of their composition using a gas chromatograph of Nucon make model number 5700 series. The gas sample was injected in the gas chromatograph through a push/pull valve attached for injection. Argon was used as a carrier gas with a flow rate of 30ml/min. A stainless steel column of 3.2mm diameter and 2437mm length, packed with molecular sieve 5A, 60/80mesh and the thermal conductivity detector were used for determining the composition of the gas (H_2, N_2, CH_4 and CO). The composition of CO_2 was determined using a stainless steel column of 3.2 mm diameter and 2437 mm length packed with Porapak Q. The temperature conditions maintained were: detector at 100^oC

and oven at 60°C. The gas chromatograph was calibrated using standard calibration mixture.

3.9. EXPERIMENTAL SET UP FOR ENGINE TESTING

3.9.1. Engine modification

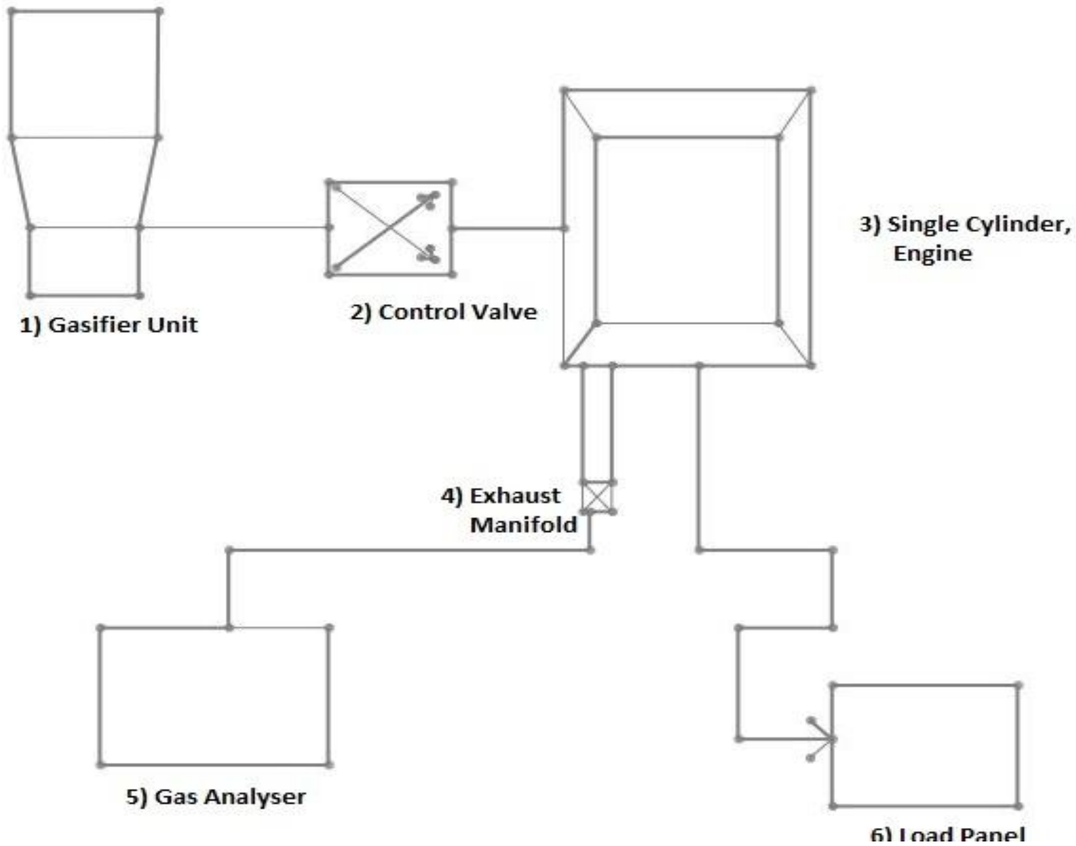
The engine taken for the experiment was manufactured by Gas Tech Pvt. Ltd. India. It was a single cylinder 4 stroke petrol engine. The engine was coupled with generator having rated capacity of 2.3kW at 1500 rpm. This engine cum portable generator was widely used in producing electricity for small households. The engine was started by battery. The engine was mounted on vibration isolators to avoid the excessive vibrations. The test engines are directly coupled to a 230 V single phase AC generator of 2.3 kW capacities to absorb maximum power produced by the engine. The engine and generator were directly coupled. The bulb loading arrangement was used for loading the engines.

The engine was first tested on its normal fuel i.e. petrol with original compression ratio i.e. 8. The producer gas was a low calorific value fuel and therefore, requires a high compression ratio. So the compression ratio was changed to 11 and again the engine was tested on petrol. Then, engine was modified for gas operation and modified engine was tested on producer gas.

3.9.2. Engine loading system

An electrical load panel was fabricated for loading the engine. Load panel consist of four 1000watt coil heaters, and electric bulb bank of many denominations like 500watt, 200watt, 100watt, 40watt and 15watt. Engine was connected to the load panel through a MCB and switches. In between engine and load panel a watt meter was connected.

A 2.3kW petrol/kerosene engine based portable generator set was selected for experimental work. An engine experimental test set up was designed for engine testing. The sub systems of the test rig were integrated and the schematic diagram of IC engine experimental test set up is shown below in figure 3.11.



1. Single cylinder 4-stroke petrol engine, 2.3 kW cum portable generator set	4. Exhaust manifold
2. Load panel	5. From Gasifier Unit
3. Gas Analyzer	6. Control valve

Figure 3.11: Schematic diagram of test set up for spark ignition engine

3.9.3. Measurement of power

The engine was started and engine was running for about 15minutes to get stabilized. After that the power rating corresponding to all the operating points were recorded from the watt meter connected in the circuit between generator and load panel. Here the Brake power output of the engine,

3.6

3.9.4. Measurement of exhaust gas temperature

The thermocouples of appropriate range have been installed to capture the temperatures at exhaust manifold, and lubricating oil sump. The thermocouples were inserted into the flow line to a sufficient extent to capture the temperature correctly. The suitable fabrication work was done to accommodate the thermocouples at desired locations. The wires communicating the signals from thermocouples to the digital indicators were connected to the appropriate terminals rigidly. The digital indicators of appropriate range were used with these thermocouples to indicate the temperatures on data display board.

The range and the type of temperature indicators installed on data display board are as follows:

i) Exhaust gas temperature indicator: Range 500^{o}C(J 100 type)
ii) Lubricating oil temperature indicator: Range 100^{o}C(Type PT 100)

These indicators were connected to the sensors firmly with due care taken. The display board was mounted on steel stand at appropriate height so that the readings can be taken comfortably.

3.9.5. Engine emission tests

The exhaust gas composition was measured by using exhaust gas analyzer (AVL DIGAS-4000 model) shown in Figure -3.12.

It measures NO_x, CO_2, CO, HC and O_2 in the exhaust gases. The basic principle for Measurement of NO_x, CO_2, CO, and HC emissions is non-diffractive infrared radiation (NDIR) and electrochemical methods for oxygen measurement. Measurement range and resolution for different gases by the exhaust gas analyzer used are given in table 3.3.

Figure 3.12: AVL Gas Analyzer

Table 3.3: Measurement capabilities of AVL-437 Gas Analyzer

Exhaust Gas components	Measurement Range	Resolution
NO_x	0 – 4000 Vol. ppm	1 vol. ppm
CO	0 – 10 vol. %	0.01 vol. %
CO_2	0 -20 vol. %	0.1 vol. %
HC	0 – 20,000 ppm	1ppm
O_2	0 – 22 vol %	0.01 vol %

3.10. ENGINE TEST PROCEDURE

All above descried sub systems required for measuring the different technical parameters of the engine performance and emission characteristics are integrated with the engine. All the necessary attachments to measure the test parameters were organized. The fuel supply lines were primed and the engine was made ready for starting and data collection. The entire test process was carried out in three phases as described below.

3.10.1. Testing of existing engine with petrol fuel

The unmodified engine was run with petrol fuel under following test matrix. The fuel tank was flushed with petrol and then the tank was filled with petrol fuel. The engine was started and allowed to run for 15-20minutes to get stabilized. Initially the engine was tested on zero load. Then the parameters like watt meter reading, temperatures of 2 points, engine RPM, was recorded. After recording these parameters the exhaust gas emission parameters like HC, NO_x, CO_2, CO were recorded by putting the probe of AVL gas analyzer into the sampling port specially designed for engine exhaust.

After completing all the above data observation work, the load on the engine was increased to 25% by switching on the bulbs of loading system. The engine was allowed again to run for about 10-15minutes to get stabilized. After this time duration entire process described in above procedure was repeated and the technical parameters were carefully recorded. After this, the load on the engine was increased to 50%, 75% and 100% by switching the appropriate lamp combination on the load panel. The engine was run to attain the stable condition. After attaining the stable condition the observations were taken at all above mentioned operating points.

3.10.2. Testing of modified engine with producer gas fuel

Experiments were initiated on the setup only after the gasifier system stabilized i.e. attained steady state operation in terms of generation of consistent quality gas. The typical time scale for attaining steady state of operation from the cold start was 30minutes. During this period the gas was flared in a burner. Once the gas composition was stabilized, the gas was supplied to the engine. The engine was operated for a few minutes at 1500RPM at no-load condition. All the tests on the engine were conducted around a constant speed of 1500±50RPM. The throttling for speed control and air and fuel proportioning was achieved using manually operated valves. Experiments were conducted at CR 11. The entire process was repeated while engine running with producer gas as fuel.

As described in this chapter, during the present work a down draft biomass gasifier was designed fabricated and installed for lantana. Gasifier was equipped with data acquisition system for temperature and pressure measurement. For producer gas analysis a chromatograph was installed. For power generation from the resultant producer gas petrol engine was modified and then, exhaustive experimentation was carried out on the integrated setup. The results of these experiments are discussed in the next chapter in detail.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter deals with the results of the determination of biomass properties, experiments on down draft biomass gasifier and as well as experiments on existing and modified engine for performance and emission characteristics are discussed. The fuel properties were measured by the standard procedures. The role of these properties on performance is briefly discussed. Then, the gasifier performance like composition of producer gas, effect of temperature and equivalence ration on composition and heating value of gas are discussed. Thereafter the engine performance like emission characteristics are evaluated based upon the experiments conducted on existing engine taking commercial petrol as fuel.

4.1 EFFECT OF PHYSICO-MECHANICAL CHARACTERISTICS OF BIOMASS ON GASIFIER DESIGN

The important physico-mechanical properties of lantana were determined by standard methods. The results are shown in Table 4.1. Biomass Gasifier design heavily depends on the biomass fuel properties and also biomass fuel properties are very important in determining satisfactory operating conditions. Biomass fuels occur in a multitude of physical forms. Each biomass fuel form can be expected to have unique problems until proven otherwise. Variation in physical form make it necessary to tailor the shapes of the gasifier, fuel drying equipment, feed systems, and ash removal equipment to each form. Therefore, the resulting gasifier design must be very fuel-specific. The detailed analyses were carried out with the help of literature support and discussed in this section.

Table 4.1: Physico-mechanical properties of Lantana pellets

Physical Property		**Values**
Avg. Length	cm	2.03
Avg. Diameter	cm	1.32
Avg. Volume V	cm^3	2.78
Weight of biomass chip	g	1.85
Density (ρ)	g/ cm^3	0.71
Surface Area (A)	cm^2	5.57
Bulk Density	g/cm^3	0.43
Void fraction F_v		0.67
Angle of Repose θ	Degree	62^o

The physical shapes and sizes of the biomass materials are complex. There is no established method, free from ambiguity, to determine the physical sizes of such geometrically irregular shapes as of biomass materials. In the absence of a suitable method, the sizes are generally expressed in average terms. In the present work lantana wood was cut into small cylindrical pieces of about 2cm length and average diameter of about 1.3cm. The values reported in the table 4.1 were the size fractions of the lantana adopted for the present study.

The value of angle of repose for lantana was 62^o. This value is of significance in the design of storage bin and biomass feed hopper. There are two angles of repose- one is ‘poured angle of repose’ and the other is ‘drained angle of repose’. The poured angle of repose is obtained when a pile of solids is formed and a drained angle of repose is formed when the solids are drained from a bin. In the storage and feeding of biomass materials, the ‘drained angle of repose’ is more important but the difference between the two angles of repose is not appreciable. Since the poured angle of repose is easier to measure, this angle has been measured for all the materials, without vibration of the horizontal support surface. In general, it can be said that the lower the angle of repose is, the freer flowing of the material is attained. As the angle of repose for lantana comes out to be 62degree which is a higher value, the hopper designed for feeding lantana in the gasifier is of the shape of inverted cone. And hence, feeding of lantana chips was very smooth.

The value of surface area reported in table 4.1 is the average value of surface. A sample of lantana chips were taken for observation. The average value of surface area was finally taken for further calculations. Surface area is very important in pyrolysis zone length prediction and hence in design. Equation 3.1 gives the relation between time of pyrolysis (t_p) and the surface area. The lower the surface area more the time is required for pyrolysis in pyrolysis zone and therefore the length of pyrolysis zone increases. This is because heat transfer between hot gases and biomass pieces is through convection. And surface area is an important parameter in convection heat transfer. So, more the surface area of chips, less the time required for pyrolysis. But surface area alone cannot decide the time of pyrolysis. Volume of the biomass chips is also plays important role in time calculation. So as the size of chip increase the surface area increases but the volume of the chip will also increase and the increment of volume is more than the surface area. And also, the volume is directly proportional to pyrolysis time and therefore the net effect is if the size of the chips increases the time of pyrolysis also increases. In the present study the gasifier was designed and tested for a chip size of 1.3cm diameter and 2cm length.

In this section, the results of the determination of physico-chemical and thermo-chemical properties of the lantana has been presented and discussed.

4.2 EFFECT OF PHYSICO CHEMICAL PROPERTIES ON GASIFIER DESIGN

4.2.1 Proximate analysis

The results of the proximate analysis of the lantana are given in table 4.2.

Table 4.2: Proximate Analysis of Lantana

Components	**% By Mass**
Volatile Matter	51.8
Fixed Carbon	37.5
Ash	3.5
Moisture Content	7.2

It is seen from the table that lantana has high volatile matter as compared to coal available in India (20-30%) (103) and therefore are readily amenable to gasification yielding considerably less residue. Compared to coal, less amount of heat is required for the reactions due to high volatile matter content which makes them possible to be gasified at lower temperatures (104) (105). Hence the biomass material i.e. lantana selected for study is potentially useful fuel for gasification. The volatile matter of biomass fuels is important because it characterizes the possibility and to some extent magnitude of tar formation in a thermo chemical conversion system. The volatiles released in the temperature range of 320 to 500^{o}C are termed as ‘Potential Tar Forming Volatiles’ (PTFV) (103). The volatiles burn as gaseous products in the flame but fixed carbon does not produce flame and burns slowly (106).

Ash is an undesirable component of any fuel. It contributes to overall weight and reduces the heating values of the material. More ash implies that more fuel needs to be combusted to heat the inert material, thus lowering the heating value of producer gas (102). The ash content of lantana is at lower side.

4.2.2 Ultimate analysis

The results of the ultimate analysis of the lantana are presented in table 4.3. This analysis is necessary to determine the theoretical air requirement for complete combustion of the lantana and to determine the equivalence ratio. The results indicate that the major elemental constituents of the biomass materials are carbon, hydrogen and oxygen.

It is seen that the lantana has low nitrogen content and thus offer a more environmentally desirable fuel properties. Also as in other biomass materials lantana too have low level of sulphur content.

4.3 EFFECT OF THERMO-CHEMICAL PROPERTIES ON GASIFIER DESIGN

4.3.1 Heating values

The higher and lower heating values for the biomass materials are presented in table as shown in the table 4.4. The lower heating values of the biomass were evaluated by using the formula given below (101).

—— — 4.1

Where

MC = moisture content of fuel on wet basis (decimal)

Y = Latent Heat of vaporization for water, ($MJkg^{-1}$)

H = hydrogen content of the fuel on the weight basis

Table 4.3: Ultimate analysis of lantana (% Dry Basis)

Components	**% By Mass**
Carbon	39.07
Hydrogen	6.03
Nitrogen	0.81
Sulphur	0.27
Oxygen (Remainder)	50.35
Ash	3.47

Table 4.4: Heating values of lantana

Biomass Material	**Lantana**

High Heating Value ($MJkg^{-1}$)	17.5
Low Heating Value ($MJkg^{-1}$)	16.06

Lantana is having energy values more than half of energy content of average coal found in India (≈ 24.00$MJkg^{-1}$) and are, therefore, important potential source of energy.

4.4 BIOMASS GASIFICATION OF LANTANA IN DOWN DRAFT GASIFIER

Gasification experiments were performed on two gasifier designs i.e., 24cm and 18cm reaction chamber diameters. These experiments were carried out at three different equivalence ratios i.e., 0.20, 0.25, and 0.30. The measurement of temperature at various locations in gasifier and sampling of gas at an interval of 15minutes under steady state conditions for compositional analysis was done. Under steady-state conditions, insignificant variations in the values for temperature, gas composition were observed. The values reported in the tables and figures are the average values of the several readings/analyses at different times-on-stream.

4.4.1 Gasifier temperature

In the present work, the uppermost layer of the stratified down draft gasifier is composed of dry lantana chips. This layer of dry lantana chips is term in the study as biomass storage zone and the temp of this zone is reported as T1. In the second layer, moisture present in lantana is dried off but chips remain chemically inactive in this zone also. This zone is termed as drying zone and the temperature of this zone is reported as T2. The third zone biomass reacts with air ad this zone is termed here as flaming pyrolysis zone. The temperature of this zone is reported here as T3. The fourth layer is made up of char from the third layer, reduces the pyrolysis gases. Therefore this zone is termed here as reduction char zone and the temperature of this zone is reported as T4. The fifth layer is constituted by inert char and the temperature of this zone is low and hence no reaction is caused. But this zone is very helpful in absorbing heat or oxygen in the changing conditions. This zone also serves as a buffer char storing zone. The temperature of this zone is reported as T5. The temperatures reported in table 4.5 are the averaged values of three readings recorded at different zones of the gasifier. These temperatures are plotted in figure 4.2 for different equivalence ratios (0.2, 0.26, 0.3, and 0.34). As seen from the table 4.5, the average temperature in the pyrolysis zone varied between 900^{o}C to 1060^{o}C, char reaction zone temperature varies from 550^{o} to 680^{o}C during gasification of lantana depending upon the operating condition, i.e. equivalence ratio. The variation of gasifier temperature reported in the present study is in line with the reported literature.

Pyrolysis and gasification processes are endothermic and therefore, heat is supplied for the process to occur. This heat is supplied by partial combustion of about 6 to 10% of the total biomass. In gasifier operation, the temperature is a function of oxygen fed to the gasifier. Therefore oxygen supply (equivalence ratio) determines the gasification products and the temperature of gasification zone i.e., pyrolysis zone. That is why; the variation of temperature different gasification zone within the gasifier is plotted against equivalence ratio.

It is seen from the figure 4.1 that, in the pyrolysis zone temperature rises rapidly with the increase in oxygen supply i.e., equivalence ratio. The air is supplied in the gasifier in the pyrolysis zone at the biomass and char interface where pyrolysis, gasification and combustion of about 6 to 10% combustion takes place. As the air supply increases the availability of oxygen also increases and therefore the combustion process dominates and results in rapid temperature rise.

As can be seen the temperature in any zone in the gasifier increases as the equivalence ratio is increased. This increase in temperature is due to increase in the rate of exothermic reactions due to larger availability of oxygen per unit mass of the biomass.

At equivalence ratio of about 0.26 the conversion of char into gas is maximum in reactive char zone as suggested from the table 4.6. But as the equivalence ratio increases, along char combustion some gas is also burned and the temperature of this zone rises very rapidly.

In this study the tar levels in the producer gas was not studied. But during experimental runs it was found that the gasifier operations around 1000^{o}C temperatures produce least tars. Wood wool placed for tar removal during gas cleaning shows almost zero tar at these temperatures. While gasifier runs at lower temperatures produced very dirty gas containing more tars.

In the present study it is found that, the temperatures around 900 to 1000^{o}C and equivalence ratio about 0.26 are best combination. Below this temperature some of the char remains unconverted/ unburnt resulting in lower gasifier efficiencies. And above this temperature and equivalence ration part of the combustible gases of producer gas will burnt and results in higher concentration of CO_2 and H_2O and lower calorific vale of resulting gas.

Table 4.5: Temperature measurement in different Zones of Gasifier during Gasification Experiments (reactor dia 18cm)

Equivalence Ratio	**Hopper Temp T1**	**Drying zone Temp T2**	**Pyrolysis Zone Temp T3**	**Reduction Zone Temp T4**	**Bed Temp T5**	**Gas Outlet Temp T6**
0.34	47	305	1006	636	673	193
0.30	70	446	996	653	665	216
0.26	84	420	978	636	652	202
0.2	87	399	963	512	430	150

4.4.2 Gas composition

The average gas composition of the gas from lantana is given in table 4.6. These gas compositions are also plotted in figure 4.2. From the table, it is found that among the fuel gases, CO has the highest concentration (19-22%, on dry basis by volume), followed by hydrogen (17 to 20%, on dry basis by volume), methane (3 to 4%). CO_2 was found vary between (3 to 10%). In producer gas the remaining is nitrogen. As the gasification is carried out in presence of air the dilution of nitrogen is there and it varies from 48 to 52% by volume. CO_2 and N_2 decrease the heating value of resulting producer gas. Fig 4.2 shows the variation in composition of fuel gases and CO_2 with equivalence ratio.

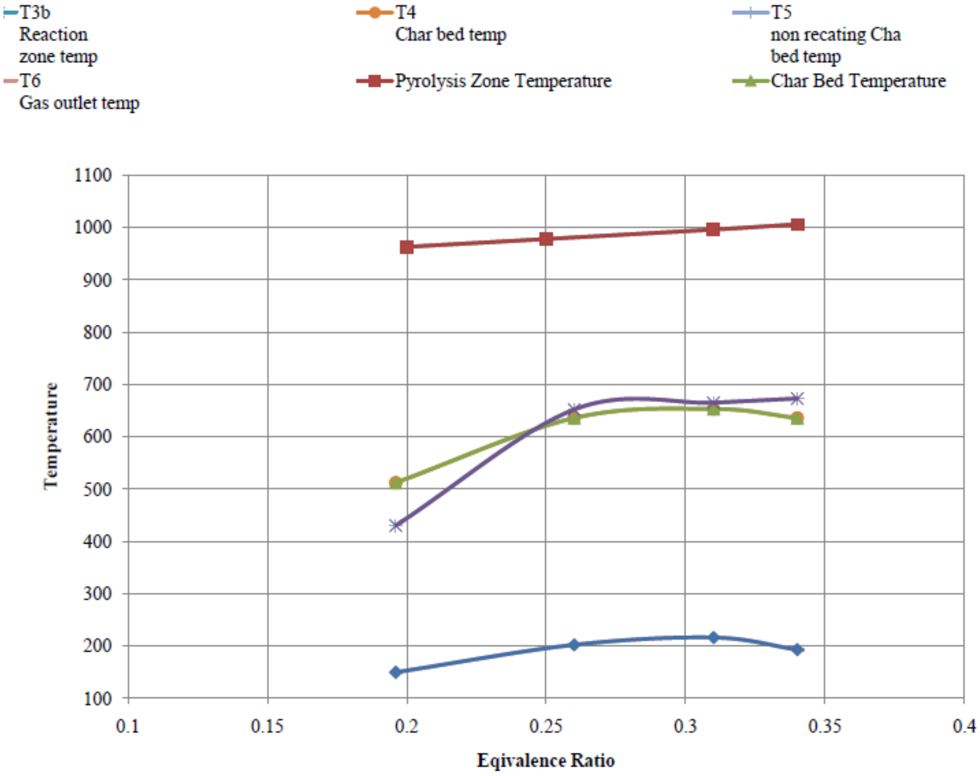


Figure 4.1: Temperature Distribution in different zones of Down Draft Gasifier

It is noted that as the equivalence ratio increased, CO_2 concentration also increased, whereas the concentration of fuel gases, viz, CO, H_2, and CH_4 decreased. The decrease in CO and H_2 concentration are sharp when the equivalence ratio is increased beyond 0.3. Whereas, CO_2 concentration increases sharply as the equivalence ratio go beyond 0.26.Figure 4.3 shows the variation of CO/CO_2 ratio, which is one of the measures of producer gas quality. Higher the CO/CO_2 ratios better the quality of gas for engine application. It is seen from the figure that, as the equivalence ration after 0.25 CO/CO_2 ratio decreases very sharply.

Increase in CO_2 is due to the increase in degree of combustion at higher equivalence ratio. At increased equivalence ratio, oxygen availability to the biomass and char are increased and thus more char and some gas are burned to form CO_2 and H_2O at the expense of CO, H_2, and CH_4. Increase in equivalence ratio also increases nitrogen concentration in the gas.

The experiments of lantana gasification were carried out on two different reaction chambers with different diameters (24 and 18 cm). Results for gas composition for the two reaction chambers are tabulated in table 4.7. Based on CO/CO_2 ratio decision was taken to go for reaction chamber with 18cm diameter.

Zainal et al. (58) compared the best optimal value for the downdraft gasifier with respect to equivalence ratio using furniture wood and wood chips as feedstock. The effect of equivalence ratio for each producer gas component was analyzed with the conclusion of an optimal equivalence ratio of 0.38 for the gasifier performance for that particular feedstock. Both Skoulou et al. (56) and Sheth et al. (51) report an optimal equivalence ratio of 0.2 for downdraft gasification of olive kernels and olive tree cutting and furniture wood. The optimum equivalence ratio varies for different biomass due to the amount of oxygen elementally present in the biomass as well as the ash content. The existing literature shows that equivalence ratio should be around 0.3-0.4 for the successful gasification.

Comparison of results reported in the present study with the results reported in the literature is not possible as no results are reported till date for gasification of lantana in the literature. In the present study 0.26 is found to be the optimum equivalence ratio for lantana wood chips giving best gas composition.

Table 4.6: Average Gas Composition of Producer Gas (Vol% dry basis) (Reactor Diameter 18cm)

Equivalence Ratio	**CO %**	**H_2 %**	**CO_2 %**	**CH_4 %**	**N_2 %**	**CO/CO_2**
0.34	19.24	17.9	9.77	2.87	50.22	2
0.31	21.66	19.76	7.11	3.25	48.21	2.8
0.26	21.79	19.68	5.54	4.02	49	3.8
0.20	21.51	20.41	5.32	2.88	49.07	4.1

Table 4.7: Gas Composition of Producer Gas (vol% dry basis)

Equivalence ratio	**Diameter of Reactor Chamber cm**	**CO %**	**H_2 %**	**CO_2 %**	**CH_4 %**	**N_2 %**	**CO/CO_2**
0.34	18	18.1	7.9	5	1.9	67.2	3.8
	24	17.5	7.7	9.7	1.8	63.3	1.9

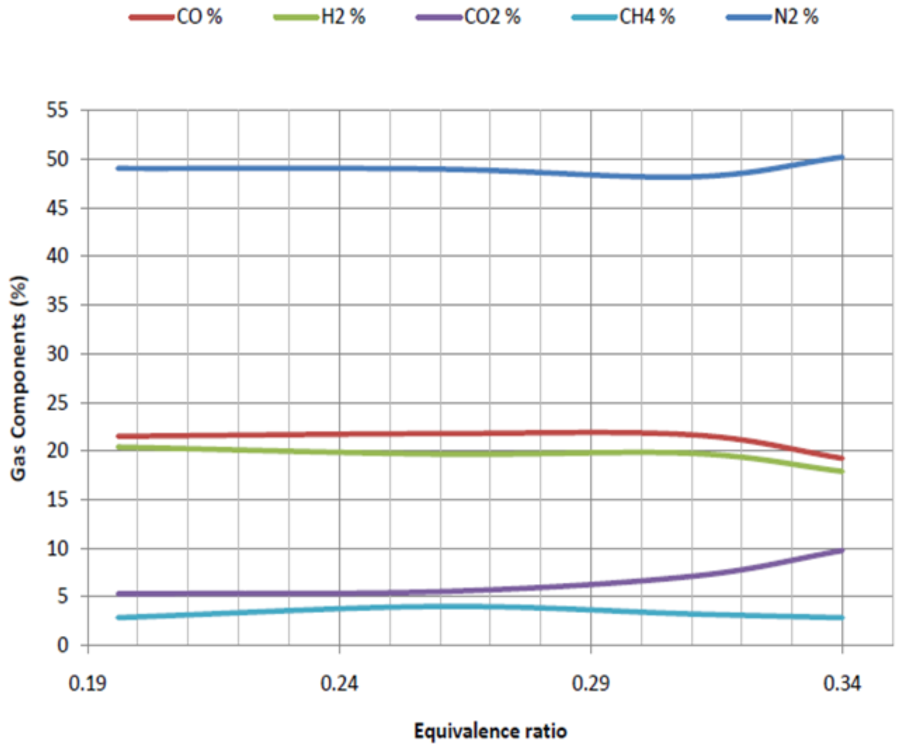


Figure 4.2: Variation of Gas Composition with Equivalence Ratio (Reactor dia 18cm)

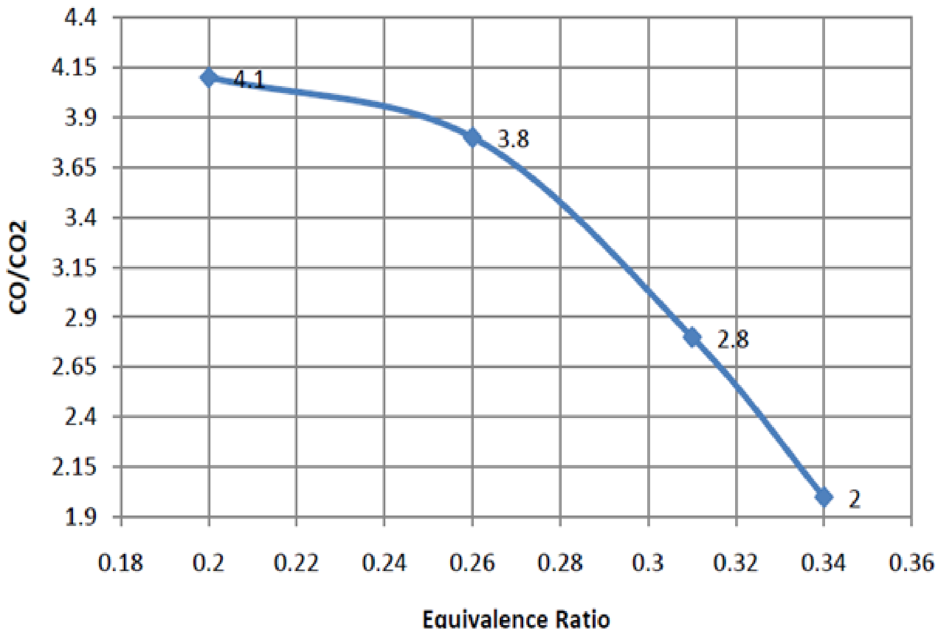


Figure 4.3: Variation of CO/CO_2 ratio with Equivalence Ratio

4.4.3. Gas heating values

Higher and lower heating values of the gas produced from the gasification of lantana is presented in table 4.8 and plotted in figure 4.4. The higher heating value is varying from 5.9 to 7MJ/Nm^3 and lower heating value varies from 5.47 to 6.42MJ/Nm^3.

It is found from the table 4.8 and the figure 4.4 that at higher and lower heating values increases with increase in equivalence ratio between 0.2 and 0.26. On further increasing the equivalence ratio, both heating values decreases sharply.

The higher and lower heating value of producer gas from 24 cm and 18 cm diameter is reported in table 4.9. The effect of reaction chamber diameter is not very significant. But the reactor chamber with 18cm diameter gave better heat value gas. The variation of high heating value and low heating value with temperature for 0.34 equivalence ratio is shown in fig 4.5.

Table 4.8: Higher and lower heating values of producer gas

Equivalence Ratio	**HHV for GAS MJ/Nm^3**	**LHV for GAS MJ/Nm^3**
0.34	5.94	5.47
0.31	6.69	6.16
0.26	6.96	6.42
0.2	6.66	6.14

4.3.4 Gas yield

The gas yields (amount of gas produced per unit mass of biomass) as obtained from experiments have been reported at atmospheric pressure and temperature. The results are presented in table 4.10 and plotted in figure 4.5 for different equivalence ratio. It is observed from the figure that the gas yield increases with increasing equivalence ratio. Variation in gas yield for equivalence ratio 0.2 to 0.3 is not much. But as the equivalence ratio increases beyond 0.3 and reaches o.34 gas yield increases. This increase is not very sharp but significant and this is because, effect of equivalence ratio on the gas yield may be due to the high production of gas in the initial phase of biomass de-volatilization. At higher equivalence ratio de-volatilization of biomass accelerated and results in greater gas yield. At higher temperatures, the tar cracking and steam reforming reactions are favored with the resultant increase in gas yield. The gas yield varied between1.6 to 2.1Nm^3/kg, depending on the operating condition.

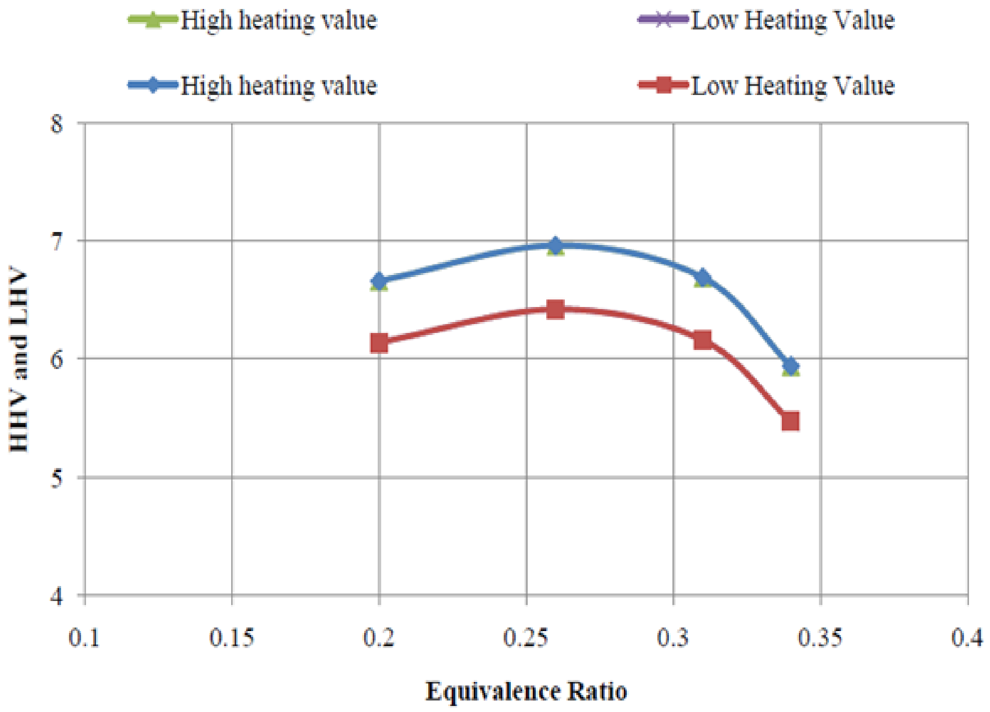


Figure 4.4: Variation of heating values of producer gas with ER

Table 4.9: Effect of reaction chamber diameter on heating values of gas

Equivalence ratio	Diameter of reactor chamber (cm)	HHV for gas (MJ/Nm^3)	LHV for gas (MJ/Nm^3)
0.34	18	4.21	3.97
	24	4.07	3.84

Results experiments conducted on gasifier with 18cm and 24cm reactor chamber diameters are reported in table 4.11. From the table it is found that, the gas yield is more in 18cm diameter reaction chamber than 24cm diameter reaction chamber. This is because with the same equivalence ratio and biomass feed rate the residence time of gases are more in the reaction chamber with bigger diameter than that of smaller. So the gas yield per kg of biomass is less in 24cm diameter reaction chamber.

Table 4.10: Gas production rate, normalized gas production rate, & gas yield

Equivalence ratio	Temp of gas at outlet °C	Density of hot gas	Gas production rate (m^3/s)	Normalized gas production rate (Nm^3/s)	Gas yield Nm^3/kg
0.34	64.57	0.99	0.0018	0.0018	2.1
0.31	73.03	0.97	0.0017	0.0016	1.89
0.26	75.1	0.96	0.0016	0.0015	1.76
0.2	79.3	0.95	0.0015	0.0014	1.674

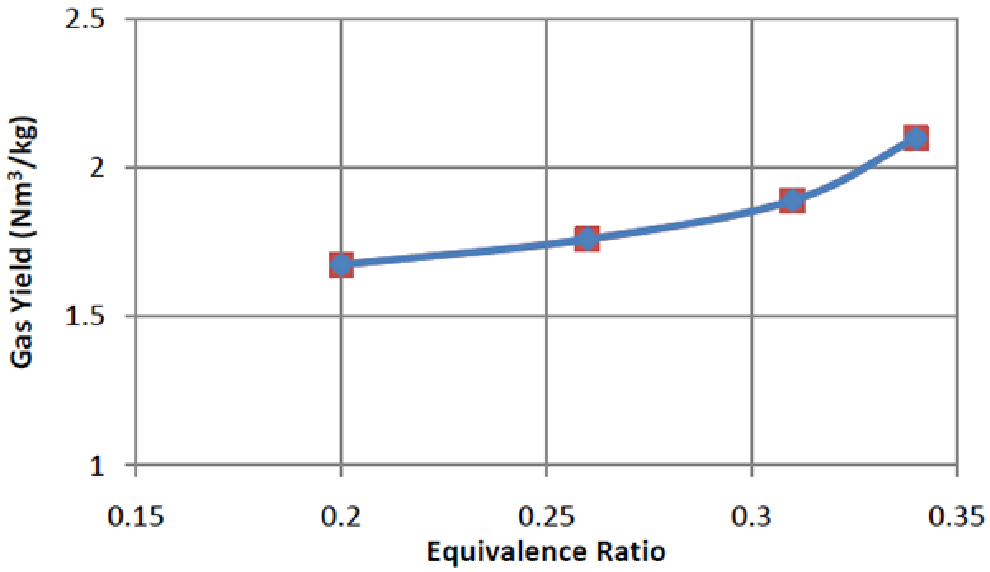


Figure 4.5: Variation of gas yield with equivalence ratio

4.4.5. Carbon conversion efficiency

Carbon conversion is defined as the ratio of carbon in the fuel converted into carbonaceous gas products. Carbon conversion for Lantana is found to depend on equivalence ratio and pyrolysis zone temperature in the gasifier, as seen from the table 4.12 and figure 4.7. With increase in equivalence ratio, the pyrolysis zone temperature increases and hence, increases in carbon conversion efficiency. Carbon conversion efficiency has almost linear relationship with pyrolysis zone temperature.

Table 4.11: Comparative results of producer gas for 18 and 24cm reaction chamber diameter

Equivalence ratio	**Diameter of reactor chamber (cm)**	**Actual density of gas**	**Volume flow rate (m^3/s)**	**Volume flow rate (Nm^3/s)**	**Gas yield (Nm^3/kg)**
0.34	18	1.04	0.002129	0.002131	2.52
	24	1.01	0.002396	0.002326	1.84

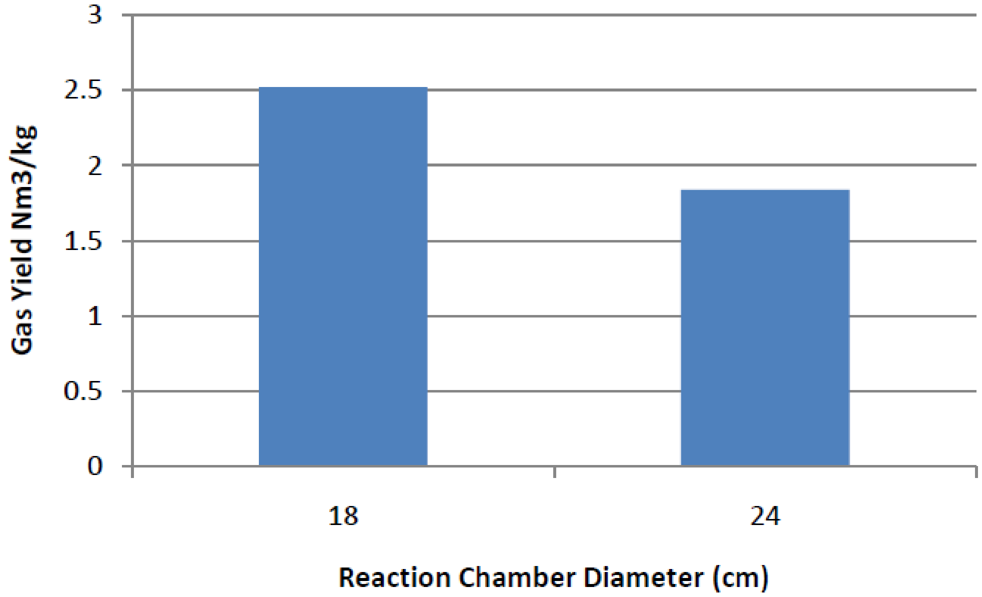


Figure 4.6: Effect of reaction chamber diameter on gas yield

4.4.6 Gasifier thermal efficiency

Table 4.13 and figure 4.9 presents the effect of equivalence ratio on thermal efficiency of the gasifier. From the table it is clear that, on increasing the equivalence ratio the gas yield (production rate) as well as energy output in gas increases. Still the thermal efficiency is found to decrease as the equivalence ratio increases. This is because the higher equivalence ratio supports high combustion rate in oxidation and pyrolysis zone which accompanied by sharp increase in temperature of this zone. Higher combustion rate increases the biomass consumption rate and therefore, the energy in input increases. This increase in energy in input causes the lower thermal efficiency of down draft biomass gasifier.

Table 4.12: Carbon Conversion Efficiency

Equivalence ratio	Pyrolysis zone temp T3 (^oC)	Carbon in gas	Carbon in lantana	Carbon conversion efficiency
0.34	1006	3.8256	1.755	45.88
0.31	996	3.8424	1.56	40.60
0.26	978	3.762	1.365	36.28
0.2	963	3.5652	1.17	32.82

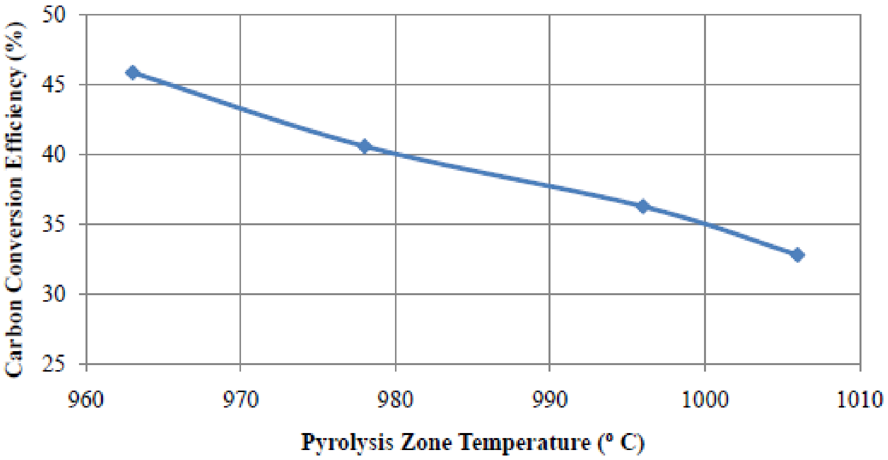


Figure 4.7: Effect of pyrolysis temperature on carbon conversion efficiency

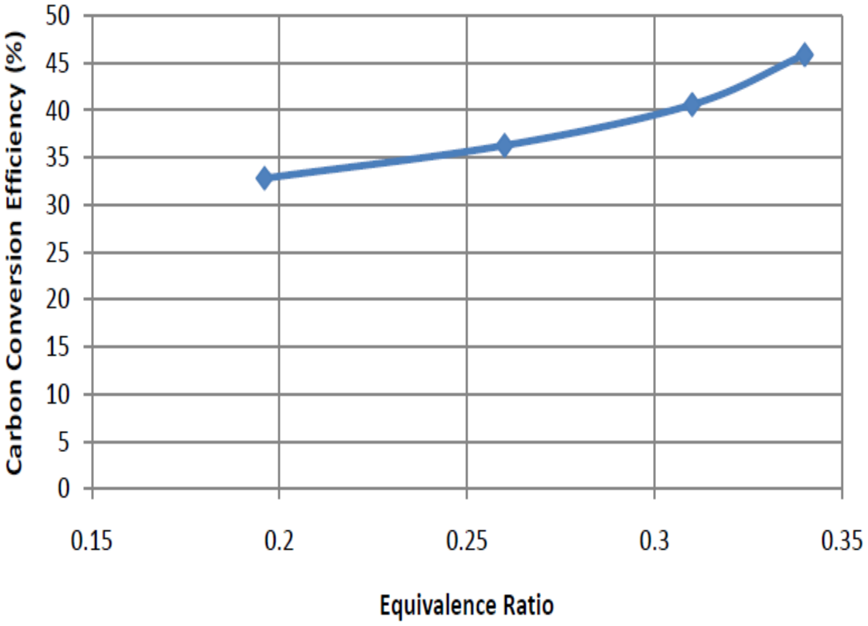


Figure 4.8: Variation of carbon conversion efficiency with equivalence ratio

Table 4.13: Thermal Efficiency of Gasifier with changing equivalence ratio

Equivalence Ratio	Chemical Energy in Gas		Energy in Feed		Thermal Efficiency
	Gas Production Rate (Nm^3/s)	Energy Output MJ/s	Lantana Feed Rate Kg/s	Energy Input MJ/s	
0.34	0.0018	0.0096	0.00125	0.0201	47.61
0.31	0.0017	0.0097	0.001111	0.0178	54.34
0.26	0.0016	0.0094	0.000972	0.0156	60.25
0.2	0.0015	0.0086	0.000833	0.0134	63.99

Table 4.14: Effect of reaction chamber diameter on Thermal Efficiency of Gasifier

Equivalence ratio	Diameter of Reactor Chamber cm	Chemical Energy in Gas MJ/s	Energy in Feed MJ/Sec	Thermal Efficiency
0.34	18	0.0085	0.013	65.4
	24	0.0089	0.02	44.5

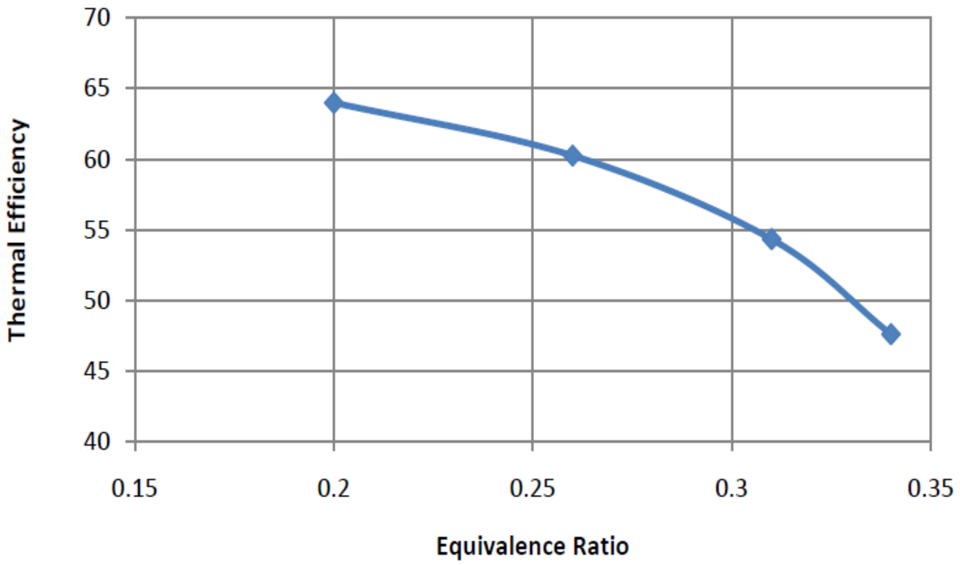


Figure 4.9: Effect of equivalence ratio on Thermal Efficiency of down draft biomass gasifier

4.5 ENGINE PERFORMANCE TESTING AND ANALYSIS

The performance of the engine in terms of power output, exhaust gas temperature and equivalence ratio are discussed in the following sections. The engine operation was found to be satisfactory. Examination of the interior components of the engine like piston and cylinder suggests complete combustion with carbon deposits are at much lower extent compared to petrol fuel operations for comparable duration run.

4.5.1 Variation of relative air/fuel ratio (λ) with brake load

Figure 4.10 shows the correlation between brake load and relative air/fuel ratio (λ) of the engine run on petrol and producer gas. The operating range of relative air/fuel ratio (λ) of engine run on petrol was observed as .75 to 1.09.The operating range of relative air/fuel ratio (λ) of engine when running on producer gas was .97 to 1.32. It is clearly seen from the figure 4.10 that the producer gas supplied with lean mixture (λ >1.0) for the same brake load.

During idling the requirement of fuel is less and therefore a lean mixture (λ >1.0) is required by the engine as suggested by the figure 4.10. As the load increases, the fuel requirement also increases and hence a comparative rich mixture is required.

Figure also suggests a de-rating of 20% of the engine as compared to power developed by engine while running on petrol fuel.

4.5.2 Brake thermal efficiency

The brake thermal efficiency indicates the net output of the engine available on engine shaft for getting utilized to operate machines. The study of brake thermal efficiency of engine fuelled with petrol and producer gas was carried out while engine operating under variable load. Brake thermal efficiency with varying brake load is shown in figure 4.11 and figure 4.12 is showing the brake thermal efficiency with varying relative air/fuel ratio (λ). From the figure 4.11, it is clearly evident that, the engine gives high brake thermal efficiency with petrol as fuel as compared to producer gas as fuel. This is because the calorific value of producer gas is very low approximately 10 times lower than petrol. But the difference in brake thermal efficiency is not much because the energy density of air/fuel mixture of producer gas is comparable with energy density of air/fuel mixture of petrol.

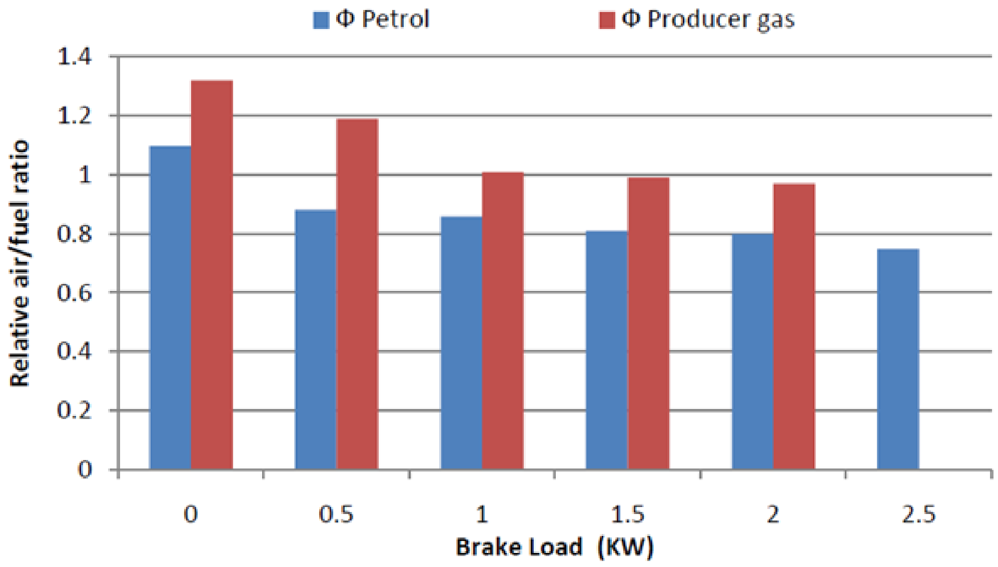


Figure 4.10: Comparison of relative air/fuel ratio (λ) at different brake loads

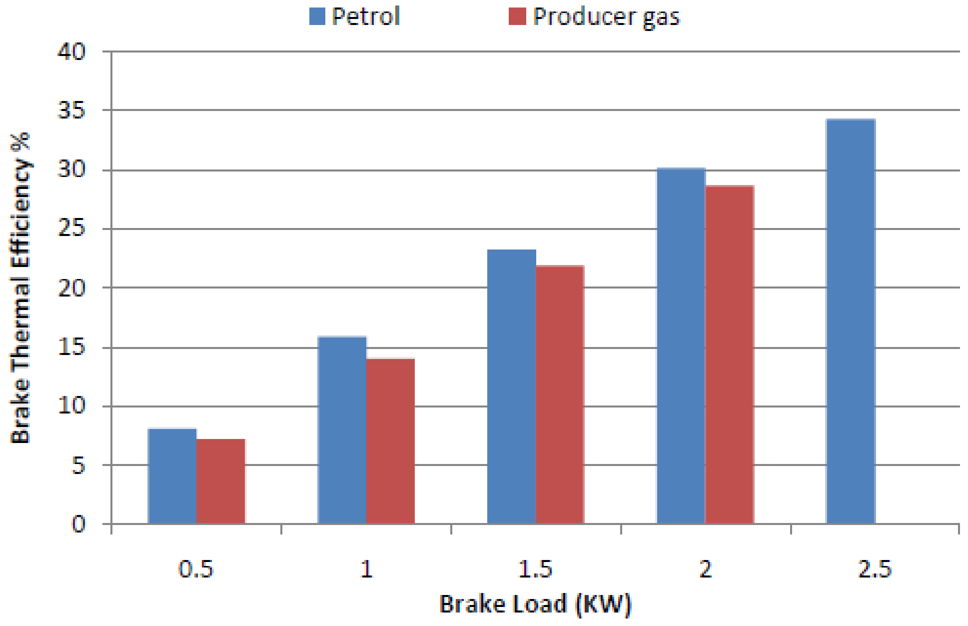


Figure 4.11: Brake thermal efficiency with brake load

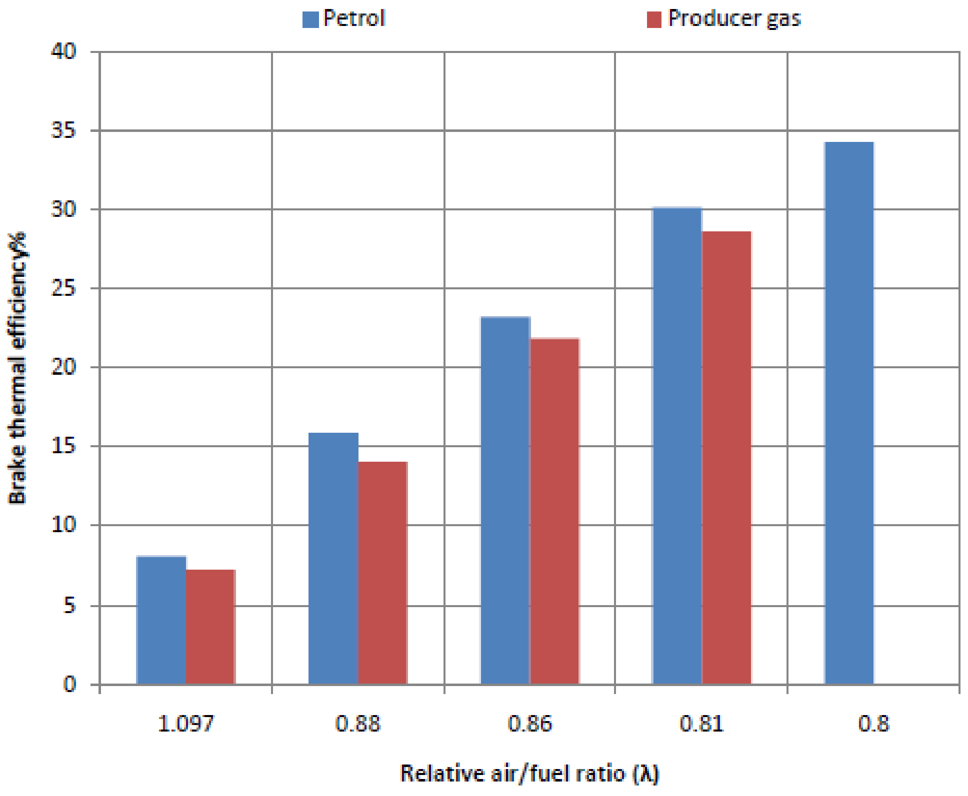


Figure 4.12: Brake thermal efficiency with relative air/fuel ratio (λ)

4.5.3 Exhaust gas temperature

The variation of exhaust gas temperature with relative air/fuel ratio is shown in figure 4.13. It is clearly evident from the figure that as the mixture goes leaner the temperature of exhaust gas decreases. This is same for petrol as well as producer gas. Relatively the range of exhaust gas temperature for the engine while running on petrol is higher. This is because the petrol fuel is high in calorific value.

The variation of exhaust gas temperature with brake load is given in figure 4.14 for petrol, LPG, enriched biogas, and producer gas. The figure 4.14 suggests that the exhaust gas temperature increases as the load increases irrespective of the fuel type. This is due the reason that, with increased load more fuel is required in order to keep the engine speed constant. And also increases the heat release and therefore the exhaust gas temperature.

In case of producer gas the slope of temperature curve is not very steep as is the case with other fuels. This due the reason that, the presence of carbon dioxide in the producer gas composition changes the combustion characteristics of fuel – air mixture. As the load increases, more gas is introduced in the combustion chamber and hence more percentage volume of carbon dioxide in the fuel/ air mixture and therefore the temperature rise is not very sharp.

At higher loads richer mixture (λ <1) is required. As the load increases, air-fuel mixture gets richer and hence the higher temperature of exhaust gas as suggested by the figure 4.13 and 4.14. The exhaust gas temperatures in case of producer gas are in the lower range than petrol and other fuels.

4.6 EMISSION *C*HARACTERISTICS

A fuel is good or bad for IC engine application depends on its emission characteristics. The engine used in the present work is a spark ignition engine with compression ratio 11 and 2.5kW rated power output at this compression ratio. Engine was first tested on petrol for base line data and then three gaseous fuels were tested namely LPG, enriched biogas and producer gas from lantana biomass. The emission results for different fuels are discussed here in subsequent sections.

The engine emission while running with producer gas as fuel is shown in figure 4.15. The figure suggests that the quantity of pollutants in the form of CO, UHC and NO_x are very low over the entire range of air/fuel ratio (λ). The variation of CO, UHC and NO_x with brake load is given in the figure 4.16

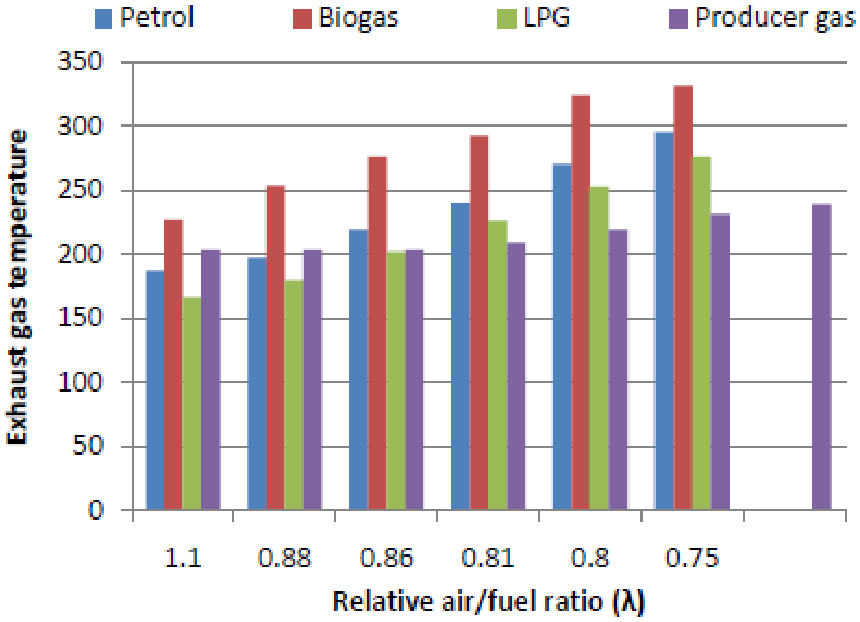


Figure 4.13: Exhaust gas temperatures with relative air/fuel ratio (λ)

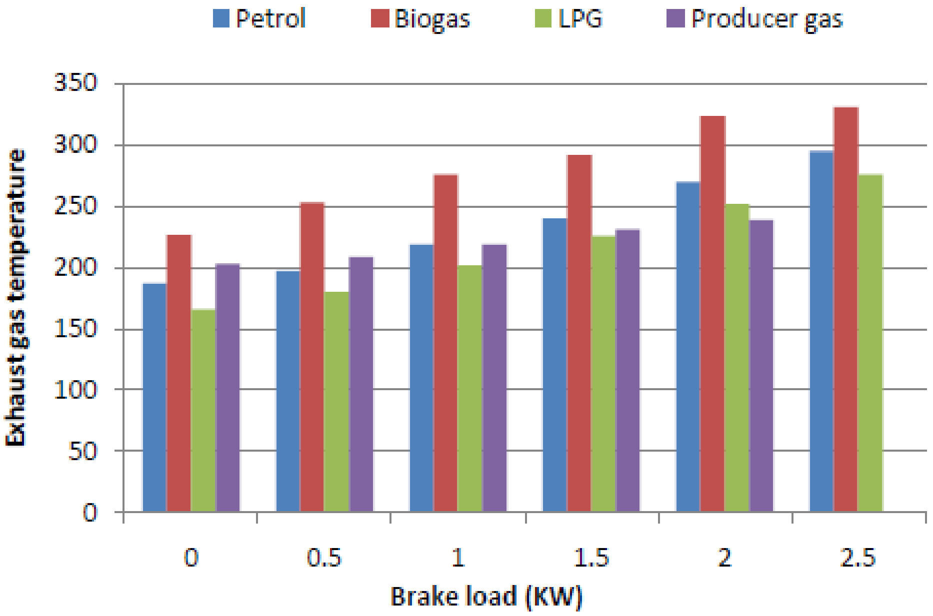


Figure 4.14: Exhaust gas temperatures with brake load

The engine was operated over a wide range of relative air/fuel ratio i.e, 0.7 to 1.02. The combine effect of emissions such as CO, UHC and NO_x were shown in figure. As maximum load the CO concentration decreases and this suggests that at high load engine require lean air/fuel mixture during producer gas operation. The NO_x concentration increases at maximum load. This is because at high load the exhaust gas temperature increases and also the NO_x concentration in emission. While unburned hydrocarbons (UHC) remains at very low level over the entire range of brake load.

4.6.1 Carbon monoxide (CO) emission

The figure 4.17 shows the variation of carbon monoxide (CO) with brake load. The figure suggests that the quantity of CO in exhaust emission is least in case of producer gas over the entire range of brake load. This is due to the complete combustion of the producer gas leaving no CO emission in the exhaust.

Highest CO emissions were observed in case of biogas at higher loads (>1.25KW). Petrol is producing more CO at lower loads but remains higher than that of LPG and producer gas.

At higher loads lean mixture is required and therefore enough air is present during the producer gas operation. Because of this is the reason CO is less in emissions during producer gas operation. While in case of other fuels like petrol, LPG and enriched biogas rich mixture is required at higher loads and because of insufficient oxygen in combustion chamber results in higher CO concentration.

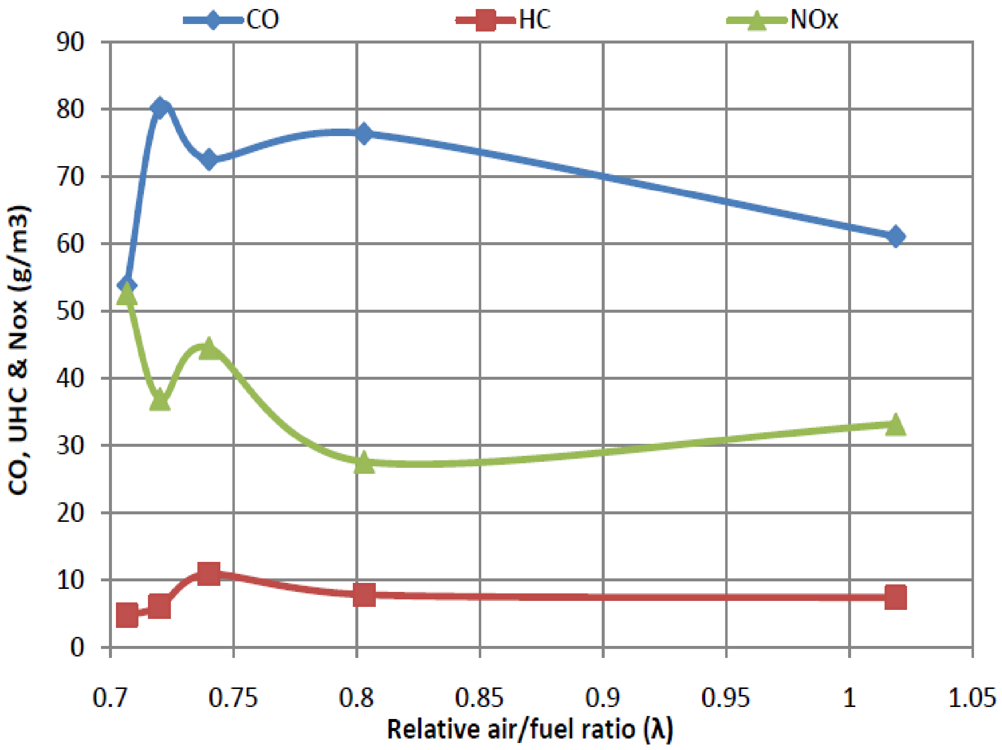


Figure 4.15: Variation of CO, UHC and NOx for producer gas with relative air/fuel ratio (λ)

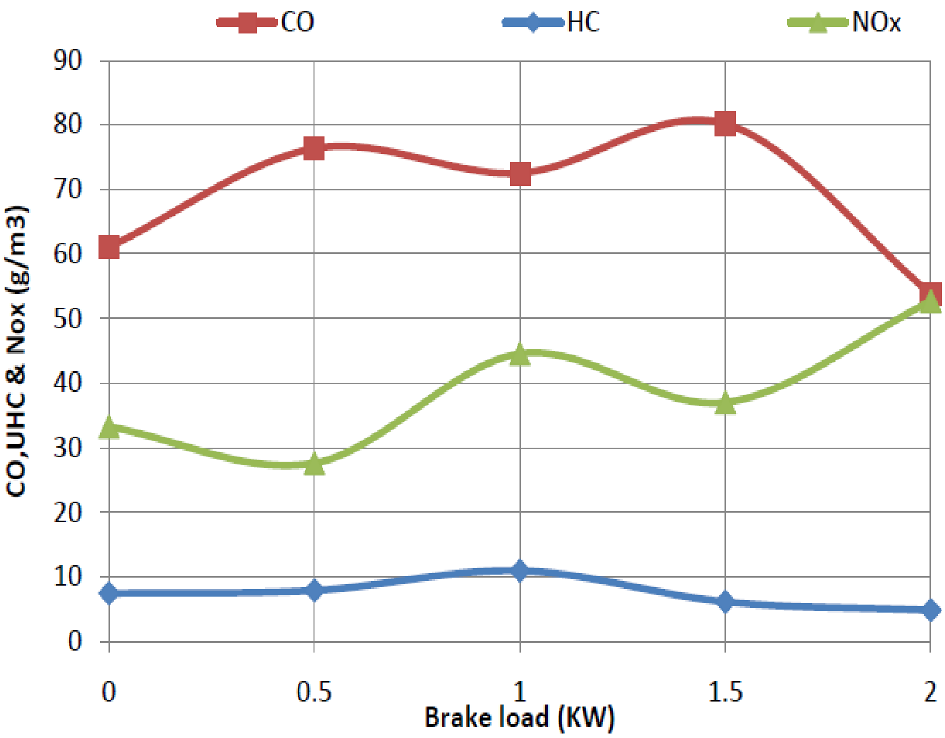


Figure 4.16: Variation of CO, UHC and NO_x for producer gas with Brake load

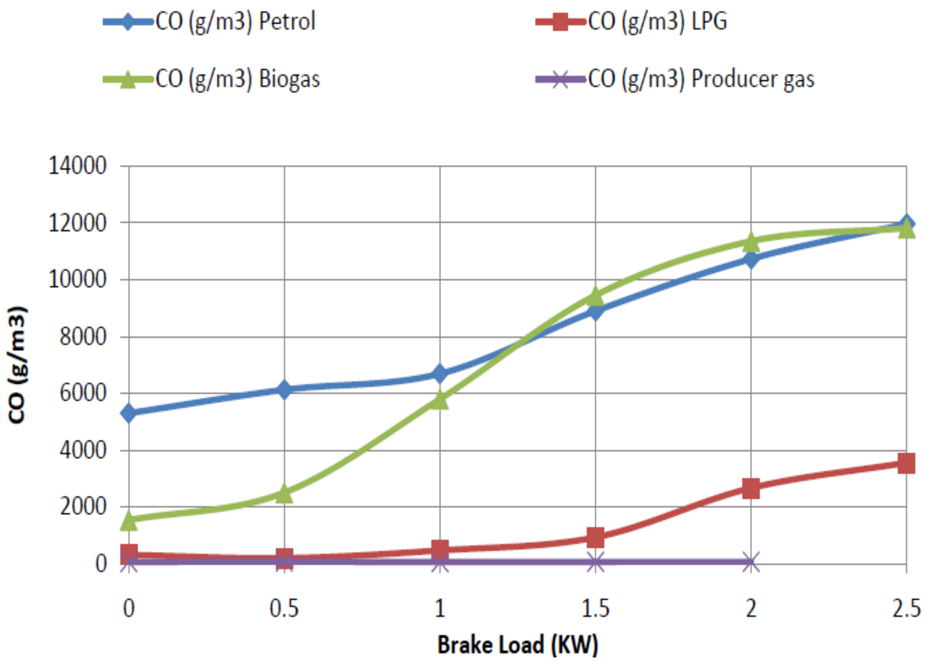


Figure 4.17: CO emission with brake load

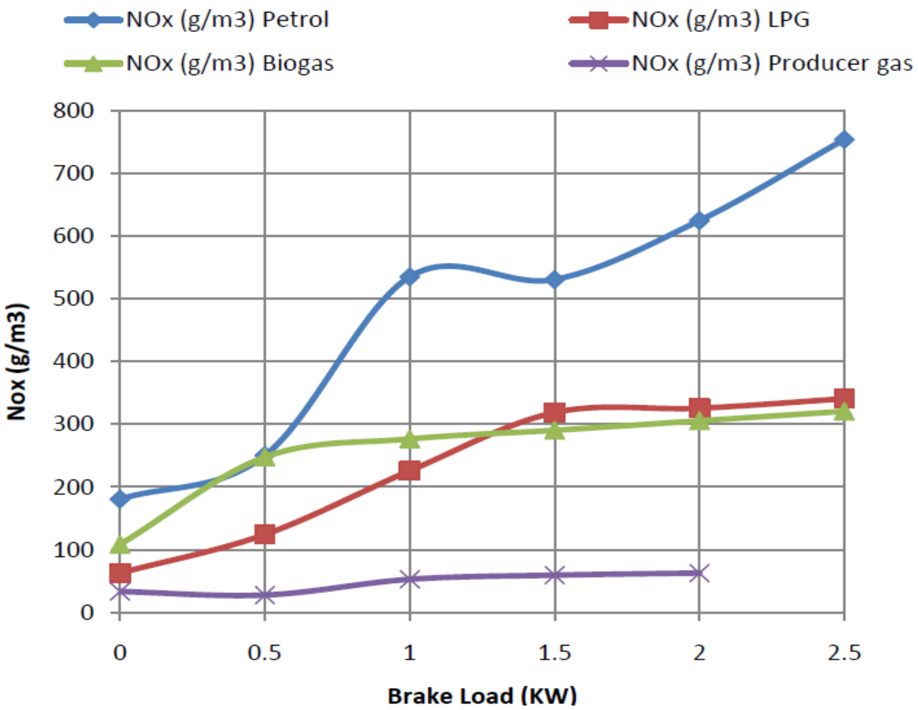


Figure 4.18: NO_x emissions with brake load

4.6.2 Nitrogen oxides (NO_x) emission

In IC engine air is essentially required for combustion of fuel and generates power. In the air nitrogen is almost 77% by weight. Normally nitrogen remains inactive at temperatures below 760°C, but as the temperature go past this limit nitrogen reacts with the oxygen present in the chamber and forms different oxides normally known as NO_x. Figure 4.18 shows the NO_x variation with brake load for different fuels. From the figure it is clearly shown that NO_x levels are very low when engine was with producer gas as compared to other fuels operation. Highest emissions were observed in case of petrol followed by enriched biogas and LPG. This is due to the reason that as the brake loads increases on the engine, the mass flow rate of fuel increases, and therefore the temperature of combustion chamber increases. Higher the combustion chamber temperature, higher the exhaust gas temperature. Figure 4.14 shows that as the brake load increases the exhaust gas temperature increases. This increased temperature supports higher NO_x formation. And therefore NO_x value increase in exhaust emission with brake load. In case of producer gas, with the presence of CO_2 in composition the temperature of combustion chamber remains low even at higher loads and therefore low levels of NO_x in exhaust emission.

4.6.3 Unburned hydro carbon emission

The conditions in the combustion chamber of a spark ignition engine support complete combustion of fuel, which means low level of unburned hydrocarbons in exhaust emission. But exhaust of SI engine fuelled with petrol contains high level of unburned hydrocarbon. This is also suggested by the figure 4.19. Unburned hydrocarbon levels were also high in case of LPG and enriched biogas. But producer gas run engine exhaust shows very low level of unburned hydrocarbons. As the lean mixture is required in case of producer for high loads and therefore sufficient oxygen is available even at higher loads. Hence very low levels of unburned hydrocarbon present in the exhaust emission of producer gas. While engine operation with petrol, enriched biogas and LPG require rich air/fuel mixture and because of that availability of oxygen is less. This is the reason of high unburned hydrocarbon levels in emission exhaust of engine.

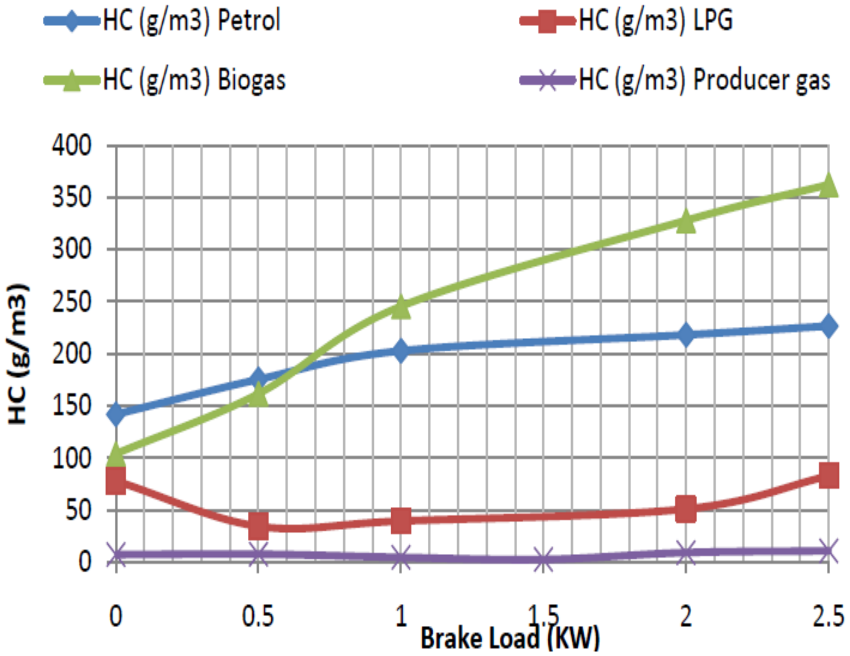


Figure 4.19: HC emissions with brake load

4.6.4 Carbon dioxide emission

Carbon dioxide does not cause any pollution locally but is a green house gas responsible for global warming. Engine operation with fossil fuels like petrol and LPG add additional carbon dioxide in the atmosphere. But engine operation with biomass derived fuels like producer gas and enriched biogas adds no additional carbon dioxide in the atmosphere. This is due to the reason because, natural degradation of biomass also emit carbon dioxide and using fuels derived from biomass also imitate the natural process. Figure 4.20 shows the variation of CO_2 emission from the engine exhaust for petrol, LPG, enriched biogas and producer gas. Trends are showing higher emission of CO_2 in case of LPG followed by petrol and enriched biogas respectively. Minimum CO_2 emissions were observed in case of producer gas because of less number of carbon atoms in the composition. Producer gas mainly consists of carbon monoxide, hydrogen, carbon dioxide, nitrogen and little amount of methane. Carbon monoxide, methane and n carbon dioxide of producer gas cause carbon dioxide in exhaust emission. But these three components only constitute around 30% by volume which is very small as compared to other fuels considered in the present work. Because of this CO_2 emission is very low with producer gas operation.

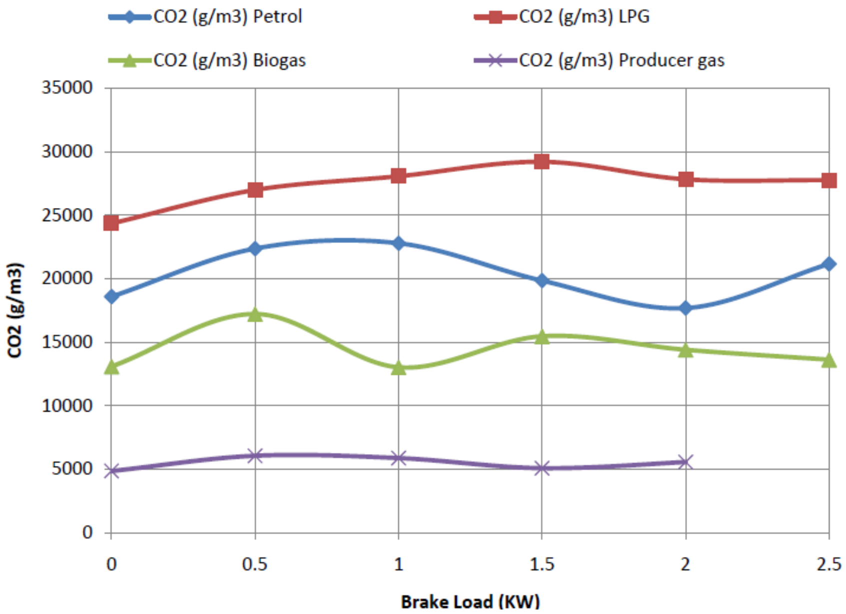


Figure 4.20: CO_2 emissions with brake load

CHAPTER 5

CONCLUSION AND SCOPE OF FUTURE WORK

The present work was carried out with a prime objective of developing a standalone family size power generating unit based on lantana biomass gasification for rural households. The main objective was to establish lantana as a biomass fuel and to develop a small size spark ignition petrol engine for producer gas operation. In literature research on use of lantana for gasification and use of small petrol engines for power generation was not reported. There are always efforts being done in areas of alternate energy sources. In same direction the feasibility of utilization of lantana biomass and small petrol engine was studied in this work.

The possibility of using the lantana in downdraft biomass gasifier and then in spark ignition engine will make the remotely established people using this modular unit self dependent because they can cut the lantana from nearby areas in their neighborhood. The use of such unproductive weed will enhance the vegetation in forest area while improving their economic conditions. The problem of the farmers and also the people using small industry machines running to the market for fossil fuels by paying ever increasing cost will be redressed.

Based upon the analysis of the results obtained from the experiments carried out keeping above objectives in mind, it is found that,

i) The lantana can be used biomass fuel in downdraft biomass gasifiers directly without any chemical or other physical processing like densification.

ii) Small spark ignition petrol engines can be modified and run by producer gas for power generation

To make the engine compatible with this producer gas, two modifications are carried out.

(1) The compression ratio of the engine was changed from 8 to 11.
(2) A gas carburetor was developed for producer gas operation with these objectives in mind
    a. Ability to maintain the required air-to-fuel ratio (1.1 to 1.2:1) with load or throttle Variation
    b. Smooth operation with minimal pressure loss
    c. Shut off the fuel in case of engine tripping or shut-down

The gas carburetor was simple in design and did not have any moving components. It had a separate port for air and fuel, where the individual ports could be modified or tuned to achieve the required air-to-fuel ratio.

Experiments conducted on the newly developed down draft biomass gasification unit and modified spark ignition engine not only suggests that, the modular unit is a competitive alternate for making rural households energy independent but also its thermal efficiency is also high. The energy conversion from biomass to electrical energy is very encouraging for future developments of the technology.

The results of experiments conducted on downdraft biomass gasifier and spark ignition engine suggests that:

i) The gas obtained from the present gasifier was almost tar free as the maximum temperature go beyond 1000°C. Down draft biomass gasifier is known as tar less gasifier. This due to the reason of very high temperature as attained in the present gasifier.
ii) The composition of the gas obtained from the present gasifier is of very high order. The resultant gas contains about 20-22% CO, 18-20% hydrogen, 3-5% CO_2, 1-4% CH_4 and rest was nitrogen.

iii) The higher heating value is varying from 5.9 to 7MJ/Nm^3 and lower heating value varies from 5.47 to 6.42MJ/Nm^3.

iv) The carbon conversion efficiency for the present biomass gasifier was found to be around 35%.

v) The thermal efficiency for the present gasifier was about 60%.

vi) The brake thermal efficiency of spark ignition engine running with producer gas was about 27%.

vii) The engine was de-rated by 20%.

viii) Exhaust emissions were found to be very low and producer gas can be claimed as the cleanest fuel and a better source of energy.

Before concluding this work two three are important to mention here

i) Lantana is a weed, destroying forests and creating food security problems for herbivores. This work is a small step in eradication of lantana and used it in a productive way.

ii) Bio-char, the byproduct of biomass gasifier is very good fertilizer and can be used in fields for better yield.

iii) The rural technology developed in the present work make the rural household's energy independent and also save environment as no additional green house gases are added.

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Research Papers And Publications:

1. Pankaj Kumar Sharma, P.K. Jain,(2006) "Solving Jobshop Layout using Ant colony Optimization". First International and 22nd AIMTDR conference in I.I.T. Roorkee, 21st –23rd Dec. 2006.

2. Jain, P.K. Sharma, P.K., (2005), "**Solving job shop layout problem using ant colony optimization technique**" Systems, Man and Cybernetics, 2005 IEEE International Conference, 10-12 Oct. 2005 Page(s): 288 - 292 Vol. 1.

3. Sudhir Kumar, Pankaj Kumar Sharma, Anirudha, (2004), "Capacity-waste- management in a thermeal power plant: A case study", National Conference in M.S.Ramaiah Institute of Technology, Bangalore (NATCON-ME-2004).