STUDY OF PERFORMANCE PARAMETERS OF A DUAL FUEL ENGINE WITH COMBUSTION OF BIOMASS FUEL FED TO A DOWNDRAFT GASIFIER

A Dissertation Submitted

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in

Thermal Engineering

Submitted by

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JUNE, 2018

DECLARATION

I, **Chandra Bhushan Tripathi** hereby certify that the work which is being presented in this thesis, entitled **"Study of performance parameters of a dual fuel engine with combustion of biomass fuel fed to a downdraft gasifier"** in fulfillment of the requirements for the award of the Degree of Master of Engineering in Thermal Engineering submitted to the Mechanical Engineering Department, TIET, Patiala is an authentic record of my own work under the supervision of **Dr. S.K. Mohapatra**, Senior Professor, Mechanical Engineering Department, TIET Patiala.

The matter presented in this report has not been submitted anywhere for the award of any other degree by this or any other University/Institute.

Chandra Bhushan

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

Dr. S. K. Mohapatra
Supervisor

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Chandra Bhushan

(CHANDRA BHUSHAN TRIPATHI)

ABSTRACT

Present energy use is largely dependent on fossil fuels which makes future sustainable development very difficult. There are drastic changes in the composition and behaviors of our atmosphere due to the rapid release of polluting combustion products from fossil fuels. As the demand of energy is growing rapidly, emission of carbon dioxide and other pollutants from industries can be expected to increase unless other alternative are made available.

Among the energy sources that can substitute fossil fuels, biomass fuels appear as the option with the highest general worldwide potential. The traditional method of direct combustion of biomass is now replaced by the modern methods of processing of the biomass to more compatible and efficient forms followed by their combustion in various combustion chambers. Modern techniques such as pyrolysis, gasification, fermentation, anaerobic digestion and esterification are much more efficient as compared to the direct combustion process. Biomass is generated in various forms such as agricultural residue, forest waste, sewage sludge, herb residue, etc.

Partial combustion of biomass in the gasifiers generated producer gas that can be used for heating purposes and as supplementary or sole fuel in internal combustion engine. A brief introduction to the basic gasifier system and characteristics of producer gas being produced is presented in this report. This report lays emphasis on the proper and efficient use of producer gas in a dual fuel engine along with blends of diesel. Biomass used is the fruit of plant "**Pterospermum Acerifolium"** commonly known as "**Kanak Champa".** The performance and emission parameters of the dual fuel engine are compared with that of diesel engine at different load conditions.

The system is experimentally optimized with respect to maximum diesel saving in dual fuel mode operation and 50% diesel consumption reduced in dual fuel when producer gas is used with diesel in comparison to diesel only. NO_x level is reduced to 67.8% in dual fuel mode at higher load conditions and at lower load it is reduced by 20%. In the dual fuel mode as compared to diesel fuel mode of running. Slight increase in noise emission of 3.2 dB is observed. Some research papers related to the study of production of producer gas are also presented in this report. Problems and limitations related to the available literature are listed in this report. Some solutions are also suggested at the end of this report.

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NOMENCLATURE

ASTM	American Society for Testing and Material
BMEP	Brake Mean Effective Pressure
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DI	Diesel Injection
EGT	Exhaust Gas Temperature
GC	Gas Chromatography
H_2	Hydrogen
HP	Horse Power
IC	Internal Combustion
kW	Kilo Watt
LPG	Liquid Petroleum Gas
NO_x	Oxides of Nitrogen
O_2	Oxygen
SO_2	Sulphur dioxide

Units

kJ/kg	Kilojoule per Kilogram
kJ/kWhr	Kilojoule per Kilowatt hour
kPa	Kilopascal
MJ/kg	Mega joule per Kilogram
Mpa	Megapascal
ppm	Parts per Milloin
Vol	Volume

CHAPTER 1

INTRODUCTION

Human life is highly dependent on energy sources and all the environmental activities done by humans or nature is because of energy flow from one form to another. We are growing fast, our demands are increasing day by day and so is our requirement of energy. After generation of electric power sources, our dependency on manual and animal labor decreased, but we need to develop new and alternative sources of power generation to fulfill our demands and develop better infrastructure to overcome future challenges.

1.1 Energy Trend in India

India is a developing nation and demand of energy is increasing continuously. To fulfill this high demand of energy, high dependency on the imported fuel from the other countries and the rise in the petroleum fuel prices affects economic conditions adversely. India's energy generation is mainly dependent on coal and hydro. In the year 2017, 67% of total power generation were from coal and other thermal power plants (219450MW), 13% of hydropower plants, 18% by renewable energy sources and 2% of nuclear power plants.

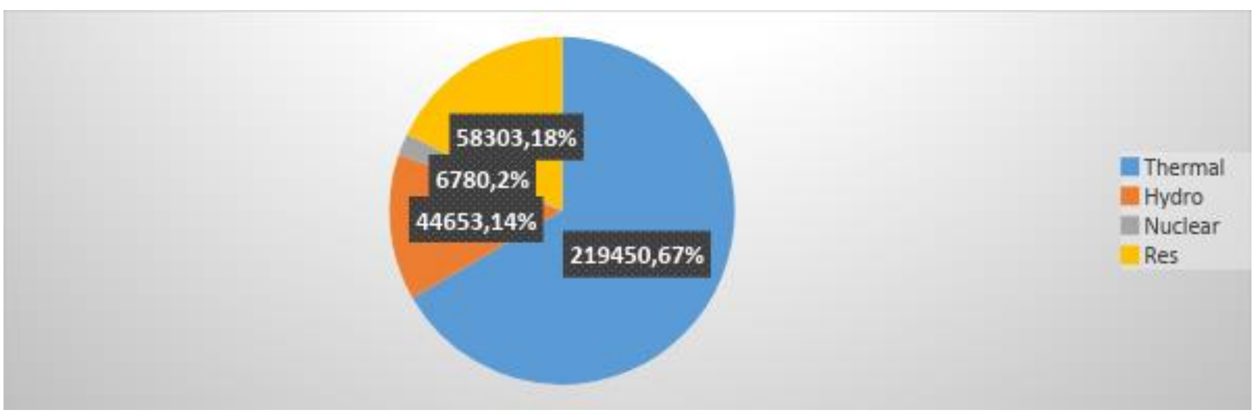

Fig 1.1: Sector-wise energy consumption in India [1]

India is a very high energy consuming country and although we are importing so much fuel from other countries, we are still unable to match our demands of energy. The data are shown in table 1.1. We can see that demand in 2012-2017 is 318413 MW and our installed capacity is around 305554 MW. So, shortage of energy is around 12859 MW. To overcome this shortage of energy, we need to develop some other sources of energy. Very high use of the conventional fuels causes environment issues as well as in future conventional fuels are going to deplete. So, these issues drew the attention of the world's scientists towards the alternative sources of fuels.

Table 1.1: Energy planning as per five year plans [1, 2]

5 Years Plan	Demand (MW)	Installed Capacity (MW)	Shortage (MW)
1980-85	52,000	47,000	5000
1985-90	75,000	65,000	10,000
1990-92,92-97	1,05,000	85,000	20,000
1997-2002	1,32,000	1,05,045	26,955
2002-2007	1,46,000	1,32,329	13,671
2007-2012	2,12,200	1,99,877	12,323
2012-2017	3,18,413	3,05,554	12,859

Apart from the shortage of conventional fuel, the environment pollution caused by it also creates a great obligation for us to develop some other environment-friendly source of energy because very high use of the fossil fuel is damaging our environment and level of GHG is increasing at the very high rate. In upcoming years, this may cause major problems. Renewable energy sources are the solution of these problems and High Renewable energy potential is available in India specially in Punjab in the form of solar and biomass (shown in table 1.2). As of March 2015, installed capacity of renewable energy in Punjab is around 200 MW in solar, 63MW in biomass power, 135 MW in small hydro projects and cogeneration power is around 410MW. Punjab has set an objective of raising the percentage of renewable energy in the total energy requirement to 15% by 2022.

Table 1.2: Renewable Energy Potential in Punjab [3, 4, 5]

Energy Sources	Country Potential (MW)	State Potential (MW)	State Exploited Potential (MW)
Solar	100000	2810	200
Small Hydro	5000	441	157.4

Biomass	19500	2700	63
Cogeneration	3500	500	362.59
Waste to Energy	3000	45	1
Wind Energy	45000	NA	NA

Solar energy requires high installation cost and large area. Same is required for the wind power plants. Power generation hours are very limited in solar and are highly dependent on weather. Wind power plants are very successful in small areas where high speed of wind is available (although sometimes medium wind speed areas too). We face the same requirements for the oceans also. Limited area is covered in these types of energy power plants. Energy exploited potential is less in biomass so if we require additional source of energy, biomass is the best option. Biomass gasification is very economical and environment-friendly method of energy generation because its thermochemical conversion efficiencies lie from 70% to 90%, which is highest among various other alternatives and has high flexibility in terms of various biomass material. Therefore, energy scenario is highly in the favor of biomass.

1.2 Biomass Potential

To organize biomass waste material, biomass can be utilized for the power generation. If biomass is not utilized properly it would create ecological hazards. India is an agriculture based country so around 620 million tonnes of agricultural residue produces per year. Apart from agricultural residue biomass available in the form of carpentry waste, sugarcane bagasse etc.

In India, Punjab has the second highest percentage of biomass among all the states. Only Rajasthan has more biomass potential than Punjab. State wise biomass potential is shown in table 1.3. Availability of biomass is not an issue in India. We are just unable to utilize our biomass resources. Biomass potential and its exploitation percentage is shown in table 1.4. If we neglect the contribution of Maharashtra and Uttar Pradesh in biomass exploitation then exploitation percentage comes down to 3.4%.

Total biomass potential in India is 17981 MW and the installed capacity of grid interactive Biomass power in the country is 4,123 MW.

Table 1.3: Biomass power potential as assessed by MNRE [1]

S. No.	State	Potential estimated by MNRE (MW)
1	Andhra Pradesh	150.20
2	Arunachal Pradesh	Not assessed
3	Assam	165.50
4	Bihar	530.30
5	Chhattisgarh	220.90
6	Gujarat	1014.10
7	Haryana	1261
8	Himachal Pradesh	128
9	Jammu & Kashmir	31.80
10	Jharkhand	66.80
11	Karnataka	843.40
12	Kerala	762.30
13	Madhya Pradesh	1065.40
14	Maharashtra	1585
15	Meghalaya	1.10
16	Mizoram	Not assessed
17	Nagaland	3.10
18	Odisha	147.30
19	Punjab	2674.60
20	Rajasthan	4595
21	Tamil Nadu	863.70
22	Uttar Pradesh	1477.90
23	Uttarakhand	6.60
24	West Bengal	368.30

Table 1.4: Estimated potential and achievement for the States endowed with 76 per cent of country's Biomass potential. [2]

S. No.	State	Potential (MW)	Achievement (MW)	Exploitation (in *percent*)
1	Rajasthan	4595	101.30	2
2	Punjab	2674.60	140.50	5
3	Maharashtra	1585	940.40	59
4	Uttar Pradesh	1477.90	776.50	53
5	Haryana	1261	45.30	4
6	Madhya Pradesh	1065.40	26.00	2
7	Gujarat	1014.10	43.90	4
Total		**13673**	**2073.90**	**15**

1.3 Biomass

All raw material present on earth is biomass, which is volatile in character, especially living things, plants and water environment. Biomass includes crop residue, remains of harvested agricultural products, leaves, animal dung. When we burn biomass, carbon dioxide is released which is further absorbed by the biomass. It means that there is no contribution of biomass in worldwide warming. Quantity of sulphur in biomass is insignificant, so the contribution of biomass in acid rain is also minimal. By the chemical analysis of woody biomass, we found that it contains the following components. [7, 8, 9, 10]

1.3.1 Cellulose

Cellulose gives strength to the biomass because of its fiber structure. Percentage of cellulose in woody biomass is around 45-50% by weight part. Because of high natural polymerization of glucose molecules, Cellulose molecules are high weight molecules. In a single cellulose molecule 5000-10000 units of glucose molecules are present. When biomass is heated rapidly, explosion like sound come because the thin microfilms of cellulose are twisted around each other and they form a tubular structure. These tubes contain moisture. Breakdown temperature of cellulose is 240-360°C. At this temperature, most of the cellulose is converted into volatile compounds and some part of it is converted into tars, and chars. [11]

1.3.2 Hemicellulose

Hemicellulose (also known as polyose) is also a very important component of biomass. The weight of hemicellulose in dry biomass is around 25-30%. The weight of hemicellulose is not that much as compared to cellulose and it contains only around 150 units of monomers. Because of its branch-like structure, the temperature of the breakdown of hemicellulose is low as compared to cellulose. It is around 200-260°C. Volatile yield is high as compared to cellulose and volatile components are high as compared to tars and chars. [12]

1.3.3 Lignin

It is also very important part of biomass and the weight of lignin in dry biomass is around 16-33%. Hard biomass materials contain a low amount of lignin as compared to soft biomass. Nature of lignin is amorphous, so it can adopt any structure. The exact structure of lignin is not known, but mostly it is present in the three-dimensional chain and highly branched structure. Lignin present in nature is of two types: guaiacyl lignin and Guaiacyl syringyl lignin. First one is mainly present in high lignin, which is formed on polymerization of coniferyl phenylpropane units. The other one is formed as a copolymer of coniferyl and sinapyl phenylpropane. Breakdown temperature of lignin is around 280-500°C and after breaking, it converts mainly into chars and phenols. [13]

1.3.4 Inorganic minerals

The presence of these minerals in biomass is very low. The contribution of these minerals in volatile yield is zero. They form very less amount of ash in the end. In biomass, generally minerals like potassium, sodium, phosphorus, calcium and magnesium are found [14]

1.3.5 Organic components

The organic components are found in traces in woody biomass materials. These components contain sugars, fats, proteins, waxes, gums, resins, vegetable oil, etc. These components prevent the plants from the insects and give immunity. [15]

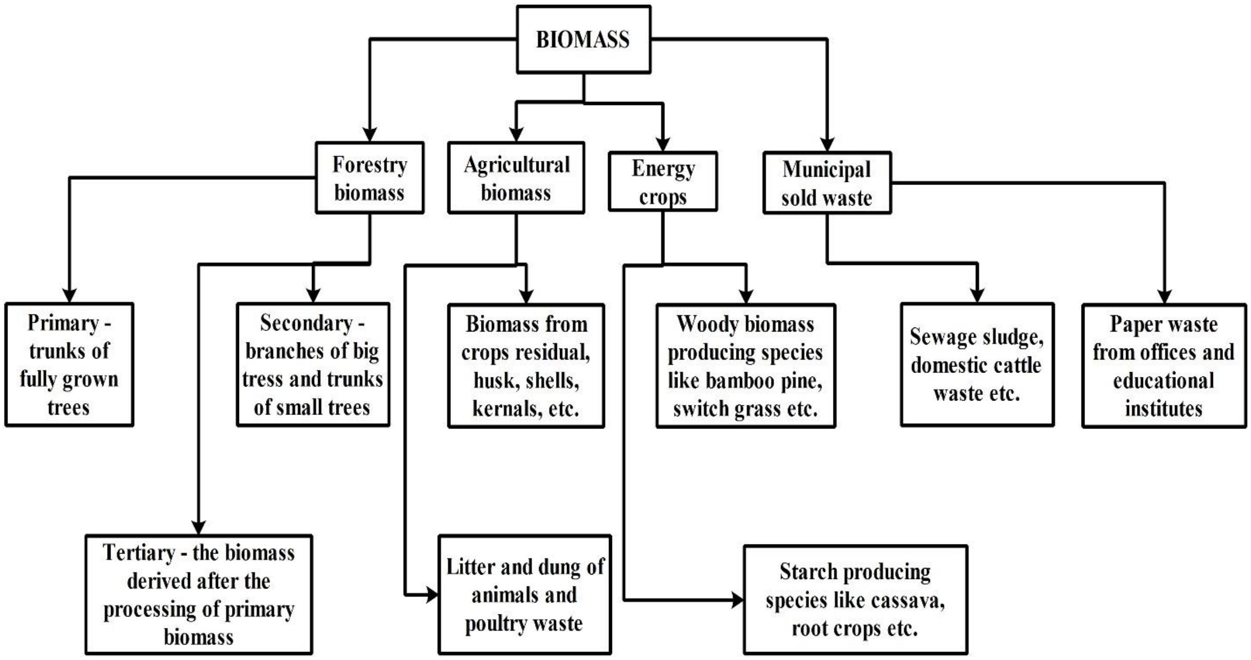

Fig 1.2: Classification of biomass [78]

Biomass is the renewable source and. By the availability of the biomass sources, they can be classified in following types.

- Forestry biomass
- Agricultural biomass
- Energy crops
- Municipal solid waste [16]

1.4 Biomass utilization technology

Useful energy from biomass can be extracted by adopting following technology-

- Direct combustion
- Anaerobic digestion
- Ethanol production
- Biomass gasification

1.4.1 Direct Combustion

Combustion is the basic practice of the converting of biomass into useful energy. From the time when human developed civilization, direct biomass burning has been fulfilling the human need for energy. Timber, agricultural waste, and community solid waste are the major feedstock utilized in direct combustion mechanism.

Products produced in this form of combustion are heat and energy in a very complex process. If the design of the combustor is proper then it can burn every types of biomass. In this process, volatile hydrocarbons (C_xH_y) are burnt in a hot combustion zone and by the different combustion mechanism biomass fuels are converted into different forms of energy which can be useful in industrial as well as commercial areas. It starts from a furnace where biomass is converted into heat energy and this heat energy, is released to heat exchanger in the form of hot gas. In heat exchange, these hot gases give energy to the process medium and convert from hot air, hot water and steam to thermal energy.

The direct combustion system is mainly of two types: fluidized bed system and fixed bed systems. In fluidized bed system, biomass are burned into a hotbed of noncombustible, granular material like sand and limestone. In this system, air is supplied from under the sand and creates turbulence. It looks like the boiling of liquid and by this, heat transfer rate is increased which allows an operating temperature below 970°C. In this, NO_x emission is reduced. The design of the fluidized bed systems is of two types: circulating fluidized bed and bubbling fluidized bed and it depends on the velocity of air. In fixed bed system biomass, is supplied by the various ways to the furnace like manual or automatic feeder. In the combustion chamber, the fuel burns and air enter from the bottom of the chamber. In stationary grate design, the ash falls into a pit and in travelling grate design, ash drops into a hopper.

Fluidized bed system is better than the fixed bed system because it has the flexibility to change biomass shape and size and in this type of system, moisture content of biomass is permissible up to 60%. It can handle high ash biomass and agricultural biomass (>50%). Construction of this type of system is compact so it has high heat exchange and reaction rate. NO_x emission is very low and it has low excess heat factor (1.2-1.4) and because of this, low heat loss from flue gas.

There are two types of cycle possible for the combining power generation system. In the first type of cycle, steam is first sent to the turbine, which produces the electrical energy. After that, the steam is sent to the process work like heating or cooling depends on the requirement. The name of this cycle is topping cycle. This is the more common cycle. In the second type of cycle, steam is first sent to the process work and after that, it is sent to the steam turbine to generate electric power. This cycle is called bottoming cycle.

1.4.2 Anaerobic Digestion- Biogas

Biogas was discovered in 1776 by Alessandro Volta and in early 1800, Humphrey Davy pronounced the presence of methane in the Farmyard Manure which is a combustible gas.

In the anaerobic digestion a gas is produced named as biogas. Methane and carbon dioxide are main components of biogas. Biogas is produced by many organic wastes like animal dung (solid as well as liquid), agricultural residue waste, waste from the agricultural product industry, wastewater, landfills and the organic component of town waste.

In biogas around 65% is methane and around 30% is carbon dioxide. Another component in biogas is H_2S, N_2, H_2, methyl mercaptan and O_2. The amount of biogas produced depends on the amount of organic waste fed to the digester and the rate of decomposition is influenced by the temperature variation.

In a biogas generation, several different types of bacteria work in different stages and they break down complex organic waste by which biogas is produced. To produce controlled biogas, a chamber, which is known as the digester is required. After the generation of biogas, drying and filtering process has to be done and after that, biogas can be used in IC engines and heating.

1.4.3 Ethanol Production

By fermentation process, starch content of biomass can be converted into alcohol (ethanol). In this process, sugar is converted into ethyl alcohol in the presence of air so, this is the process of aerobic digestion. Ethanol products use specific enzymes to convert starch crops such as maize, wheat, and barley into fermentable sugar. Technology which is used to convert cellulose to alcohol through fermentation is called hydrolysis. In recent times, ethyl alcohol is also produced from a variety of sugars by fermentation. Ammonia is used to reduce acidity. The liquid is distilled when alcohol has accumulated around 8-10%. One liter of alcohol is produced from 2.5 liters of fractionated and rectified cane molasses.

Transportation and storage of ethanol are much easier than that of the hydrogen. Most of the bio-ethanol is produced in Latin America especially in Brazil. Now a days, the value of the bio-ethanol is increasing. So, more policies are being introduced in support of development and implementation of ethanol.

1.4.4 Biomass Gasification

Biomass gasification is a very old technique of extracting useful energy from biomass. In biomass gasification, combustible gas is produced from the carbon-containing material. The first use of gasification started in 1812, with a gas company in London in which they burned the feedstock in the absence of oxygen. Because of this thermal decomposition of fuel took place and they formed volatile gases and solid carbon. This process is called dry distillation or pyrolysis. First time producer gas was used in IC engine in 1881 but after that use of producer gas decreased because of the fossil fuel. Then in the 2nd world war, producer gas was reintroduced because of unavailability of petroleum at that time. After the war, gasifier systems were taken over by the liquid fossil fuels. Now when the fossil fuels are going to deplete, use of gasification has started for the third time in history. The feedstock which can be used for biomass gasification are-

- Wood
- Agricultural waste

- Municipal solid waste

Gasification is a thermo-chemical partial oxidation process in which carbon-rich material present in the organic substance is converted into combustible gases, i.e. CO, CH_4, H_2, N_2, and CO_2. By-products are liquids, tars, charcoal, ash, and slag. Biomass are burned in a closed chamber which has limited supply of oxygen, sometimes also steam and because of the limited supply of oxygen, biomass doesn't get burnt completely and partial oxidation products such as CO etc. is formed which can be further oxidized and can result into a significant amount of energy. The temperature of the process is around 850°C and pressure in biomass gasifier is atmospheric or elevated. Products of the gasification process can be summed up by the following reaction.

$$\text{Carbohydrate matter } (C_6H_{10}O_5) \longrightarrow C_xH_Y + C_LH_MO_N + CO + H_2 + \text{Heat}$$

1.5 Advantages of Gasification

As compared to all the biomass utilization techniques, biomass gasification is the best suitable alternative to conventional fuels due to following advantages-

- The biggest advantage of the biomass gasification is that in this, we can feed the variety of the feedstock with changing the design of the gasifier.
- It has the highest thermo-chemical conversion efficiency of around 70-90%, which is highest among all the biomass utilization techniques.
- Area requirement for installation of gasification equipment is low, per unit output of energy in the form of heat and electricity.
- Output capacity, mainly in high output range depends on the only supply of feedstock rather than technical consideration.
- Synthesis gas, which is the product of biomass gasification can be used for power generation as well as feedstock for the chemical industry.
- Turn down ratio is high of gasification equipment compared to biogas.

1.6 Gasifiers

The gasification process is performed in a closed chamber which is known as the gasifier. The temperature inside the gasifier is around 1000-1100°C. The product of the gasification process is producer gas which contains combustible gases like CO, H_2, CH_4 and some non-useful products like tar and ash. The most important parameter of a gasifier design is that biomass products are reduced to charcoal and charcoal is converted efficiently into CO and H_2. Gasifier construction is a very simple task and can be achieved by any well-equipped shop using basic sheet metal and welding techniques. At the wartime in Europe, many countries constructed almost one million gasifiers in just a few years. Gasifiers are generally constructed from easily available material like steel pipe, sheet and plate. At the time of choosing the material, we should avoid exotic alloy, special shapes and those techniques which require high initial setup and tooling cost except where the requirement is justified.

1.6.1 Types of gasifiers

Basically, gasifiers are classified into two types: fixed bed gasifiers and fluidized bed gasifiers. The difference between these gasifiers is shown in the table 1.5.

Table 1.5: Difference between fluidized bed and fixed bed gasifier. [17]

Fluidized bed gasifier	Fixed bed gasifier
(+) Distribution of particle size is broad. (-) Tar content is high in the gas. (-) The carbon conversion rate is low as compared to the fixed bed gasifier around 85-90%. (+) Investment is low. (+) No problem with feedstock fines. (-) Possibility of particle size is limited around up to 50 mm	(-) Particle size as uniform as possible. (+) Almost tar-free gas. (+) Conversion rate of carbon is high around 90-99%. (-) High investment cost. (-) Feedstock fines must be agglomerated. (+) possibility of particle size is up to 100 mm. (+) Discharge of liquid slag.

In the gasifier the interaction of air and biomass takes place so they can be classified by how air and biomass interact with each other. Now we are going to discuss various types of gasifier one by one.

- Fluidized bed gasifier

In the fluidized bed gasifier, fuel and air are supplied from the bottom of the gasifier from different inlets. Biomass, which can be used in these types of gasifiers are crushed/milled biomass so that it can be fluidized easily. In this type of gasifiers, the zones are not well defined. Reactive fuel suits this type of gasifier because operating temperature is low. Carbonaceous matter suffer elutriation i.e. small particles get combined and form the bigger particle and because of this, it falls down and can't take part in the gasification process. Because of this reason, efficiency of carbon conversion is less as compared to the fixed bed gasifier. [18]

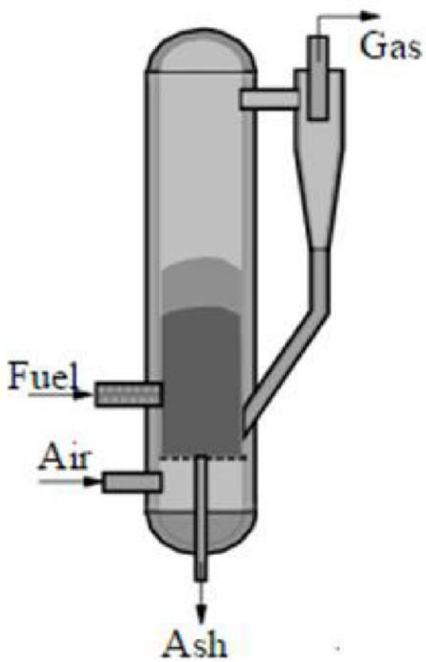

Fig 1.3: Fluidized bed gasifier

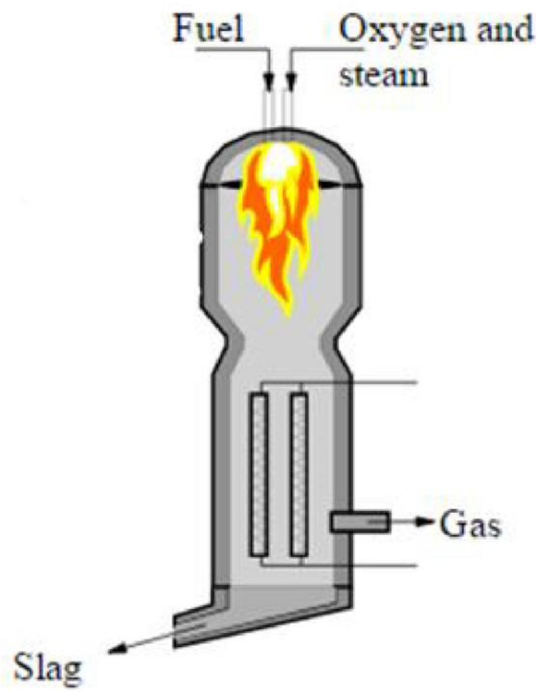

Fig 1.4: Entrained flow gasifier

- Entrained flow gasifier

In the entrained flow gasifier, fuel is supplied to the gasifier with the help of steam and oxygen at a constant rate. Gasification takes place in the downward direction in a concurrent fashion. Temperature and pressure of these gasifiers are very high, so we can't use air as use of air may increase NO_x which is highly undesirable property. The temperature of the gasifier is very high and because of this, ash gets fused into slag. Only hydrogen, oxygen and carbon dioxide are the products of this gasifier. Because it has high temperature so there is no formation of tar and methane. Some amount of H_2S is also present which can be removed by acid cleaning. [19]

- Plasma Gasification

This is a new gasification technique and some recent modifications have also been made in this type of gasifier. This type of gasifier is a mixture of both downdraft and updraft type of gasifier. Fuel and gasifying agent moves in downward direction same as the downdraft gasifier whereas gas moves in upward direction same as the updraft gasifier. The temperature of this gasifier is very high. Biomass are burnt with the help of plasma torch or arc. In this type of gasifier, we can easily use high moisture biomass (50%-60%) like agricultural waste, waste sewage and fresh forestry waste. Ash comes out at the temperature around 3000°C and fuses into slag which has its own use. [20, 21, 22]

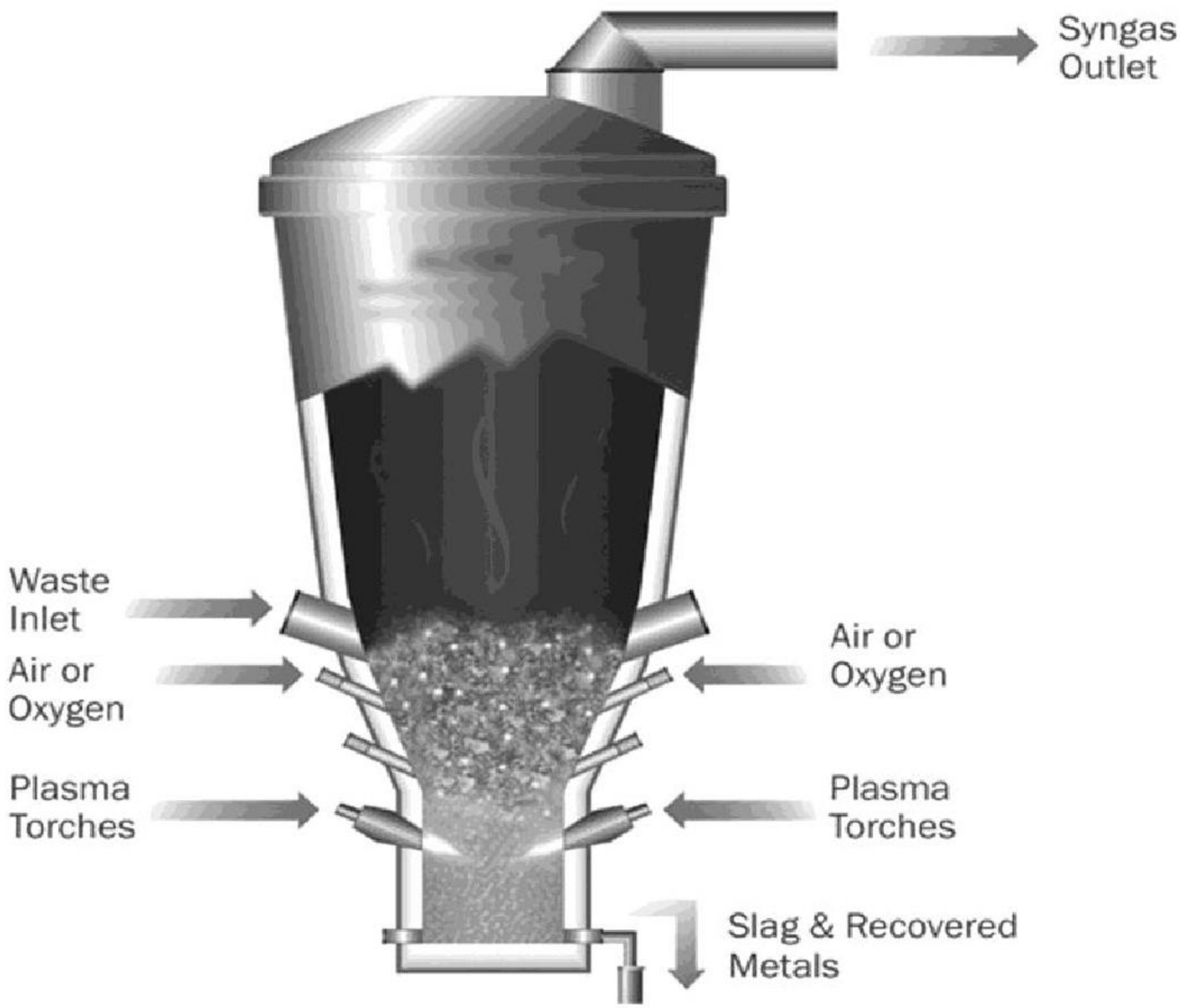

Fig 1.5: Plasma gasifier [23]

- Updraft Gasifier

In this type of gasifier, direction of raw material is downward and the air is introduced in the gasifier from the bottom of the gasifier and moves upward. Producer gas also moves upward. In this type of gasifier, well-defined zones are present. Gas passes from the pyrolysis and drying zone at very last and most of the tar formation happens in the pyrolysis zone. So, some tar is trapped in the drying zone, but most of the tar content is carried out by the producer gas. That's why the percentage of tar in the producer gas in these types of gasifier is very high. These gasifiers are also known as counter-current gasifiers. [24]

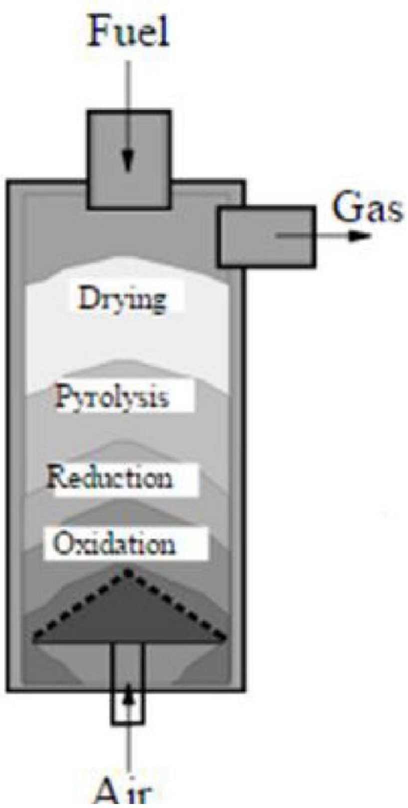

Fig1.6: Updraft gasifier

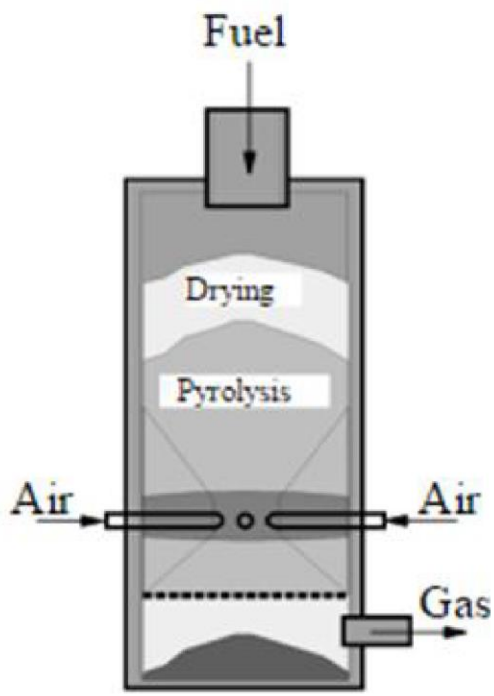

Fig 1.7: Downdraft gasifier

- Downdraft Gasifier

This is the fixed bed type of gasifier. In this type of gasifier, air enters from the bottom of the gasifier same as the producer gas and biomass is fed from the top of the gasifier. The air inlet is designed in such a way that gas flows in a downward direction. Because of the heat in the chamber drying, a pyrolysis of the biomass takes place. These gasifiers are also known as concurrent type of gasifier because in these types of gasifier, producer gas and air flow in the same direction. The tar content of these types of the gasifier is very low because tar is mostly formed in pyrolysis zone and producer gas does not have much contact with the tar. So in this type of gasifier, tar formation is low. [25]

Of all the types of the gasifier, we selected downdraft gasifier because it fulfills all of our requirements. Advantage and disadvantages of different gasifiers are shown in table 1.6.

Table 1.6: Advantages and disadvantages of various gasifiers [26]

Sr. No.	Gasifier type	Advantages	Disadvantages
1	Updraft	Pressure drop is small. Thermal efficiency is good. The tendency of slag formation is less	Highly sensible towards tars and moisture. Startup time of IC engine is a little bit high. Reaction capability with heavy gas load is poor.
2	Downdraft	Flexible towards the adoption of gas production to load. Low sensitive towards charcoal dust and tar content	Taller design. For small particle size, it is not feasible.
3	Cross Draft	Design's height is short. Response time to load is very fast. Gas production is flexible.	Highly sensible towards slag formation. Pressure drop is high

1.7 Process Zones in Gasifier

Gasification process has four distinct zones. They are-

- Drying zone
- Pyrolysis zone
- Combustion zone

- Reduction zone

There can be considerable overlapping of the zones, but we assume each one is a separate zone in which various thermal and chemical reactions take place.

1.7.1 Drying Zone: - This is the first process in gasification. This zone extracts excess moisture present in the biomass and temperature is around 100°C to 130°C. In this, no chemical reaction takes place. Only some amount of volatile and extra moisture leaves the biomass. [27]

1.7.2 Pyrolysis Zone: - This comes after the drying zone and is very important and complicated part of gasification. In this zone, thermal breakdown of biomass takes place. Here the lignocellulosic matter gets pyrolyzed and is converted into char and other volatile like CO_2, CO CH_4, and C_nH_n. Temperature is high in this zone (around 200-250°c) compared to drying zone.[28]

1.7.3 Combustion Zone: - In this zone, the combustion of biomass starts in the presence of limited supply of oxygen and controlled oxidation takes place. Here, a product like tar, gases, i.e. CO, CO_2, CH_4, and hydrocarbons are formed. The temperature of this zone is higher (around 850-900°C) than the pyrolysis zone temperature. [29]

1.7.4 Reduction Zone: - This is the zone where the main part of the gasification takes place and all the products, which are formed in the combustion zone are further reduced to the CO, CH_4, H_2, and CO_2. N_2 is also formed, but the temperature of the gasifier is low. So N_2 behaves like an inert gas. In this zone, recombining and random dissociation of these compounds can be seen. [30]

Mainly four types of reactions take place in this zone. These are the Boudouard reaction, methanation reaction, steam reforming reaction and water-gas reaction. Reaction equations of the gasification process are shown in table 1.7.

Table 1.7: Reaction chemistry in biomass gasification [31]

Process	Chemical reaction	Change in enthalpy (KJ/mol)
Partial oxidation	$C + \frac{1}{2}O_2 \rightarrow CO$	−110.50
Complete oxidation	$C + O_2 \rightarrow CO_2$	−393.50

Reaction with hydrogen	$C + 2H_2 \rightarrow CH_4$	−74.80
Reduction of carbon dioxide	$C + CO_2 \rightarrow 2CO$	172.40
Partial oxidation with Steam	$C + H_2O \rightarrow H_2 + CO$	131.30
Water-gas reaction	$CO + H_2O \rightarrow H_2 + CO_2$	41.10
Methanation	$CO + 3H_2 \rightarrow H_2O + CH_4$	206.10

1.8 Dual Fuel Engine

At the time of world war one, Dr. Diesel introduced the concept of dual fuel engine because at that time shortage of conventional fuel. [32] In dual fuel engine two types of fuel are used, one is gaseous and other one is liquid. In some cases, both the fuels can be gaseous, but at least one fuel has to be gaseous. [33] At the time of the First World War enough infrastructure was developed to generate significant amounts of natural gas. Due to lack of resources its use can be limited to household purposes.

Natural gas has a nonpolluting nature, so nowadays it’s highly recommended to run both heavy and light vehicles. [34] High compression ratio is required for the gaseous fuel, but they have enough self-ignition temperature so combustion is self-sustained in many cases. But in some cases where can’t take place at its own ignites by a combustion fuel. [35] The nature of the diesel engine is robust and heavy duty. A compression ratio of the diesel engine is high, so it is preferred to make dual fuel engine by modifying the existing diesel engine. The response of the diesel engine is quick to the speed, variation in the load, nature of the fuel and change in the supply. In the current study a dual fuel CI engine is used for the experiment. [36, 37]

1.8.1 Dual Fuel CI Engine

The dual fuel CI engine is made by modifying CI engine. In DFCI Engine, at the inlet valve of the engine a gas carburetor is installed. [38] Use of the gas carburetor is to control the fuel supply and send a homogenous mixture of air and gaseous fuel. [39] In the compression stroke mixture of air and gaseous fuel is compressed and then just before the completion of the compression stroke it gets ignited by the spray of diesel. [40] DFCI engine is ignited by diesel instead of spark plug so no problem related to knocking in DFCI engine. Diesel gets atomized when sprayed inside the combustion chamber and because of this large flame centers are created, which help in ignition of the gas - air mixture. [41, 42, 43] Ignition of DFCI engine is quite rapid and efficient. Scope of some modifications in DFCI engine is also available such as supercharged and turbocharged engine. By the use of the turbocharged or supercharged engine more air supply is provided to the combustion chamber, thereby reduction in HC emission and increase in engine performance. [44]

1.8.2 Advantages of Dual Fuel Engine

Advantages of dual fuel engines over the diesel engine are listed below.

- Saving of conventional fuel.
- Reduction in CO, HC, SO_x and NO_x emission.
- These engine are highly responsive so in case of emergency easily shifted to diesel/gasoline mode.
- If biogas is coupled with dual fuel engine, exhaust of the engine can be used to provide heat for the digestion process.
- Dual fuel engines are nonpolluting engine because gaseous fuels are environment friendly.
- On any cylinder part or in the exhaust no residue is left behind.

1.9 Properties of Producer gas

The product of the gasification process is producer gas and it is affected by many factors, i.e. temperature, pressure, in-house time and warm up losses. So, variation in the gas which is produced from the various biomass is obvious. Gasifier design also affects the composition of the gas. Same biomass can give different amount and quality of gas at different gasifiers. If we use air, then almost 50-55% of the producer gas are nitrogen which is useless for us. The high nitrogen percentage is because of the quantity of nitrogen in the air is around 72%. If we use oxygen instead of air, then the nitrogen percentage decreases. Although the use of oxygen is little bit expensive as compared to air, but this loss is compensated by the end product methanol which is very high energy quality item. On an average, around 2.5 m^3 of producer gas can be produced by the 1 kg of biomass at S.T.P and about 1.5 m^3 of air is consumed in this process. The energy conversion efficiency of the gasifier is about 60-70% and is defined as-

$$= \left(\frac{Calorific\ value\ of\ gas}{kg\ of\ fuel}\right) / (avg. calorific\ value\ of\ 1\ kg\ of\ fuel)$$

Composition of the producer gas is a little bit different for various fuels. For Pterospermum Acerifolium producer gas composition is 19.5% CO, 17.6% H_2, 1.6% CH_4, 12.2% CO_2, and 49.1% N_2 on an average, temperature of the producer gas, which is leaving the gasifier is around 300-400°C, but if the temperature of the producer gas is greater than 500° then partial oxidation of gas takes place. Mainly this happens due to higher air flow rate through the gasifier than the design value. [9, 45, 46]

1.10 Gasifier Fuel Characteristics

The main aim of the gasification process is not only the generation of the producer gas by burning a biomass fuel at the 20-40% of stoichiometric air, but also reducing economical cost which can attract the customers. Considering this point, fuel characteristics have to be evaluated.

A gasifier fuel can be classified using following parameters.

- Water content
- Dirt content
- Tar/pitch content
- Energy content and bulk density of fuel
- Slag and ash characteristics
- Biomass type

1.10.1 Water Content

Low moisture fuels are desirable because high moisture content causes many troubles in gasification. High moisture content consumes more energy to evaporate excess moisture before gasification process. High moisture content also puts extra load on filtering and cooling equipment by increasing the pressure drop because of condensing liquid. To remove the moisture from the gasifier, generally we sundry the biomass before using it. In the biomass, less than 20% moisture content is desirable.

1.10.2 Dirt Content

Excess amount of dirt can choke the IC engine, so it has to be removed from the producer gas. The gasifier design should be in order to prevent generation of dirt not more than 2-6g/m^3. By the high dirt content, extra load is put on the filters and because of that, we need to clean and maintain the filters after some time interval. [47, 48]

1.10.3 Tar/Pitch Content

Tar is the most undesirable content of the gasification because high amounts of tar can get deposited in the carburetor and intake valve which causes sticking and troublesome operations. Tar content is produced in the pyrolysis zone by the highly irreversible process. Physical property of tar depends on the temperature and heat rate. Approximately 200 chemical components are present in the tar. If the design of the gasifier is good, then it should put out less than 1g/m^3 of tar. [47, 48]

1.10.4 Energy content and bulk density of fuel

The superior the energy content of the fuel, the analogues are the gasifier capacity since for one charge one can get power for prolonged time through this. [45, 49]

1.10.5 Slag and Ash Characteristics

The amount and composition of the ash affect the working of the gasifier by two ways-

- After ash fusion, it forms slag and because of this, descending run of biomass feed is hindered.
- It gives shelter to the points in fuel where ignition is going to start and because of this fuel’s response time is decreased.

Ash and tar removal are the two most important parts of the gasification system and if the perfect ash removal system is installed then almost all the ash particles gets separated from the gas. Till now, wood and charcoal have been tested and proven to be reliable. Ash content in charcoal is very low and charcoal is almost tar free. So, this is the reason why charcoal was the favorable fuel at the time of world war second. At present time when enough supply of wood is not possible, agricultural residue is the attractive option to use. [50]

1.10.6 Biomass type

Biomass element content affects the producer gas composition. Producer gas production is highly depended on the O_2/C fraction and H_2/C fraction. When there is an increase in the H_2/C fraction, the producer gas production also increases. If there is lower ER for gasification then the concentration of O_2 is elevated in biomass. [1]

1.11 Present Work

To fulfill our energy demand without affecting the environment, biomass is an economical and viable energy source among all the other alternative energy sources. An energy conversion process must be effective in the case of biomass and biomass gasification has, the more effective energy conversion and use of its end product is also more effective. The objective of this study is to give a new biomass material which can give good results and for which availability is not an issue. In the present work, a downdraft gasifier is attached with a variable compression ratio diesel engine. The engine was running at dual fuel mode in which diesel is the pilot fuel and producer gas is the secondary fuel. For the production of the producer gas, fruit of Pterospermum Acerifolium is used as gasifier fuel, which is a totally new biomass fuel. The main focus of the experiment is to study the performance, emission and noise characteristics of the dual fuel engine.

1.12 Organization of the thesis

The substantial amount of work has been done on the utilization of biomass on a downdraft gasifier by many researchers and they have produced producer gas by using different biomass fuels. They used the gas to run the different types of engine and studied the performance of the engine. So, in order to identify the scope of the work, the literature review is carried out which is presented in chapter 2 of this thesis along with gaps in the literature and problem formulation. Experimental setup and methodology of the experiment is discussed in chapter 3. Results come from the experimentation discussed in chapter 4, under the name of results and discussion. The conclusion of all the results are presented in chapter 6. Some suggestions are also given to improve the design and future scope of the biomass gasification. References of all the papers is given at the end of the report.

1.13 Summary

The current chapter addresses energy trend in India and importance of biomass as an energy source. Some basic knowledge about the component present in biomass after that type of biomass utilizing technique is discussed and advantages of biomass gasification are discussed. Special attention has been given on types of gasifier and zones present in the gasifier. Also, the motivation behind the research work and thesis outline is discussed at the end of the chapter.

CHAPTER 2

LITERATURE REVIEW

In this chapter, review of some important research papers related to the gasifier, engine's emission characteristics and the performance of the dual fuel engine under various operating conditions has been covered. Some papers on noise characteristics are also reviewed.

2.1 Review of previous research work

Sohan Lal et al (2017) studied the performance and emission characteristics by using a variable compression diesel engine and downdraft gasifier to find that maximum diesel saving attained is 64.3% at compression ratio 18. HC emission reduced to 63% if compression ratio is elevated to 18 from 12 and effects of dual fuel mode compression ratio are less as compared to diesel fuel mode. Maximum cylinder pressure is achieved at compression ratio 18 is 47.19 bar for diesel mode and 54.49 bar for the dual fuel mode. CO_2 emission increased when load increases in both diesel and dual fuel mode and it is higher in dual fuel mode. By the study of this paper we find that the engine is giving good results at compression ratio 18.

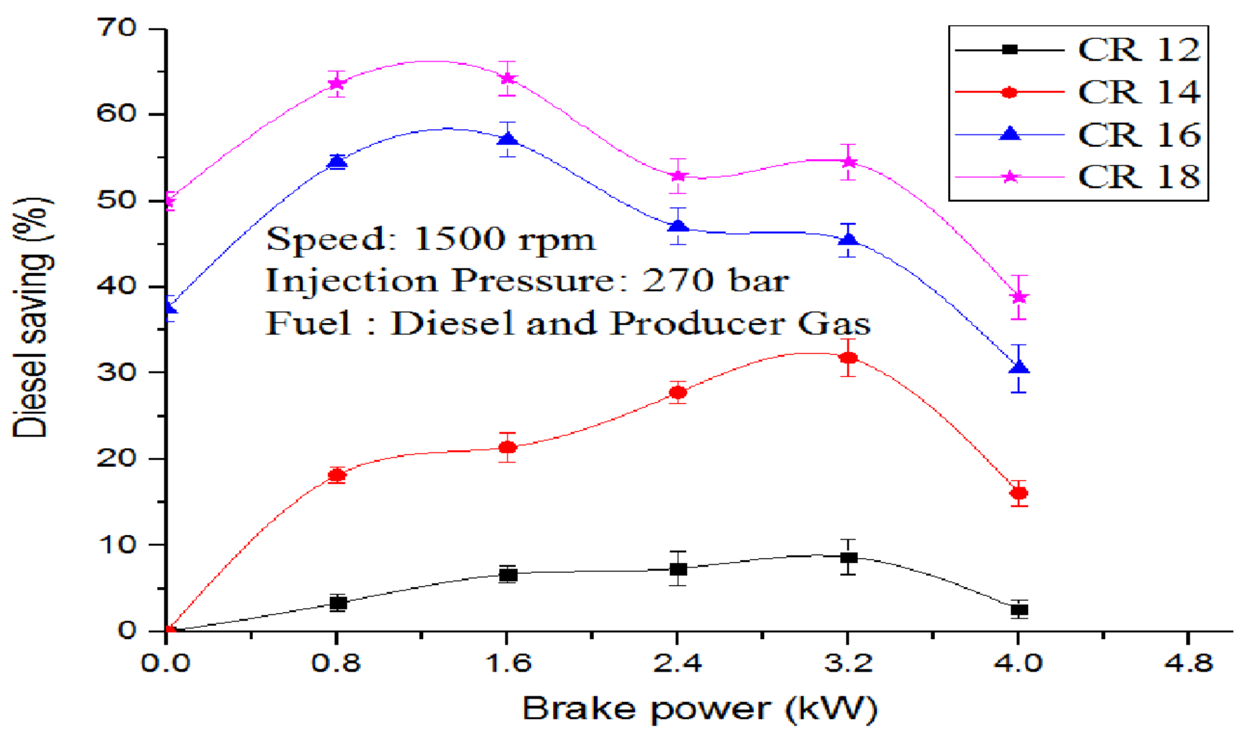

Fig 2.1: Variation of diesel saving with brake power at different compression ratio. [51]

Kirsanovs et al (2017) studied the biomass gasification by the help of downdraft gasifier**.** Experiments were performed on the real plant on various operating conditions. Different types of wood chips were used as the biomass fuel and effect of the moisture content in biomass is studied because it has significant effect on the results. To achieve higher CV of the gas air supplied in the gasifier was divided in to parts i.e. primary and secondary. To present the cold and hot gas efficiency, calorific value and gasifier capacity, a regression model was also developed.

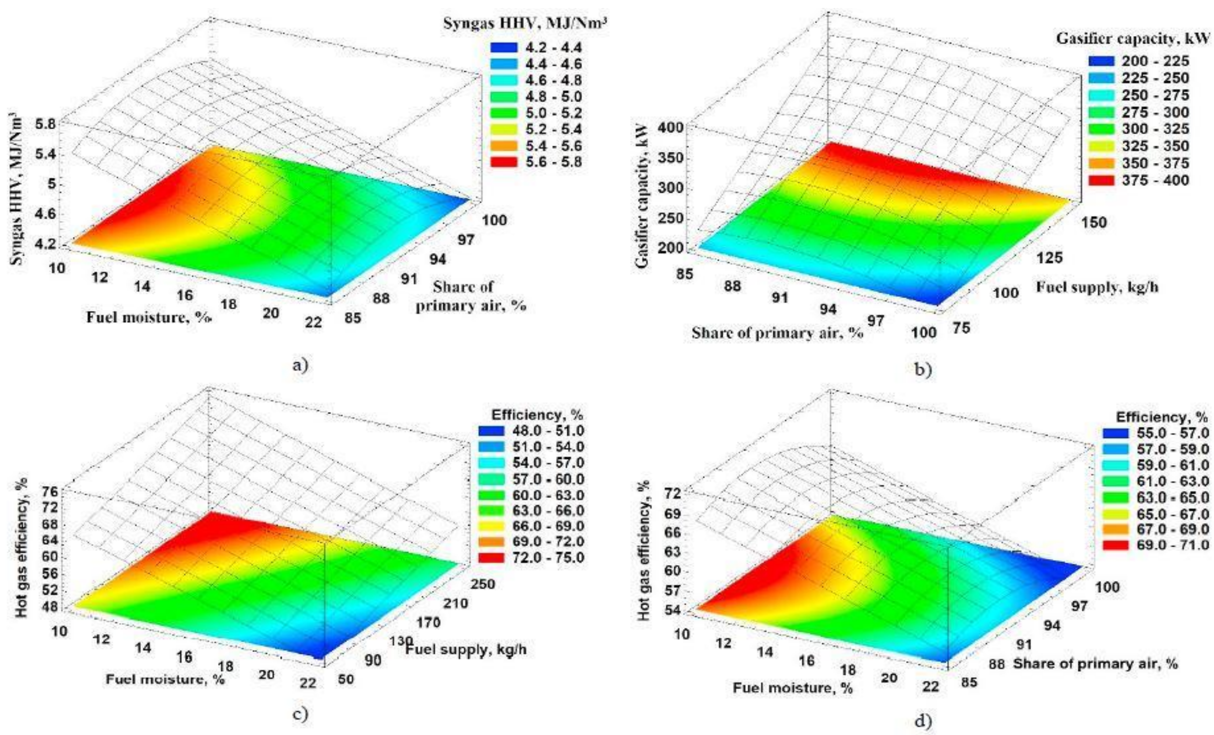

Fig.2.2: Influence of a) fuel moisture and share of primary air on the syngas calorific value; b) share of primary air and fuel supply on the gasifier capacity; c) fuel moisture and fuel supply on the hot gas efficiency; d) fuel moisture and share of primary air on the hot gas efficiency. [52]

Heat released from syngas cooling was used for fuel drying. They found that the moisture content of the fuel decreases to 10.9 % from 21.1 %, then hot gas efficiency increases by 17.4 %. Calorific value is increased by the use of air supply division and maximum gasification efficiency is achieved, when primary gas is 92.5%. Fuel supply came down to 94 kg/h from 153 kg/h, favor reduction of plant thermal capacity by 173 kW and efficiency by 5.0 %.

Singh et al (2016) performed experiments on the downdraft gasifier by using a mixture of two different biomass in 1:1 ratio. The biomasses were sugarcane bagasse and carpentry waste. Producer gas and diesel were blended and fed to a dual fuel engine and found that diesel consumption and NO_x emission are reduced significantly. An increase of 3.4dB sound level is observed in dual fuel mode and concentration of CO and HC is also increased but with a slight modification, the system can be improved regarding emission and performance characteristics. Some modification is also suggested in the design of gasifier like throat of the gasifier is not suitable for the low density fuel because of the bridging.

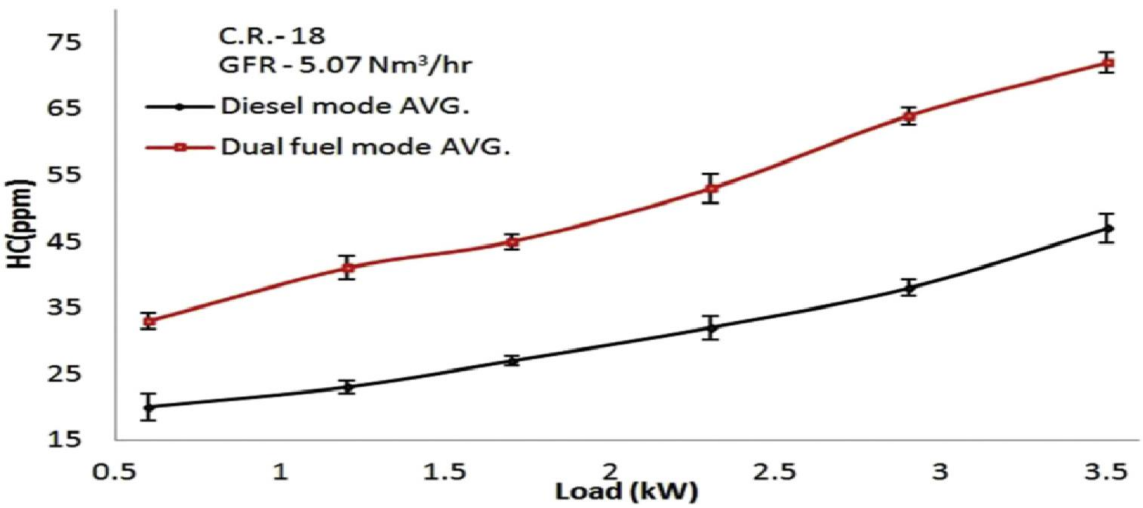

Fig. 2.3: HC emissions with load variation. [53]

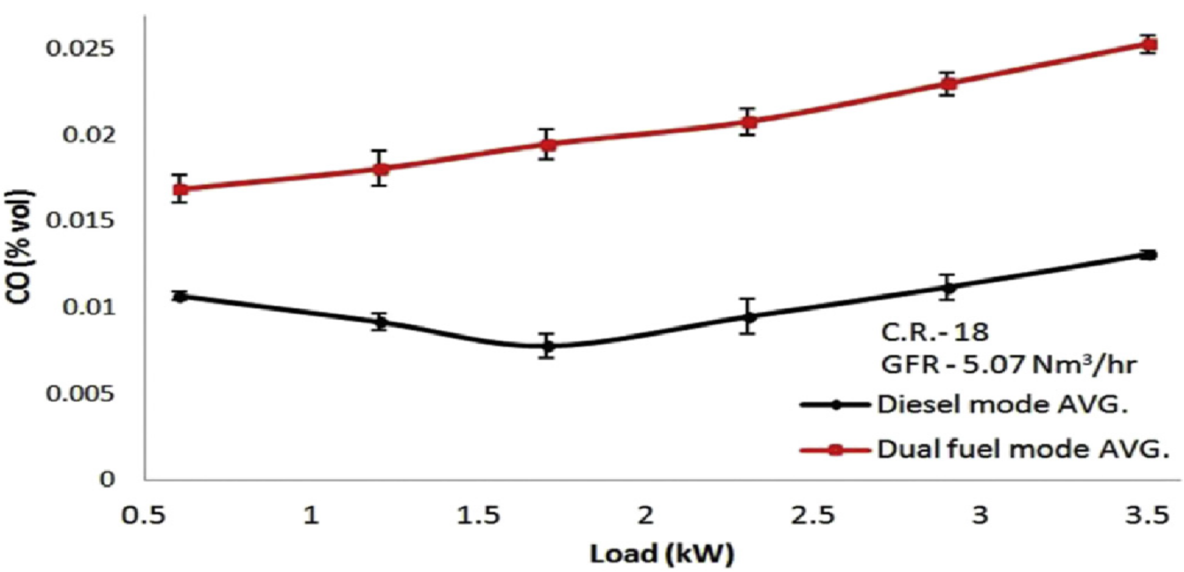

Fig. 2.4: CO emissions with load variation. [53]

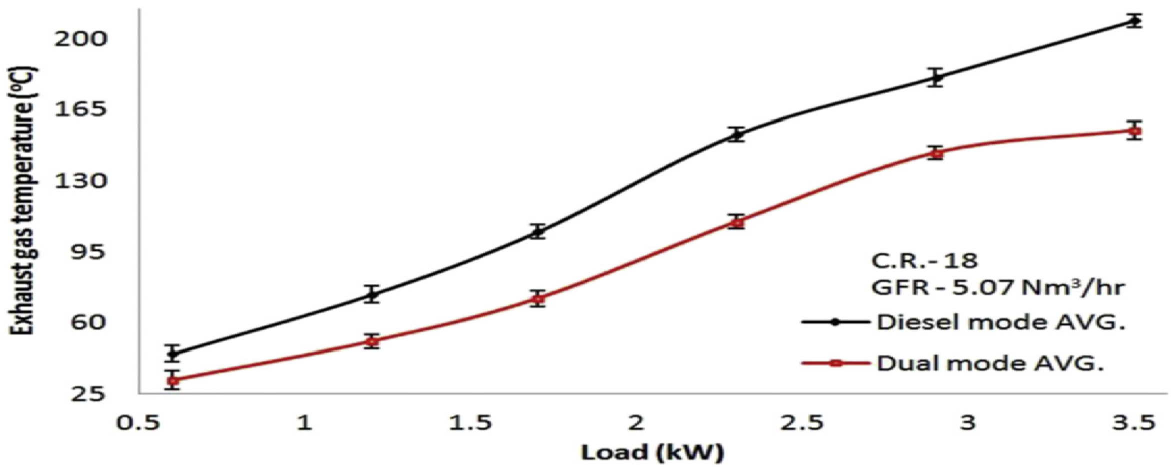

Fig. 2.5: Exhaust gas temperature with load variation. [53]

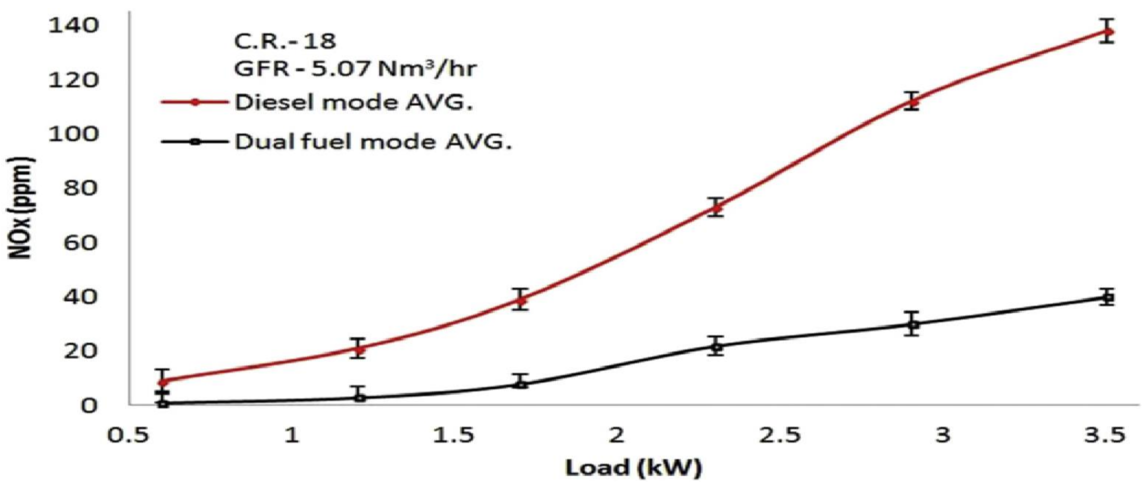

Fig. 2.6: NOx emissions with load variation. [53]

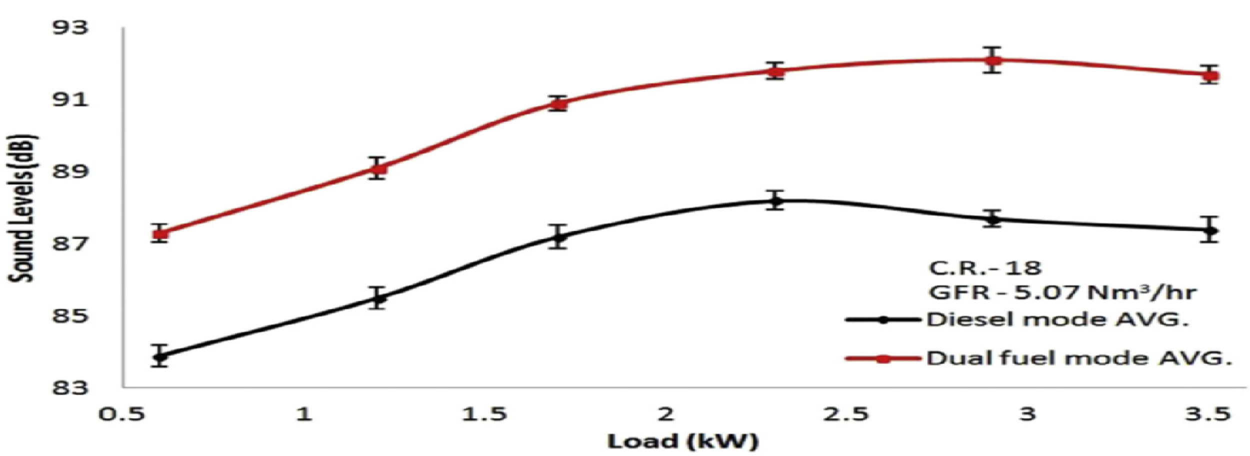

Fig. 2.7: Variation of noise levels with variation in load. [53]

Malik et al (2016) studied the dual fuel engine performance parameters by using a downdraft gasifier and fuel fed to the gasifier is cotton stalk. They found that the fuel consumption in dual fuel mode is always favorable as compared to the diesel fuel mode and around 51% diesel saving is achieved. CO emission is high in dual fuel mode and emission of NO_x is reduced. Brake thermal efficiency of a dual fuel engine saw an improvement of 40% as compared to diesel fuel mode because of the high methane percentage in the producer gas. Cost of power generation using biomass gasification is much lesser than the traditional power generation sources because low cost or waste biomass feedstock is used for the producer gas generation.

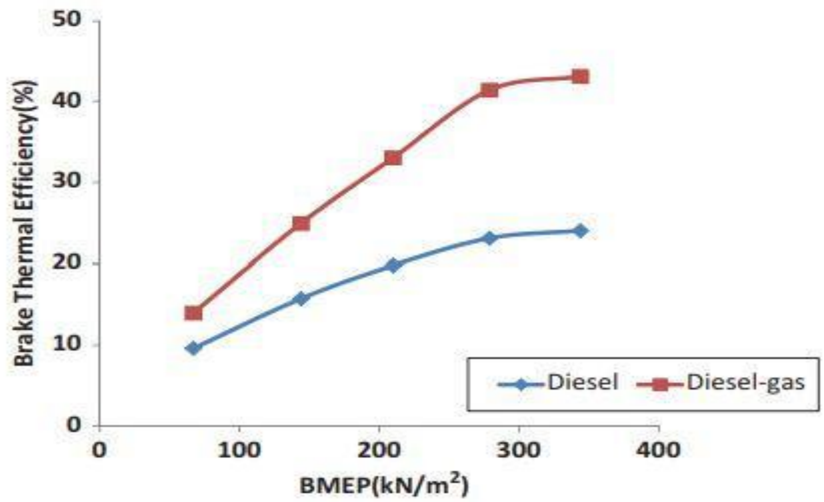

Fig. 2.8: Brake thermal efficiency of engine w.r.t. BMEP. [54]

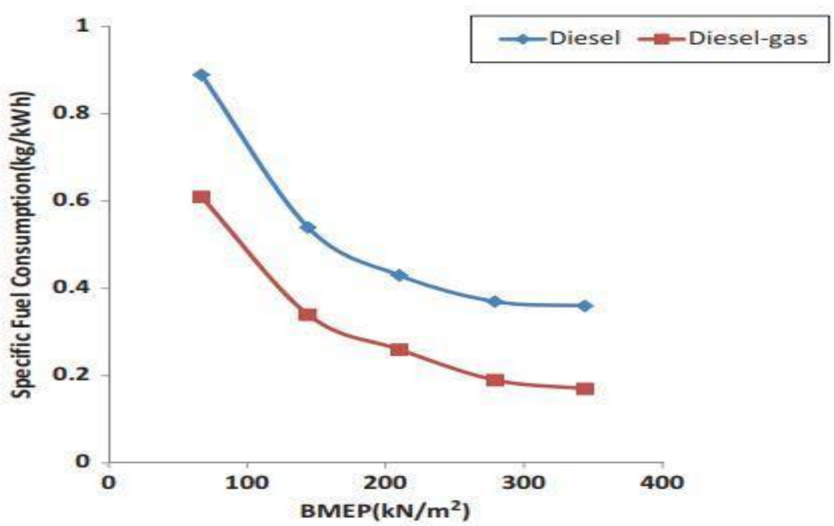

Fig. 2.9: Specific fuel consumption of engine w.r.t. BMEP. [54]

Dhole et al (2014) studied the performance and emission characteristics of twin dual fuel engine by using the blend of hydrogen and producer gas with diesel. They found that a blend of hydrogen and diesel at the ratio of 20:80 results in an 8% increment in the brake thermal efficiency. The blend of producer gas and diesel at the ratio of 30:70 results in a 7% decrease in brake thermal efficiency. The conclusion of this paper is that the blend of producer gas, hydrogen and diesel have much better results in performance and emission of twin fuel engine with respect to the blend of producer gas with diesel and hydrogen with diesel. NO_x emission was reduced and hydrocarbon emission was increased by using blends.

Jain et al (2014) studied the air pollutants emission from burning of biomass in India. Punjab, Uttar Pradesh, Haryana and Maharashtra are the biggest contributors regarding crop residue burnt in farms. Rice, wheat and sugarcane are the major crops whose residue are subjected to farm burning. By the major burning of rice and wheat residue in Uttar Pradesh and Punjab is the major concern not only for GHG emission, but also for environmental pollution. To avoid this burning of residue, biomass gasification is the best option.

Shrivastava V et al (2013) performed experiments on downdraft gasifier by using mustard oil cakes and wood chips in the ratio of 3:7 as biomass fuel. They studied the performance and emission parameters of the engine. The engine used was a four stroke, single cylinder, air cooled engine developing power of 4.4kW at a rated speed of 1500 rpm running on a dual fuel mode. The great advantage of dual fuel mode is the NO_x emission is reduced by the 18.60% with D+PG4lpm at full load. Dual fuel operation with D+PG4lpm improves both CO and HC emissions up to 15.38% and 17.39% respectively at full load in comparison with diesel. This gives us an indication towards the insufficiency of oxygen in the combustion chamber.

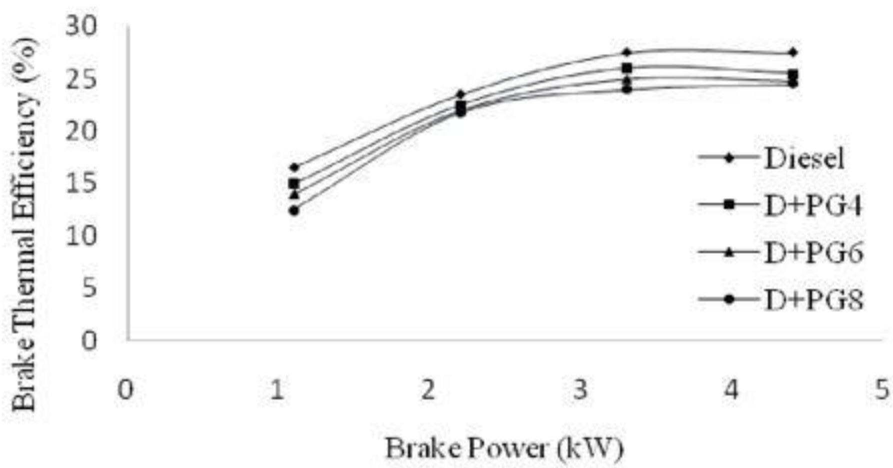

Fig 2.10: Effect of brake power on brake thermal efficiency in dual fuel mode [4]

Bika et al (2011) in their study, used a single cylinder cooperative fuels research (CFR) engine to study the combustion characteristics and knock of three blends of synthesis gas 100% H_2, 75% H_2 and 25% CO and 50% H_2 and 50% CO by volume and all the samples were tested at three different compression ratios (10:1, 8:1, and 6:1) and three different equivalence ratios (0.8, 0.7 and 0.6). They found that if CO fraction is increasing in an H_2 /CO mixture, the knock limited compression ratio (KLCR) also increases at a given spark timing which in turn reduces the overall burn duration and increases ignition lag/flame development time. There is no effect on indicated efficiency if CO fraction is increasing. They suggested that if usage of synthesis gas is being considered as a fuel in SI engines, the results of up to 50/50 H_2/CO mixtures are more important. Higher CO fraction increases resistance to knock. Because of this, it has the potential of producing higher indicated efficiency.

Erlich C., et al.; (2011) developed a downdraft gasifier in which every kind of dry biomass can be gasified by making pellets of the biomass. In other words densification of the biomass. Many raw material used as a biomass fuel i.e. sugarcane bagasse, empty fruit bunch and wood. Pellets of the biomass is produced by the pellet mill model - CL3 which has capacity 20 kg/h. four types of pellets were made sugarcane bagasse pellets of 6 mm diameter, wood pellets of 6mm diameter, EFB pellets of 8 mm diameter and EFB pellets of 6mm diameter.

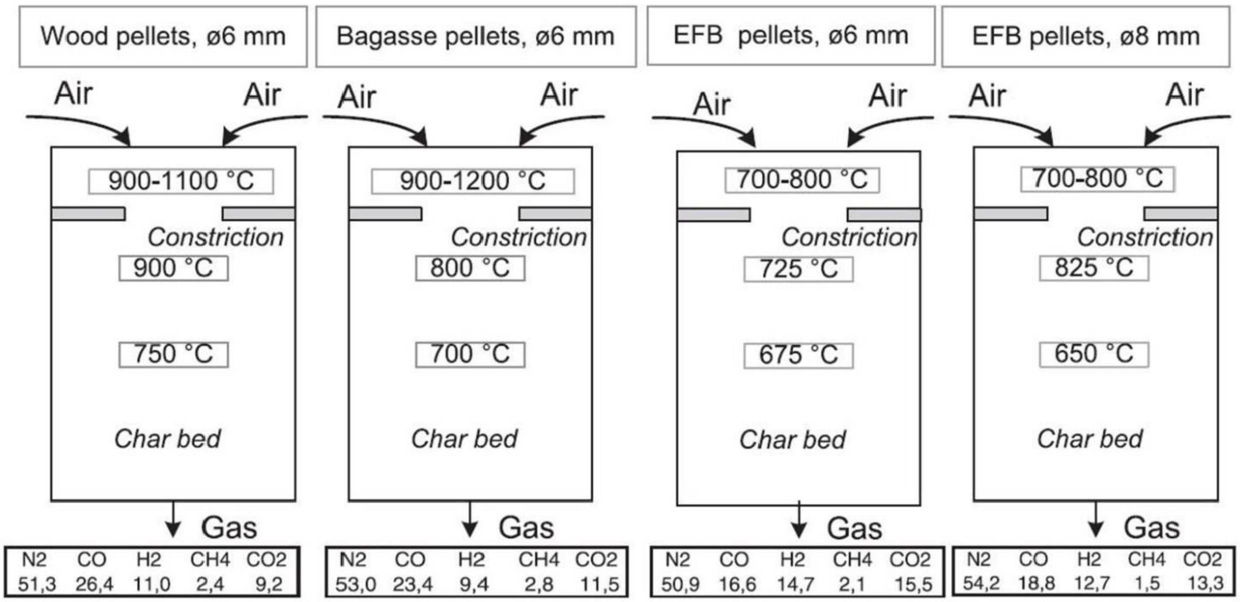

Fig. 2.11: Information of the gasification of the four different fuel pellets [55]

Son et al (2011) in their research paper, developed a downdraft gasifier which is combined with a small gas engine system for power generation and studied the characteristics of syngas production by the biomass gasification. Gasifier temperature of this operation is around 1000°C and air ratio for gasification was 0.3-0.35. Lower heating value is 1100-1200 kcal/Nm^3 is achieved and cold gas efficiency is 69-72%. Compared to other fixed bed gasifier system, tar generation volume in this is around 10-30%. The tar for the proposed downdraft gasifier applied in this study was shown to be level of 3.9-4.4 g/Nm$^{3.}$ So, gasification conversion performance can be enhanced by this gasifier. They confirmed by this study that stable power generation can be achieved and HC emission is less than 200 ppm and NO_x emission is under 40 ppm.

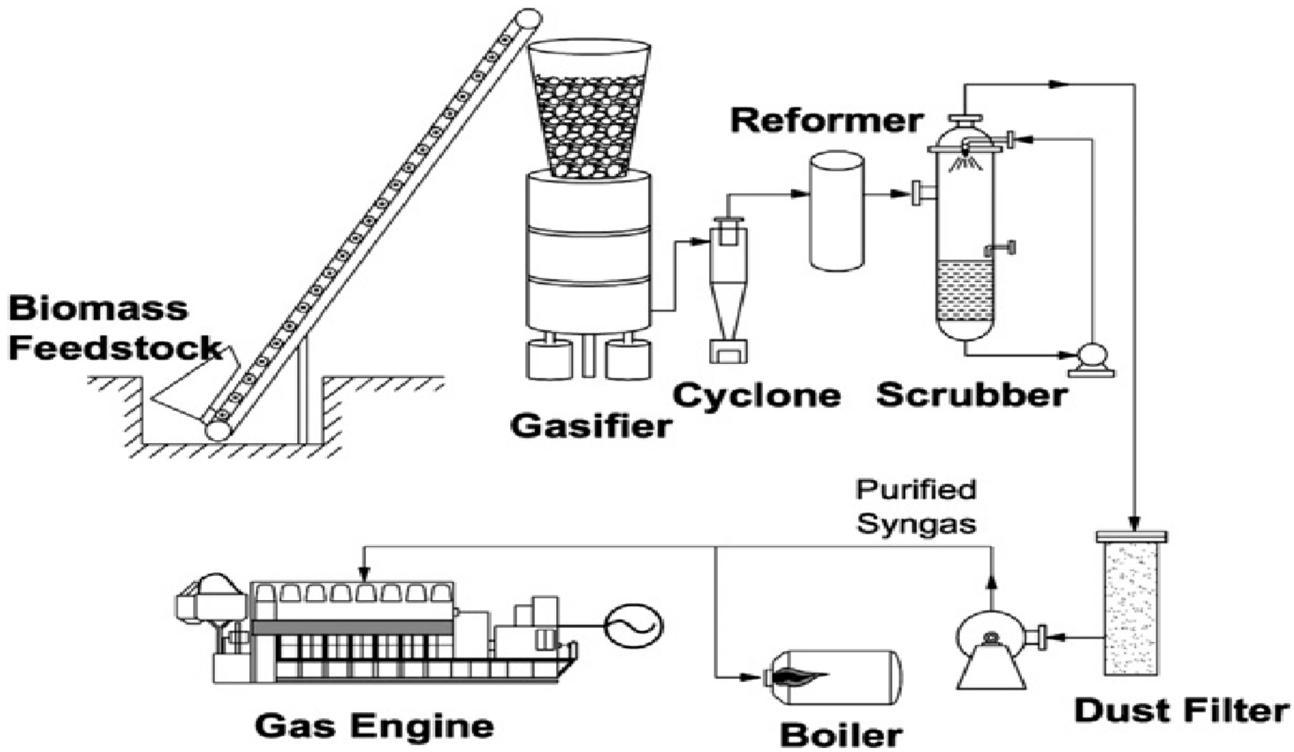

Fig. 2.12: Flow diagram of the downdraft gasification power generation system. [56]

Chen et al (2010) proposed a syngas production model from municipal solid waste gasification with air in fixed bed reactors. To predict the MSW gasification, the Aspen plus simulator model is used. Through this model, moisture concentration, air equivalence ratio, effects of gasification temperature on the composition of syngas, heat conversion efficiency, carbon conversion and the lower heating value of syngas are investigated. The results show that gasification lowers the heating value, heat conversion efficiency, and carbon conversion improves if the temperature is high. Trend of heat conversion efficiency is first increasing and after reaching maximum, decreasing in nature. The favorable air equivalence ratio is 0.5 for the gasifier. The optimum temperature is 600°C. Conversion efficiency and carbon conversion is increased by higher moisture at lower ratios.

Ramadhas A.S. et al (2008) used a downdraft gasifier and it was coupled with a canon. The engine setup was four stroke direct injection engine setup. Rated power output of engine is 5.5 kW and speed is 1500 rpm. To generate the producer gas coir pith was used. Apart from that rubber seed oil was also fed to the gasifier by blending it with diesel and producer gas. They found that engine showed decreasing trend in brake power when operated on dual fuel mode. Increased CO emissions in oil-gas mode as compared to any other mode.

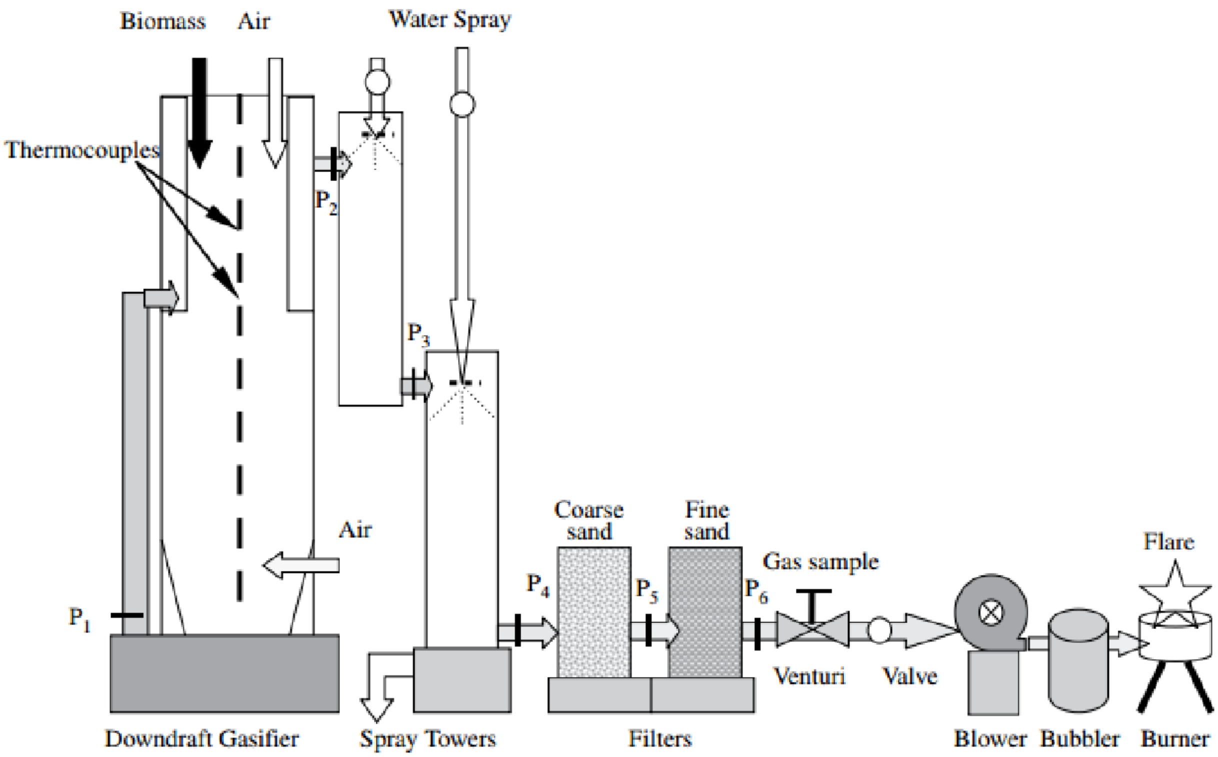

Fig. 2.13: Schematic diagram of the 75 kW downdraft biomass gasifier system [57]

Sridhar G et al (2007) performed experiments on an engine which is made by Kirloskar capacity of 23 kW at 1500 RPM. They installed a gas carburetor in the inlet manifold and converted the engine into a dual fuel engine. By using a centrifugal compression they increased the compression ratio up to 19.4:1. Engine operates on four modes, rice bran oil+diesel mode, mixed fuel mode, diesel+producer gas mode and the diesel mode. In mixed fuel mode, mixture of all three fuels supplied to the engine. For every mode of fuel performance and emission characteristics of the engine was tested. They found that, maximum HC emission was generated by both diesel and dual fuel mode at 84% load, this is because of the incomplete combustion. At every load condition CO_2 emission was higher on mixed fuel mode. At higher load values NO_x and CO emission suppressed to a great extent in mixed fuel mode as well as diesel-gas mode.

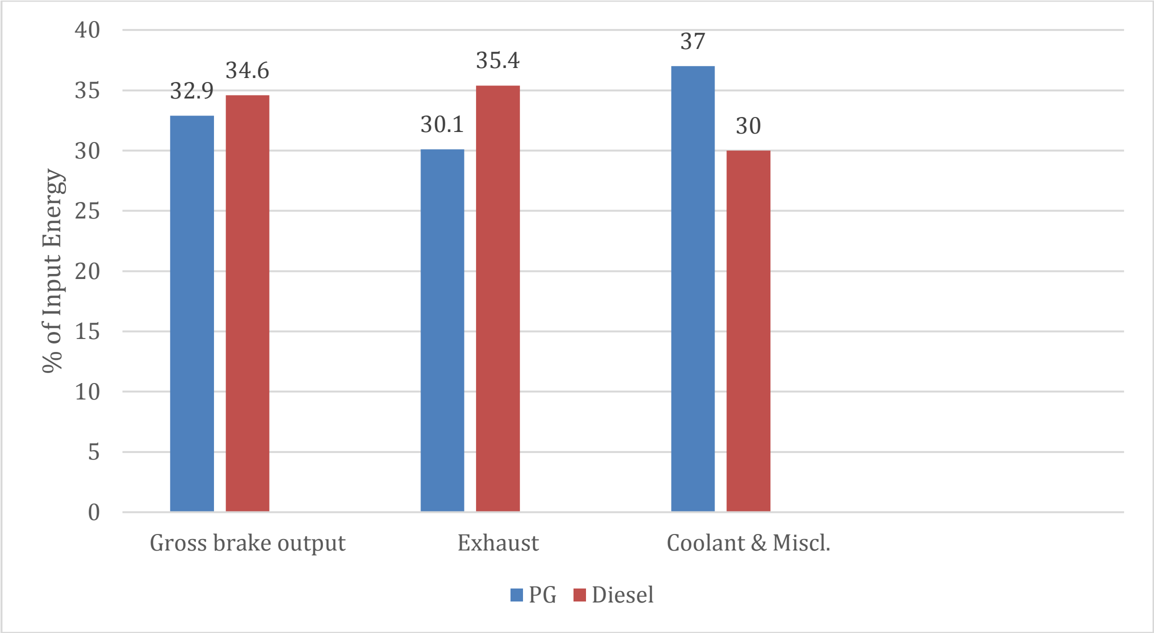

Fig. 2.14: At maximum brake output comparison of energy balance in diesel and producer gas mode [58]

Singh et al (2006) performed experiments on the open core downdraft gasifier by using the cashew nut shell to investigate its properties and effects on gasification. The performance of the gasifier was calculated in terms of fuel consumption rate, the gasification efficiency and calorific value of producer gas at different gas flow rates. The results showed that the trends are similar to the woody biomass with high conversion rate. In general, if the gas flow rate is increased then volumetric efficiency, calorific value and gasification efficiency are also increased. Maximum gasification efficiency was (70%) at a gas flow rate of 130 m^3/h and specific gasification rate of 167 kg/m^2h and it was comparable to the wood. This proved that cashew nut shells could successfully be used as feedstock for the open core down draft gasifier.

Hanaoka et al (2005) studied the gasification with woody biomass components. Experiments were performed by using downdraft fixed bed gasifier at atmospheric pressure and 1173 K temperature. They used air-steam mixture instead of air. Gasification conversion in lignin, cellulose and xylem were respectively 52.8%, 97.9% and 92.2% on a carbon basis. Composition of product gas in cellulose were 27.0 mol% CO_2, 35.5 mol% CO, and 28.7 mol% H_2. Composition of CO were higher than the composition of CO_2 and H_2. Composition of producer gas in lignin and xylem were 25 mol% CO, 32 mol% H_2, and 36 mol% CO_2 and CO composition is lower than the composition of H_2 and CO_2.

R.Uma et al. (2004) investigated the emission characteristics of dual fuel engine at different load conditions. In the reported work studied the NO_x, CO, HC, SO_x and particulate matter in the flue gas for their various characteristics on the diesel fuel mode and compared this data with dual fuel mode. Apart from the emission characteristics, diesel replacement on dual fuel mode is also investigated. At lower loads, concentration of NO_x and SO_x is increased. At all load condition, on the dual fuel mode, concentration of CO and HC is significantly increased. At higher load conditions decrease in NO_x and SO_x emission is observed. A significant amount of pilot fuel is also replaced by the secondary fuel.

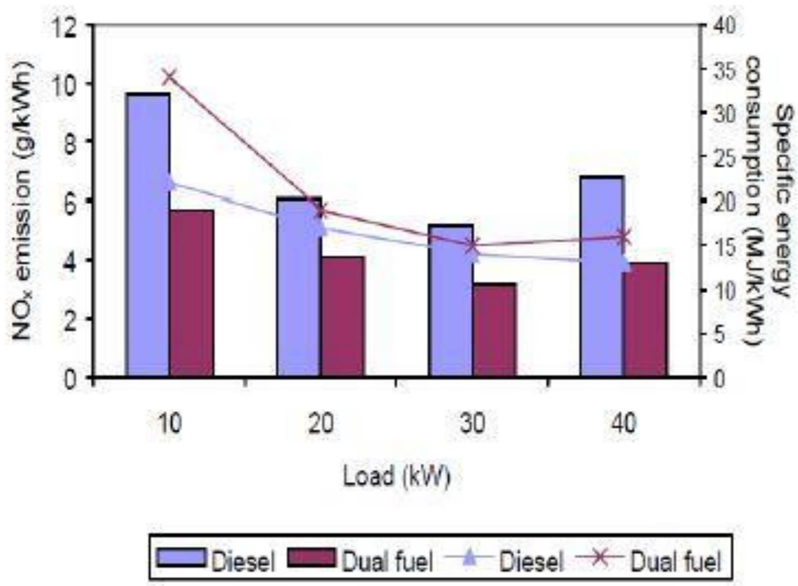

Fig. 2.15: Comparison of NOx emission in diesel and dual fuel mode [59]

Wu et al (2003) studied the performance analysis of 1-MW biomass gasification based electric power generation system. From the results of the experiment, we can say gasifier performance characteristics are strongly influenced by the operating temperature and the ratio of air to fuel. They found that temperature of 780°C, equivalence ratio of 0.26, gasification efficiency of 70%, 80% conversion efficiency of carbon and LHV 5.8 MJ/m^3 are the optimal operating parameters for the wood powder feed. During biomass gasification, fly ash carried by the flue gas and tar produced are the major factors affecting the continual operation of electric power generation system. Because of the fly ash, loss of sensible heat takes place which leads to less efficient electric power generation system. The emission of SO_2 and NO_2 of fuel gas from biomass gasification is below 20 ppm as compared to coal based power generation. The diesel engine can be run with twin fuelling with diesel replacement rate of 67-86%. At part load condition, if emissions are increasing then the engine performance decreases. At all operated load condition, carbon monoxide emission from twin fuel engines were more than the diesel engines.

Zainal et al (2002) performed experiments on the downdraft gasifier by using wood chips and furniture wood as the biomass fuel and studied the effect of equivalence ratio on the gas composition, gas production rate and calorific value. The calorific value of the gas increases as the equivalence ratio increases but after attaining the peak value, it starts decreasing because of an increase in equivalence ratio. The gas flow rate per unit weight shows the increase in nature as equivalence ratio increases. Even if the equivalence ratio is optimal, complete conversion of carbon to gaseous fuel does not take place. If we design the cone of gasifier at 60° angle then the effect of bridging can be reduced because the angle of repose of wood is 45°

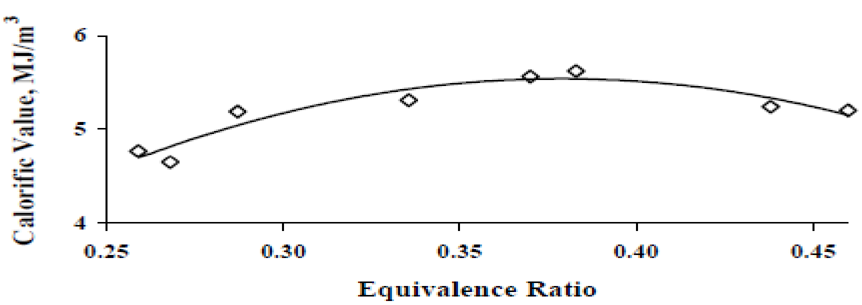

Fig. 2.16: Variation of calorific value with equivalence ratio. [60]

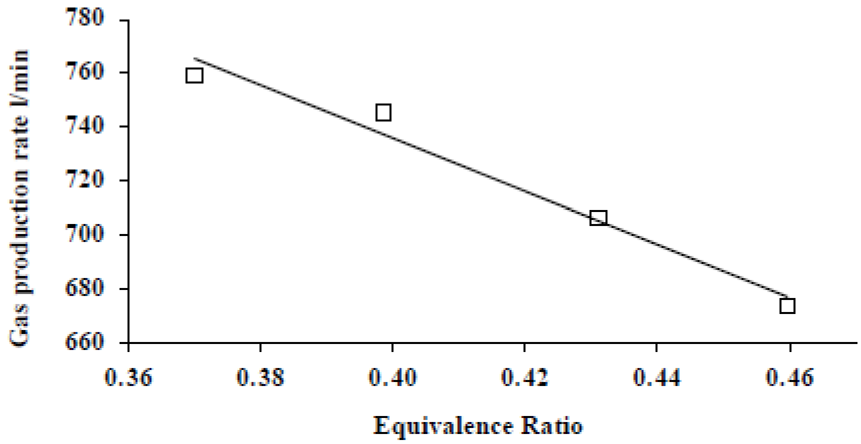

Fig. 2.17: Variation of gas production rate with equivalence ratio. [60]

A variation of the calorific value shows that the optimal equivalence ratio is 0.38. The cold gas efficiency of the gasifier is about 80% and overall efficiency of the biomass electric power producing system is around 10-11% and consumption of biomass material is around 2 kg/kW h.

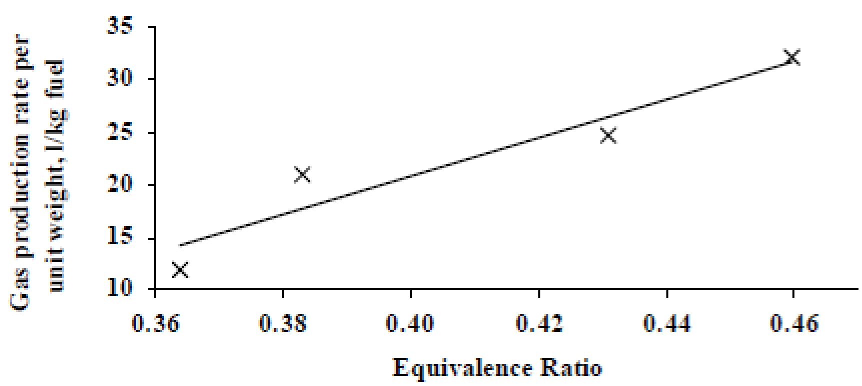

Fig. 2.18: Variation of gas production rate per unit weight of the fuel with equivalence ratio. [60]

Tripathi et al (1999) compared the unit cost of biomass based gasifier, liquefied petroleum gas and coal in institutional cooking system. For measuring the cost of all three systems, they made a mathematical formula and in this formula, they also considered the labor cost. They found that for a biomass gasifier system, unit cost is Rs 0.38/MJ for a 29kW_{th} and Rs 0.24/MJ for 291kW_{th}.

The trend in the LPG and coal based systems is almost similar with slight decrement in unit cost of thermal energy with the boost in thermal ranking. The overall result of the research is that biomass gasifier is cost effective as compared to coal and LPG based systems over $58kW_{th}$. The data is shown in the table 2.1.

Table 2.1: Unit cost of thermal energy in industrial cooking system. [61]

Thermal Ranking (kw_{th})	Unit Cost of thermal energy (Rs/MJ)		
	Gasifier based system	LPG Burner	Coal Oven
17.5	0.44	0.34	1.26
29	0.37	0.34	1.25
58	0.32	0.34	1.25
116	0.28	0.34	1.24
291	0.23	0.34	1.24

Jorapur R., et al.; (1997) by using low density biomass, manufactured a commercial-scale gasification structure (1085 MJ h^{-1}). Sweet sorghum stalks bajra stalks, sugarcane leaves and bagasse, were used as fuel in the gasifier. CV of the gas is 3.57-4.85 MJ/mm^3 and char produced in the system is 24wt%. First they used the system in the laboratory and then installed it into a metallurgical company where system was modified by them. After modification the system was fitted in the oil-fired furnace. The furnace was operated completely on the gasification system and they found output quality was enhanced.

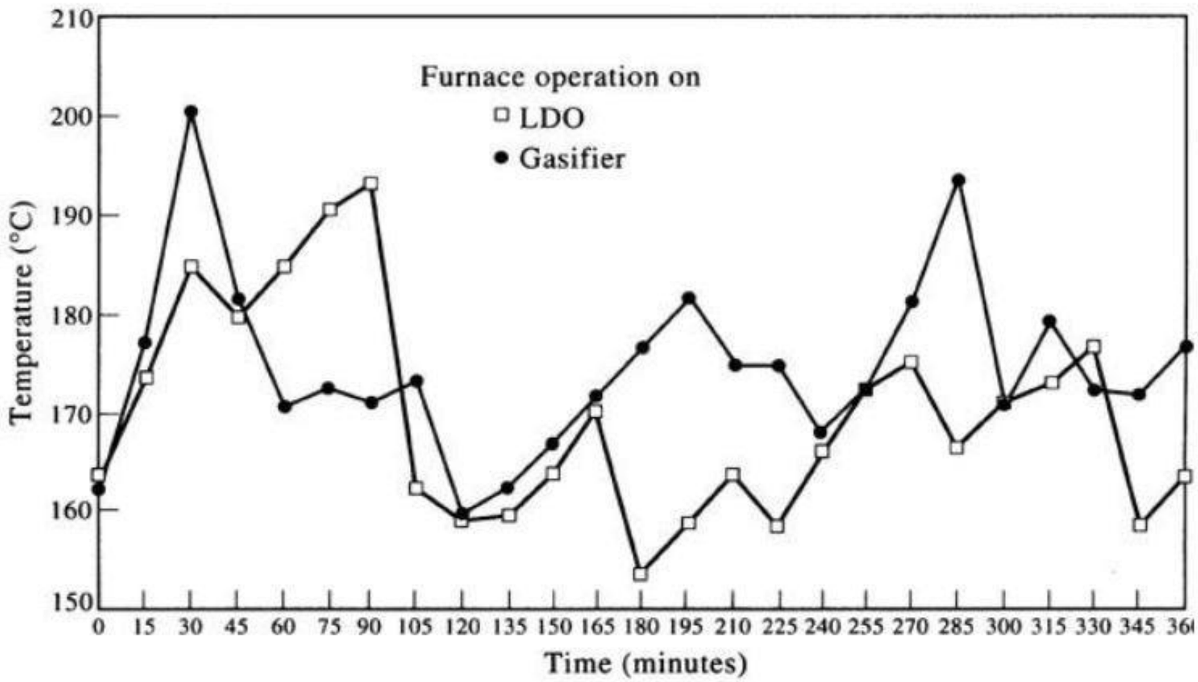

Fig. 2.19: Furnace temperature variation with time [62]

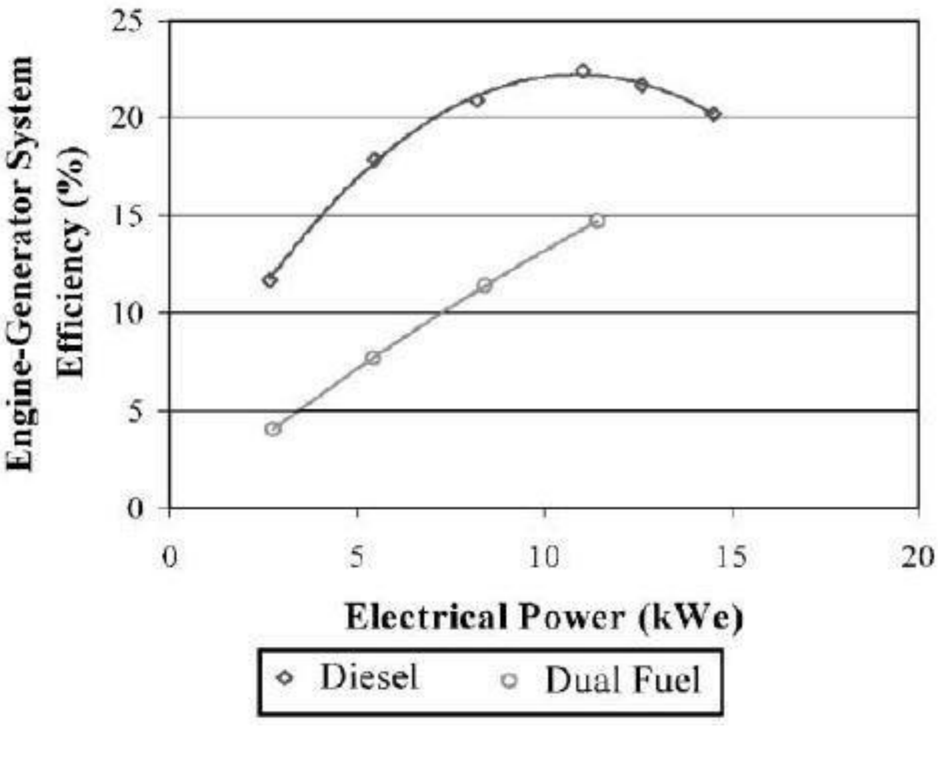

Fig. 2.20: Variation of engine–generator efficiency with electrical power output. [63]

2.2 Reflections

From the review of the research papers based on biomass and its usage in different areas, many advantages of biomass usage are noticeable. Some advantages and challenges of using biomass are mentioned below. [64, 65]

2.2.1 Advantages

- Use of biomass is nontoxic and biodegradable so no harm to environment.
- Economy of India would be strengthen by developing the biomass usage machinery.
- By the use of the biomass, import of the costly biomass is decreases.
- Knocking tendency of the engine is reduce, because biomass has reasonable cetane number.
- Biomass is usable with the established petroleum diesel infrastructure without no major modification.
- No aromatic and sulphur present in biomass.

2.2.2 Challenges

Some challenges present in the use of biomass as the IC engine fuels are mentioned below. [66, 67, 68]

- Storage and handling of the producer gas is difficult
- Price of the biomass is dependent on the various factors like drying, availability and transportation.
- Consistency, reliability and homogeneity of biomass feedstock is questionable.
- If we want to develop a major industry on biomass based IC engine than continuous availability of biomass needs to be assured.

Most of the villages in remote location areas still without the electricity. If we want to give electricity to remote places than decentralization of generation and distribution by using locally available resources is the only option. NASA's Earth Observing System Data and Information System released a photo of crop burning in North India (Figure 2.21). In this image red dots show the crop burn area in North India those are mostly located in the region of Punjab and Haryana. Each spot denotes thermal and fire anomalies detected by NASA's satellite. Effect of crop burn is very critical and it causes lots of health and environment issues. Effect of crop burn in Punjab and Haryana is shown in figure 2.22.

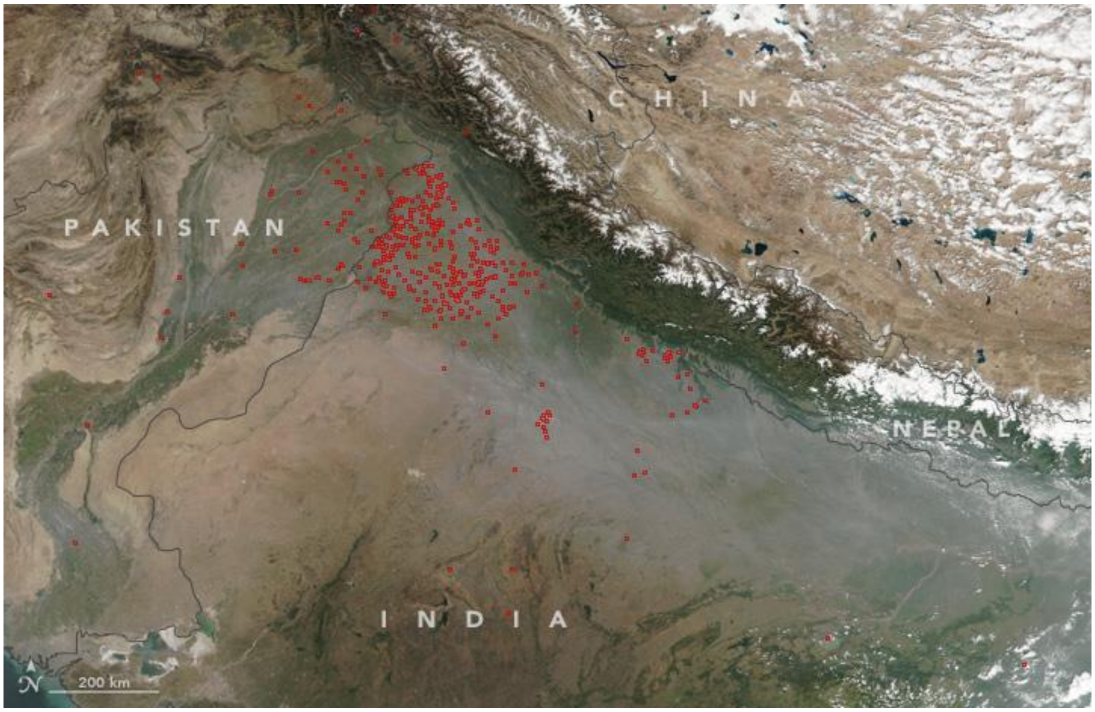

Fig 2.21: Crop firing in North India [69]

As a report presented by Hindustan times, tonnes of agricultural residue is burned in the month of October every year. Burning of crop residue triggers heavy smog formation in Delhi-NCR region in every October- November. Smog is very harmful for the environment because burning of one ton agriculture residue releases 2kg of SO_2, 3 kg of particulate matter, 199 kg of ash and 60 kg of CO. Those are harmful components and causes lots of environment pollution. Although lots of effects on environment by crop burning but it has not received much attention by the policymaker of India till now.

Increasing fossil fuel import causes large outflow of foreign exchange and its damaging the environment so now focus shifted towards the sustainable, renewable, eco-friendly and cost effective alternative fuel. Biomass gasification fulfilling all he above requirements so it was decided to research on gasification of bio-residue for possible power generation.

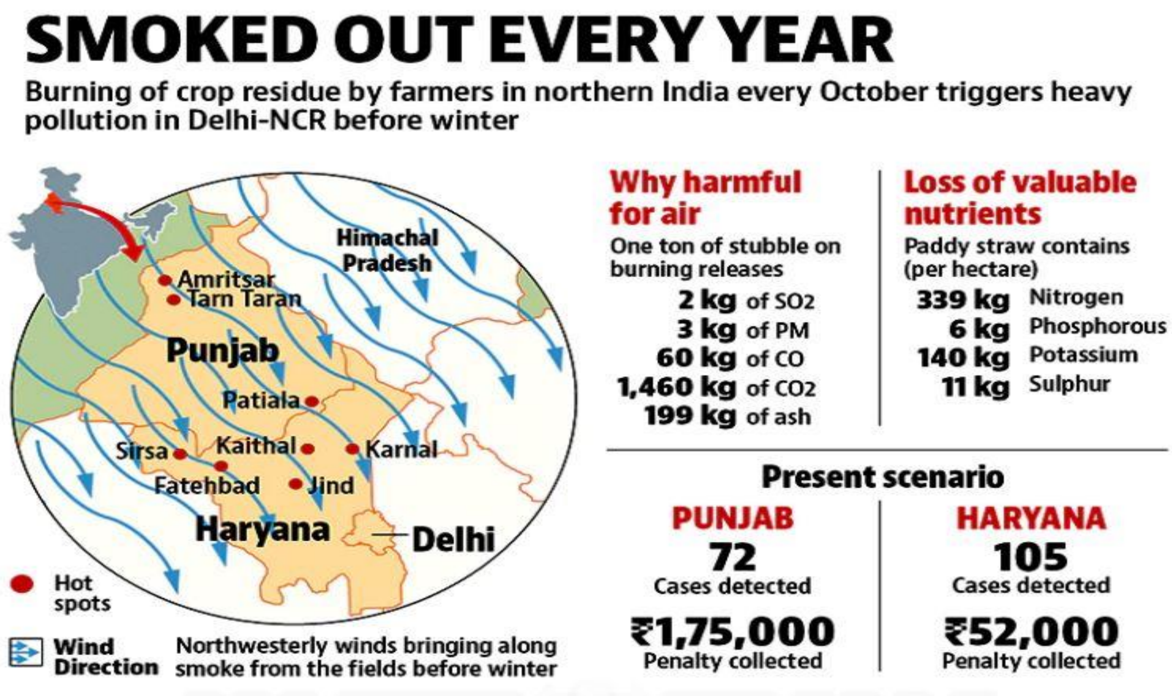

Fig 2.22: Crop firing and its effect on environment [70]

2.3 Problem Formulation

From the above literature review it is observed that lots of attention towards the biomass gasification from different agricultural residue but availability of agricultural residue highly depends on the season and weather. Availability of Pterospermum Acerifolium is significant and is widely distributed across India and not a single research on gasification of Pterospermum Acerifolium is observed. Following aims and objectives were planned in this work.

- **By using biomass fuel (Pterospermum Acerifolium) and diesel, study the performance of 5 kW dual fuel engine.**
- **Study the emission and noise characteristics of the dual fuel engine using Kanak Champa as feedstock in gasifier.**
- **Comparison of proximate analysis of Pterospermum Acerifolium with other biomass to ensure it is good for gasification or not.**

CHAPTER 3

EXPERIMENTAL SETUP

In the present study, Pterospermum Acerifolium plant, commonly known as Kanak Champa's fruit is used for the gasification using a downdraft gasifier. Investigation of various performance and emission characteristics of the engine using producer gas which is generated from the Kanak Champa are being covered this study. A methodology which is followed in the study is represented by the following flow chart in figure 3.1

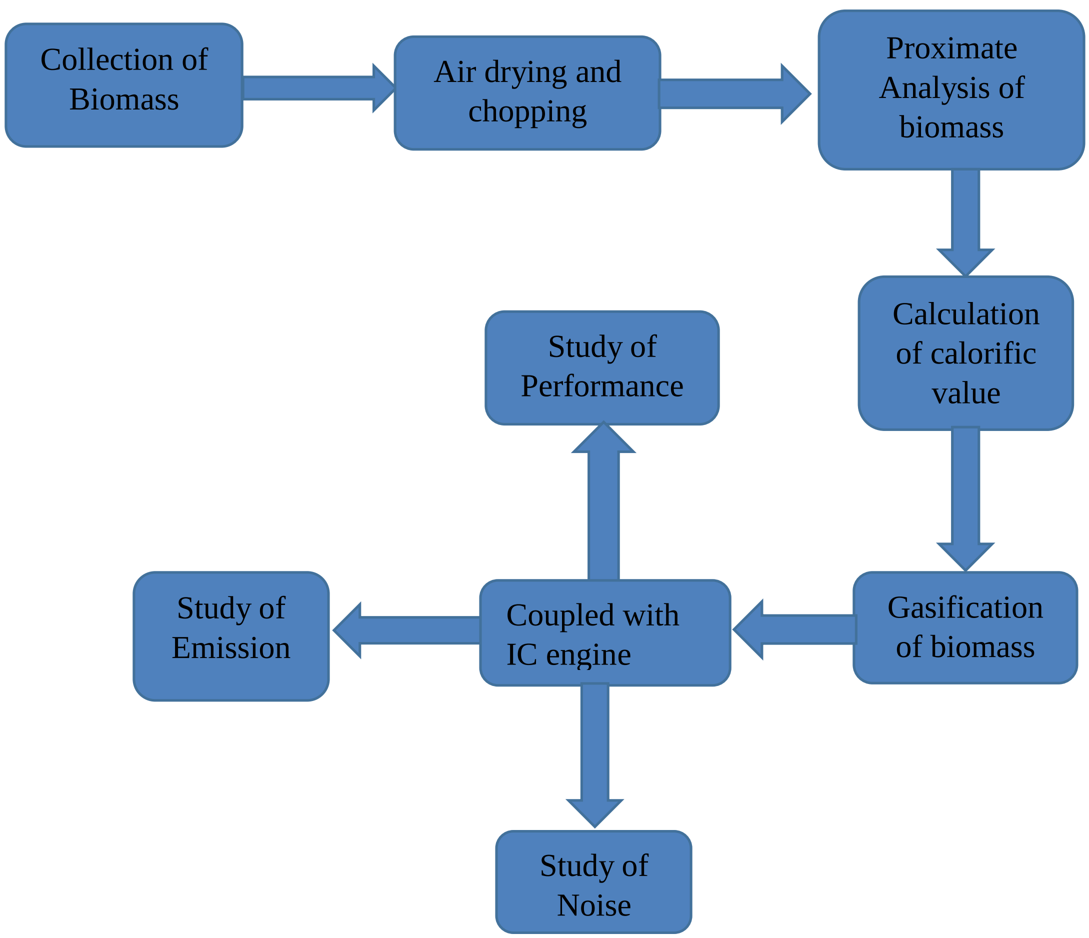

Fig. 3.1: Flow chart of methodology adopted for experimentation

3.1 Collection of raw material

In subcontinent region, Pterospermum Acerifolium occurs throughout the sub-Himalayan tract E region of the Yamuna, but is more towards the wetter eastern hills, MP and Orissa have scattered population. Outside India, its range extends through Myanmar and Thailand into Java. By the help of the gardener, approximately 150kg of biomass is collected which is totally wasted and burnt openly if not used as a biomass.

Fig. 3.2: Collection and Air drying of biomass.

3.2 Chopping

Air-dried sample of raw biomass is chopped into required size of below 20 mm by the help of chopper present in the mechanical department workshop. The full size of the biomass cannot be fed into the gasifier as it will cause choking. So, the chopping is required. If we want to develop it into large scale, we need to develop a proper chopper for this biomass because chopping by other instrument is time-consuming and can’t be used for larger scale operations.

Table 3.1: Size and Moisture Specification of Raw Material (air dried basis)

Raw material	Size		Moisture	
	Before	After	Before	After
Pterospermum Acerifolium	7-7.5 inch pieces	20-25 mm	<15%	<5%

3.3 Proximate Analysis

To determine the volatile matter, ash content, moisture content and fixed carbon proximate analysis is performed on the air-dried basis. The proximate analysis of samples is carried out by the standard ASTMD3172-73 (1984) and volatile matter content in the test sample is determined according to ASTMD3175-89. Ash content is determined by the ASTMD3174-89 method in electric furnaces and fixed carbon content in the test sample was calculated by the difference. 2gm powder of the wood piece was used for the proximate analysis and small silica crucible was used for the testing. First, silica crucible was cleaned and dehydrated by using an electric oven at 110°C and after that, it was placed in open for 15 minutes to cool down to atmospheric temperature. After that, it was weighed accurately using the digital weighing machine. The sample taken in the crucible is placed in an electric oven for removing moisture. Samples are heated for 1 hour at 110°C and stirred after some time interval so that the effective evaporation of moisture can take place by exposure of lower biomass. After removing a sample, it is placed in the desiccators. Now sample is weighted again and decrease in mass gives moisture content. Then put it back to muffle furnace at the temperature around 250°C for 30 minutes and after that weighted again. It is found that the volatile matters and remaining part put into the muffle furnace at the temperature of 600°C. It is burnt into ashes and the sample is weighted again. This loss in mass gives us ash content.

Fixed carbon in the sample is given by the following relation:

$$FC = \text{Total weight} - (\text{Moisture} + VM + \text{Ash})$$

3.4 Calorific Value

The calorific value of the sample was calculated by the oxygen bomb calorimeter according to ASTM D2015-(1985) standard. 1 gm of the sample was taken in the nichrome crucible and for the ignition, cotton thread of 15cm long was placed in the crucible over the sample. Both the electrodes of the calorimeter were connected by the nichrome fuse wire. A bomb was filled by the oxygen at the pressure of 25 to 30 atm. By switching on the current through the fuse wire, same was ignited and temperature rise of water was recorded accordingly. Calorific value of the sample was determined using following formula.

Calorific value = $(2382.32 \times T/x) - (E_1 + E_2)$

T = change in temperature of water

X = sample weight

$(E_1 + E_2)$ = weight of nichrome wire and cotton thread

Calorific value and result of the proximate analysis of the sample is shown in the table 3.2

Table 3.2: Proximate Analysis and Calorific Value of raw material (air dried basis)

Component	Pterospermum Acerifolium	Standard
Volatile matter (VM) (%)	71.95	CEN/TS 15148
Moisture (M) (%)	9.1	CEN/TS 14774-3
Ash (A) (%)	0.98	CEN/TS 14775
Fixed Carbon (FC) (%)	17.97	FC = 100 - VM - M - A
Calorific Value (CV) (kJ/kg)	21583.8 kJ/kg	BS EN 14918

3.5 Gasifier System

In the current study, a down draft gasifier system is used which is installed in the University campus. After generation of producer gas, cleaning of the gas is necessary so gas cleaning setup is also installed after the gasifier system. Schematic diagram of the gasifier along with cleaning system is shown in figure 3.3. Specification of the gasifier provided by the manufacturer according to the catalogue is shown in the table 3.3

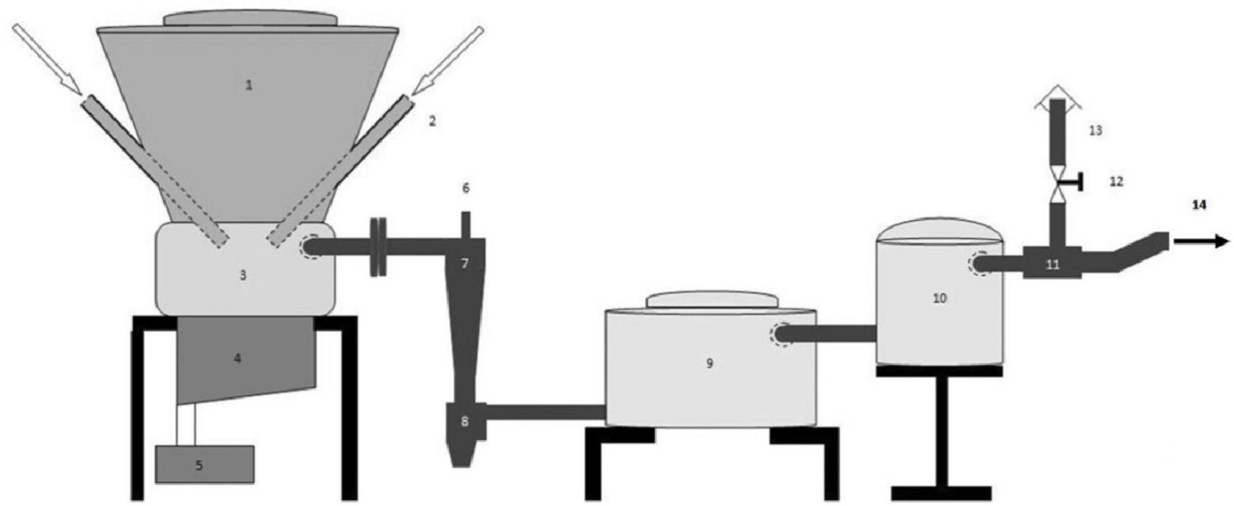

Fig. 3.3: Schematic diagram of the basic downdraft gasification system coupled with cleaning system

Parts of the gasification system are:-

1: Hopper and Zone 1 – Drying & pyrolysis

2: Air inlet

3: Zone 2 – Combustion

4: Zone 3 – Reduction

5: Drain tub for ash removal

6: Water inlet for the scrubber

7: Scrubber for cooling and cleaning of gas, particulate and moisture removal

8: Drain box

9: Secondary filter for tar

10: Safety filter for ultra-cleaning of gas

11: Bypass valve

12: Flare control valve

13: Flare burner for testing gas quality

14: Gas outlet for its further use

Pictures of the gasifier system were taken by myself shown in the figure 3.4

Fig. 3.4: Gasifier system

Fig. 3.5: Air opening

Table 3.3: Gasifier Specifications

Gasifier Make	Ankur Scientific Energy Technologies Pvt. Ltd.
Gasifier Model	WBG-10
Type	Downdraft with throat
Material of construction	Mild Steel, Stainless (SS 310) and molded refractory cement
Number of Air Nozzles	2
Flow rate (Nm3/hr)	25
Hopper Capacity (kg)	60
Combustion Zone Temperature (°C)	1100
Avg. Gas Calorific Value (kJ/Nm3)	4393.2 to 5439.2
Start Up	Through engine suction / Blower
Gas composition	CO=19±3%, H_2 = 18±2%, CO_2 = 10±3%, CH_4 = up to 3%, N_2 = 50%
Thermal Output (kW)	30.21

After coming out from the gasifier, the temperature of the producer gas is high and can't be fed into the engine. Apart from cooling of the producer gas carries a decent amount of tar and soot particle and we need to clean the gas because gas with tar and soot particles can deposit at the carburetor. So, for the cleaning and cooling of the cleaning system is installed after gasifier system and in this system consist following filters.

- Scrubber
- Secondary Filter
- Safety Filter

Scrubber: Gas temperature is around 450°C which is coming from the gasifier and it needs to be cooled so in the scrubber gas passes through the cold-water jets. Apart from cooling some dust, particulates and some part of tar washed out. Gases like HCL, H_2S, SO_2 and NH_3 are soluble in water also comes out. [71, 72, 73]

Secondary Filter: After the scrubber gas passes through secondary filter which is a cylinder like structure filled with the wood powder. The gas passes through the voids present in the wood powder and some particulate traps in them and extra moisture if is presently also absorbed by the wood it gives around 99% clean gas and temperature is around 45-50°C. [74, 75]

Fig. 3.6: Scrubber

Fig. 3.7: Secondary Filter

Safety Filter: To get ultra-clean gas safety filet is installed, which is small in size as compared to secondary filter. It contains paper filters which is able to catch extra small soot particles and by this, gas cleans around 99.99% and temperature is around 30-40°C. [76, 77]

Fig. 3.8: Safety filter

3.5.1 Precautions

- After some time-interval the ash from the reactor shall be cleaned.
- Size and moisture content of the biomass should be under the permissible limit.
- Biomass shall be fed carefully into the gasifier so that nails, stones and sand are not poured into the gasifier.
- Other than the feed door of the gasifier no parts or subsystem is an open when gasifier in operating condition. They should be opened after the cooled down of the gasifier and not in operation.

3.5.2 Problems in Gasification System

- Bridging and choking of the biomass if the size of the biomass fuel is not accurate.
- Storage and control of the gas is not possible so some part of the gas is going into the engine but another part is going to waste.
- Lack of data of air fuel mixture as well as engine to carry out proper modification.
- No such safety device and metering device to control the explosive and poisonous producer gas.

3.6 Producer gas Composition

Gas composition is done in the SAI LABs which is situated in our University campus. The method used for determining the gas composition is gas chromatography (NUCON5765). Gas sample is collected in the sampling bulb (gas sampling tube) shown in the figure 3.9. It has two ends and either of the ends can be attached to the gas pipeline for the collection of the sample. Gas enters in the bulb by piercing the septum tube.

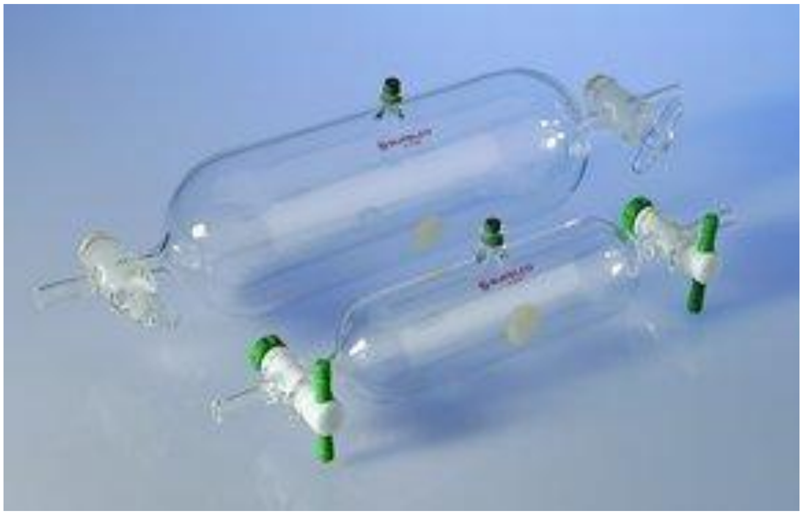

Fig. 3.9: Gas sampling bulb

First, attach the tube from one end and initially open the inlet valve for 5-10 seconds for cylinder to become pressurized. At this time, outlet valve has to be closed. After 10 seconds, carefully close the inlet valve. Now to vent the gas, open the outlet valve. Leave the outlet valve open until we can no longer hear gas escaping and then close it. This is to remove air from the bulb. Now again close the outlet valve and open inlet valve. After 15-20 seconds, close the inlet valve. Final report of the producer gas chromatography is shown in the table 3.4. The remaining percentage of the gas is nitrogen, but the temperature of the engine is low so nitrogen behaves like inert gas in the combustion chamber. Because of this, there is an increase in the NO_x emission in dual fuel mode.

Table 3.4: Composition of products present in producer gas

Gas	The percentage is presented in gas
Methane	1.6
Carbon Monoxide	19.5%
Carbon Dioxide	12.2
Hydrogen	17.6

3.7 Dual Fuel Engine Setup

Producer gas obtained from the safety filter is now entered in the inlet manifold of the dual fuel engine. In inlet manifold, producer gas is mixed with air. The flow rate of the gas is measured by the U tube orifice type flow meter. Reading comes out in the form of pressure drop in U tube manometer. A U tube manometer is shown in the figure 3.10.

Fig. 3.10: U tube manometer for Flow measurement

A single cylinder, dual fuel compression ignition engine is used for the experiment which is cooled by water and has electric start. The speed of the engine is controlled by the governor and because of the governor, engine is almost constant (1500 RPM). This setup gives the results of brake power, indicated power, volumetric efficiency, thermal efficiency, air fuel ratio, fuel consumption and heat balance.

Although the engine is of variable compression ratio type, but the readings have been taken on the compression ratio of 18:1 as from the past studies, it has been noted that the best results are obtained at the compression ratio 18:1. Various performances and emission characteristics of DFCI engine are studied. The flow rate control valve is used to control the gas flow rate and set at the 5.07Nm^3/hr. Three trials of the experiment are conducted at the same parameters to ensure correctness and repeatability. The engine was tested on dual fuel mode where diesel and producer gas are primary and secondary fuels respectively. Water valve was opened before starting the engine to supply cooling water to the water jacket.

Fig. 3.11: Dual fuel engine setup

Water supplied to the engine for cooling is at 250 LPH to 75 LPH. And an experiment was conducted at different load conditions from 0 to 10 kg. For air and gas flow, two orifices of diameter 20mm and 15.31mm respectively are used. All the graphs are plotted by using the average value of the corresponding parameters. Dual fuel engine setup is shown in the figure 3.11and dual fuel engine characteristics are shown in the table 3.5.

Table 3.5: DFCI Engine Specifications

Parameter	Specification
Engine make	Kirloskar
Engine model	AV-1
Engine type	VCRE (Variable Compression Ratio (CI Engine)
Cylinders	1
Strokes	4
Start type	Electric Start
Bore	87.5mm
Stroke	110mm
Capacity of the engine	553 cc
Connecting rod length	234 mm
Compression ratio	12-18
Dynamometer	Eddy current type
Dynamometer arm length	185 mm
Orifice diameter	20 mm
Fuel	Diesel alone and blends of diesel and producer gas
Cooling system	Water cooling
Maximum Power (Brake Power)	3.5 kW at 1500 rpm
Injection Pressure	190 bar
Dynamometer load nature	Mechanical load (0-12 kg)

3.7.1 Engine

The engine used in the study of performance and emission characteristics is a naturally aspirated, single cylinder, direct injection compression ignition engine made by Kirlosker. Bore diameter is 80 mm and stroke length is 110 mm. The output of the engine is 5HP at the speed of 1500 rpm, which is rated on the engine. For applying load, the engine is coupled with an eddy current dynamometer. A cooling system is also installed for cooling down the engine and the engine is mounted on the stationary frame.

3.7.2 Dynamometer

The engine is connected to a swinging field electrical generator meter with ward, which allows the engine to be started and motored likewise. By the dynamically changing the field sector current, load is controlled. The data acquisition panel board is fixed to the engine by the manufacturer which gives the reading of load (voltage and current). Reading was taken on different load condition so a reliable and accurate load measuring system was essential. For load measuring, an eddy current type dynamometer is installed with the engine which has a load cell of strain gauge type and a loading unit. The eddy current type dynamometer is shown in figure 3.12.

Fig. 3.12: Eddy current type Dynamometer

Load is applied by supplying current to the dynamometer by using a loading unit and load applied on the engine is measured by the load cell. By the dynamometer, we can measure the force, torque or power produced by the engine and by this we can apply load on the engine. In eddy current type dynamometer, load can be changed rapidly and this is beneficial in the rapid load setting. Parts of eddy current type dynamometer are rotor, bearing, shaft, casing and bed plate. The rotor is mounted on the shaft and the shaft is running in the bearings. Bearing rotates within the casing which is supported in ball bearing. Inside the casing, two field coils are connected in series. When a current is supplied in this coil by the loading unit, a magnetic field is generated inside the casing across the air gap on either side of the rotor. When the rotor turns in a magnetic field, eddy current gets induced and create a breaking effect between the rotor and casing. The rotational torque, which is exerted on the casing is measured by a strain gauge load cell. A load cell is a device which converts a mechanical signal into an analogous signal.

3.7.3 Speed Measure

The speed of the engine is measured by an electromagnetic pickup in conjunction with a digital indicator which is fixed to the data acquisition panel board. Near the flywheel of the engine, a magnetic pickup is fitted with pins mounted on the periphery. The signal which is generated from the engine is fed to show unit that shows speed in the range of revolution per minute (rpm).

3.7.4 Fuel Consumption Measurement

By using a fuel tank, fuel is supplied to the engine which has fuel sensor and. A glass tube is mounted on the fuel tank and it is connected to the data acquisition system. The fuel flow rate is measured by the time required for the consumption of a known amount of fuel.

3.7.5 Exhaust gas temperature measurement

At the exhaust manifold of the engine exhaust, a Nickel-Nickel chromium thermocouple is fixed which gives the reading of the exhaust gas temperature. This reading is noted by the data acquisition panel board.

3.8 Experimentation Methodology

For study of performance analysis of dual fuel engine performance and emission parameters, the experiment is conducted in two modes-

- Single fuel mode (only diesel)
- Dual fuel mode (blend of producer gas and diesel)

The result of the performance of the engine is compared in terms of Brake power, brake specific fuel consumption, brake thermal efficiency, and exhaust gas temperature. Emission of the engine is analyzed in relation with NO_x, CO, HC. Noise level at different level is also evaluated.

3.8.1 Experimental Procedure

- First, check all the electric connections and proper earthing.
- Make sure water supply is proper in the main water supply tank.
- Diesel is properly filled in the fuel tank and fuel knob is placed on regular position.
- After starting water pump, set cooling water flow for calorimeter 80 LPH and for the engine at 300 LPH and insure adequate water supply for dynamometer.
- After starting the electric supply to the computer, open the engine software.
- Apply load by using the rotary knob.
- Start electric power supply to the flue gas analyzer.
- Start the engine switch and let the engine run on the minimum load.
- Change fuel properties (specific gravity and calorific value) in the software by choosing configure option.
- Choose run option in the software and after that run the engine for 15 minutes, so that the engine gets stabilized and then turn the fuel supply switch to metering position. Now choose the log option of the software. After 1-minute, the display of the computer changes to input mode and then enter the value of water flow in cooling jacket and calorimeter and then the file name (applied only for the first reading) in the software. First reading for the engine is logged in at no load condition. After that, turn the knob at regular position.
- Now open the valve of flue gas analyzer by closing the back-pressure valve. When the valve has stabilized, take reading for flue gas.
- Now increase the load to 2 kg and allow the engine to run for 10 minutes, so that the engine gets stabilized and after that turn the fuel knob to metering position. Now, choose the log option from the software. After one-minute, feed the cooling water and turn back the knob to normal position. Take the reading of flue gas analyzer.
- Repeat the procedure for loads 4, 6, 8 and 10 kg.
- Now reduce the load at minimum position and make sure rpm of the engine does not go beyond 1500.
- After saving the files, put off the engine and computer.
- For the cooled down of the engine, allow water pumps for 10 minutes and then put off the pumps.

3.9 Measurement of Performance Parameters

The ratio of power developed to the maximum usable power (at the same speed) is called as load. Specific fuel consumption depends on the load and speed. The performance of the engine depends on the relationship between speed, specific fuel consumption and power developed at every operating condition, but speed and load should be in useful range.

The performance of the engine mainly depends on how well the engine is working. It is measured as how the input energy is consumed and how efficiently it gives output energy as compared to other engines which also run on the same speed and load. The performance of the engine is judged based on two factors: engine power and engine efficiency. These parameters are studied under specific fuel consumption and efficiency curves respectively.

Brake power is an important parameter in engine experiment. Determining the time required for consumption of given volume fuel gives the fuel consumption of the engine. The mass of the fuel is obtained by multiplying the density to its volumetric fuel consumption. Following parameters were measured from the experimental engine setup.

- Brake power
- Brake mean effective pressure
- Specific fuel consumption
- Brake thermal efficiency
- Air fuel ratio
- Exhaust gas temperature
- Unburned HC, NO_x and CO emission

3.9.1 Brake Mean effective pressure

For improving different fuels, BMEP is an important concept. Average pressure exert on the piston through one complete operating cycle is termed as brake mean effective pressure. It can be defined by the Inside the engine average pressure of the gas based on neat power. BMEP does not depends on the RPM and size of the engine. BMEP is expressed as follows.

$$\mathbf{BMEP = (4\pi T/V_H) \times 10^{-2}}$$

T = brake torque (in Nm) and V_H = engine total displacement volume (in L)

3.9.2 Brake Specific Fuel Consumption

Brake specific fuel consumption is defined as the fuel flow rate per unit power output. Lower value of BSFC is desirable. It means engine is consuming less fuel to generate same amount of energy. When we testing on various fuels this is the most important parameter. Expression of BSFC is as follows.

$$\mathbf{BSFC = (M_A/AFR) \div P}$$

M_A = mass flow rate of intake air (g/h)

P = Brake power (kW)

Power can be calculated by following expression.

$$\mathbf{P = T\,(2\pi N/60) \times 10^{-3}}$$

N = speed of engine (rpm).

3.9.3 Brake Thermal Efficiency

Brake thermal efficiency is the ratio of, thermal power available in the fuel to the power the engine delivers to the crankshaft. It is highly depends on how energy is converted because efficiency is normalized with fuel heating value. Expression of the BTE is as follows.

$$\mathbf{BTE = (3600 / (BSFC \times LHV)) \times 100}$$

LHV = Lower heating value of fuel (MJ/kg)

3.9.4 Exhaust gas Temperature

Enthalpy contain in exhaust gases of an IC engine is very significant and they also contain unburned combustion products. Amount of incomplete combustion products is low when air fuel ratio is high. System efficiency is depends on the exhaust gas temperature.

3.10 Noise and its characteristics for DF engines

Unwanted form of sound is known as noise. Nature of noise is quite disturbing and annoying. Noise coming from vehicles, loud speaker, and heavy machines are few form of noise. [78]

3.10.1 Terms in sound analysis

3.10.1.1 Sound waves

Sound waves are generated due to variation of pressure in mechanically operated instruments. [79]

3.10.1.2 Sound power

Sound is a form of energy and sound produced due to the pressure variation. A significant amount of power is linked when transfer of sound happen, which is known as sound power. Sound power is measured in watts (W). [79]

3.10.1.3 Sound pressure level

Sound pressure level is the logarithmic ratio of the measured sound intensity to the reference sound intensity. Sound intensity level measured in decibel (dB). [80]

3.10.1.4 Sound intensity

Sound intensity is the ratio of sound power to the area covered by the sound. Sound intensity is also defined by measurement of the power through certain area up to that distance which is covered by sound waves from its source. [81]

3.10.1.5 Sound intensity level

Sound intensity level is measured in decibel and it is the ratio of measured sound intensity to the reference sound intensity. [81]

3.10.1.6 Hearing range

Hearing range is the range of frequencies which can be heard by a normal living creature. Hearing range is different for different living creature. For human this range is 20 Hz to 20 kHz.

3.10.1.7 Threshold of hearing

Threshold of hearing is the sound level whose pressure is 20 μPa. Absolute threshold of hearing is the level of a pure tone which can hear by a normal human ear who has normal hearing. [82]

3.10.1.8 Threshold of pain

It is the pressure level which is painful for a human being and it causes problems like physical damage and hearing impairment. Value of threshold of hearing lies above 130dB. [83]

Table 3.6: Threshold of pain [83]

Sound level	**Sound pressure**
120 dB	20 Pa
130 dB	63 Pa
134 dB	100 Pa
137.5 dB	150 Pa
140 dB	200 Pa

3.10.1.9 Noise

It is the unwanted sound which can be loud as the jet or tiny as the mosquito buzz. Some examples of sources with their respective sound levels are shown in table 3.7.

Table 3.7: Some examples of sources with their respective sound levels. [84]

Source	**Sound power (W)**	**Level (dB)**
Lowest audible sound for persons with excellent hearing	0.000000000001	0
Voice-very soft whisper	0.000000001	30
Quiet-Duct silencer, self-noise at +1000 ft/min	0.00000001	40
Voice-conversational level 0.00001	0.00001	70
Dishwashers-upper range	0.0001	80
Food blenders-upper range	0.001	90
Auto on highway	0.01	100

Blaring radio, centrifugal fan at 22,087m³/hr	0.1	110
Large chipping hammer	1	120
75 piece orchestra, Vane axial fan at 169,900 m3/hr	10	130
Centrifugal fan at 849,000 m³/hr	100	140
After burning jet engine	100000	170
Saturn rocket	100000000	200

3.10.2 Noise characteristics of a dual fuel engine

Dual fuel engines have many reciprocating machinery, they are the sources of noise. Mainly two types of noise present, these are:

3.10.2.1 Exhaust noise

Exhaust gases present in the engine manifold sent into the atmosphere, with the help of tail pipe. Exhaust gases get compressed during the scavenging action. Because of this compression of exhaust gases pressure waves generated which produce the sound waves. These sound waves come out in the form of exhaust noise. From engine manifold to gas exhaust to the atmosphere many orifices present and because of these orifices gas gets compress and decompress. So these orifices work as the secondary sources of exhaust noise. [85]

3.10.2.2 Combustion noise

Uneven and unsteady combustion of the fuel in the combustion chamber causes combustion noise. In the dual fuel engine the pressure forces are responsible for the combustion noise and these pressure forces mainly depends on fuel injection system. And fuel injection system is further dependent on fuel’s physical and chemical properties like viscosity and bulk modulus. In case of CI engine it depends on cetane number and in case of SI engines it depends on octane number. Combustion noise is also depends on design of the combustion chamber. Some other reasons of combustion noise are as follows: [86]

- Improper combustion of the fuel because of uneven charge distribution.
- In case of DFCI engine knocking and in case of DFSI engine detonation are the causes of combustion noise.

For measuring the noise level SC-310 – sound level meter which is manufactured and marketed by M/S CESVA, Spain and it is tested and approved by ARAI Pune is used. Noise produced at the running of the engine is measured by noise level meter. CESVA sound level meter is shown in Figure 3.13.

Fig. 3.13: Sound level meter.

3.11 Emission characteristics of the DF engines

Emission in dual fuel mode is lower than the single fuel mode. At higher loads in dual fuel mode diesel and gaseous particles are well distributed and combustion happens rapidly so not much chance of incomplete combustion. That's why emission in dual fuel mode at higher load is very less. [87]

At lower load condition is little bit different, air deficient atmosphere present inside the combustion chamber which leads the incomplete combustion of the pilot fuel. Due to this concentration of HC and CO emission is high but exhaust gas temperature and NO_x emission is not that high because of the incomplete combustion of the fuel, temperature inside the combustion chamber is not high enough to form NOx same in the case of exhaust gas temperature. Reduction of NO_x is around 45% to 70%. [88]

Analysis of the flue gases was done by the Sophisticated Analytical Instruments Laboratories Society (SAI Labs, Patiala) by using flue gas Analyzer (Horiba) for unburnt hydrocarbons and Analyzer (KM9106) for nitrous oxide and CO.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Performance Characteristics of the DFCI Engine

For measurement of performance parameters, a computerized CI engine set up is installed. This setup is connected to a high- speed data acquisition system which was provided by Apex innovations. All the performance parameters are discussed below and to get better graphical representation, the average of the all the values at each load condition has been taken.

4.1.1 Brake Power

Brake power shows the linearly increasing trend with increase in load in both dual fuel and pilot fuel mode. Highest break power is 2.88 kW in dual fuel mode and in the pilot fuel mode, it is 3.29 kW. Brake power in dual fuel mode is slightly less because the CV of the gas is low. The brake power curve is shown in Figure 4.1. This trend of the brake power is there because of the incomplete combustion of the dual fuel and the air-deficient atmosphere in the cylinder. The quantity of air in the combustion chamber is low because the mixture of air and producer gas is sucked into the combustion chamber and this leads to incomplete combustion of the fuel.

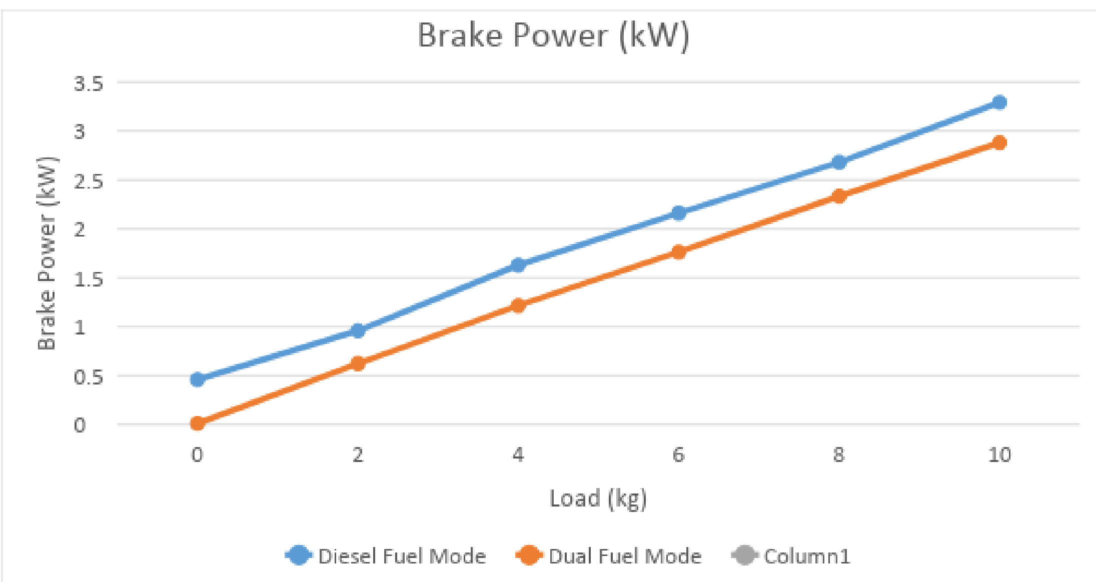

Fig. 4.1: Variations of brake ower to change of load

4.1.2 Brake Thermal Efficiency

Brake thermal efficiency shows the increase in nature as the load increases (same as the brake power) because brake thermal efficiency is proportional to the load (same as the brake power). Brake power in diesel fuel mode has the highest value as 28.19% and the lowest value as 4% and in dual fuel mode, the highest value is 25.14% and the lower value is around 1.61%. Reason of the low value of brake thermal efficiency in dual fuel mode is incomplete combustion of the fuel and low CV of gas. Curve of the brake thermal efficiency is shown in figure 4.2.

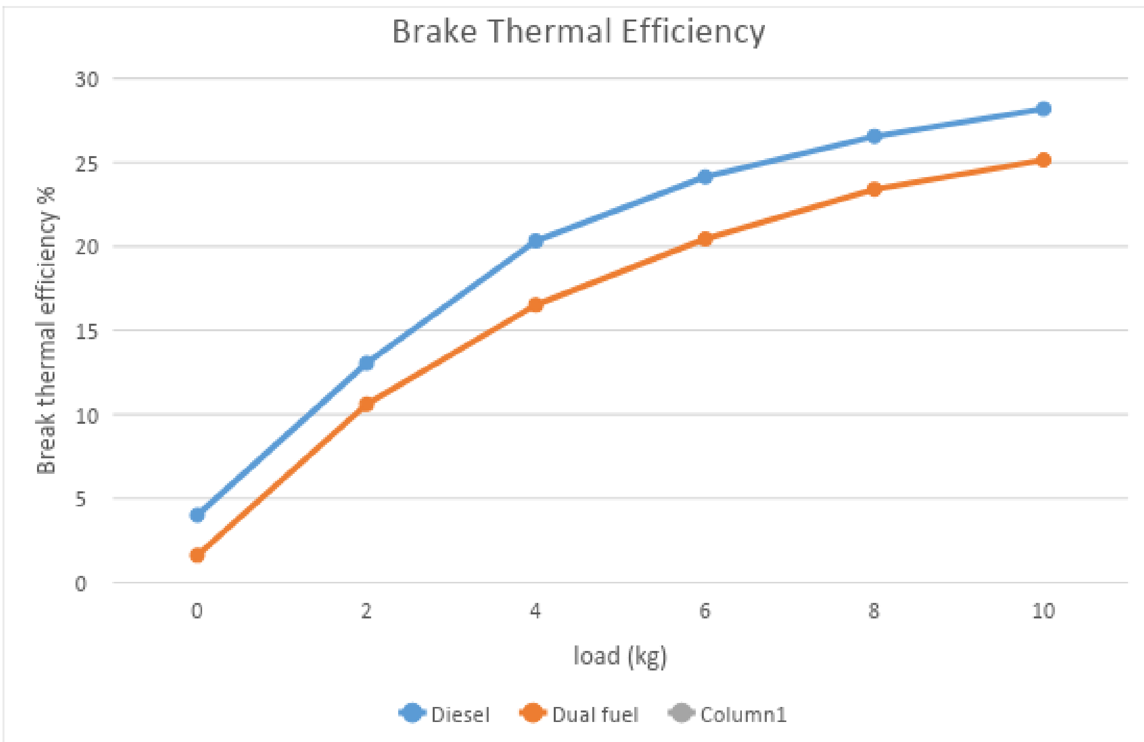

Fig. 4.2: Brake thermal efficiency with a variation of load

Effect of different size particles on the brake thermal efficiency is almost negligible Hanoka et al (2005) reported that cellulose type biomass have 27% by vol. CO_2, 35.5% by vol. CO and 28.7% H_2 in the producer gas. Energy level is increased by the use of producer gas in traditional IC engines.

4.1.3 Fuel Consumption

If we replace the diesel fuel by some amount of producer gas then consumption of diesel fuel is less in this case. Fuel consumption shows the constant increase in both the cases as the load increases. In the dual fuel mode, diesel fuel consumption is around 45-50% lesser than that of diesel fuel mode. This is because in dual fuel mode, mixture of diesel and producer gas is fed to the engine, but in diesel mode, only diesel is the fuel fed to the engine. At higher loads, diesel fuel saving is higher in dual fuel mode as compared to lower loads because at higher load, fuel mixture provides better ignition. Curve of the fuel consumption is shown in figure 4.3

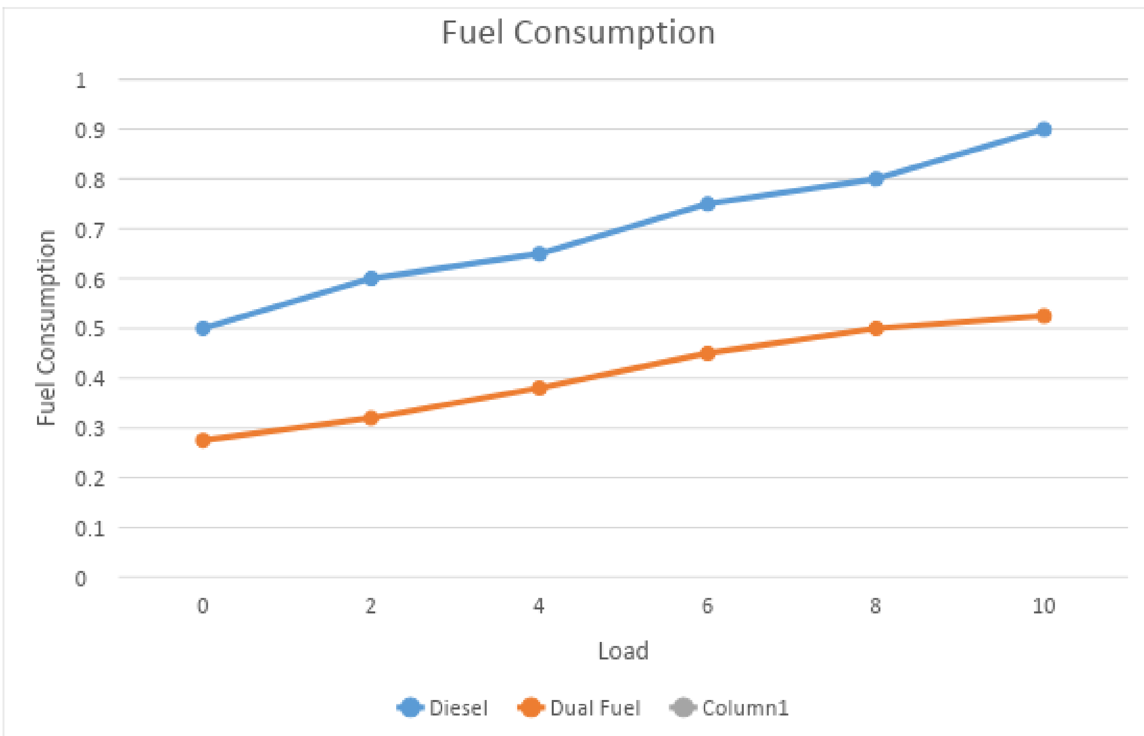

Fig. 4.3: Diesel fuel consumption with variation of load

4.1.4 Brake Specific Fuel Consumption

Brake specific fuel consumption curve shows the decreasing trend as load increases in diesel mode. In the dual fuel mode, it shows a sudden decrease in the curve for around 33%v of load and after this point, it follows the constant decrement in the curve. At the start of the engine, there is high gas consumption at the lower load to generate a significant amount of power output. So, BSFC starts with high value. After that, governor supplies a high amount of diesel to fulfill the power output and because of this, there is a sudden decrement in the BSFC. After that, more diesel is injected as the load increases, which results into the constant decrease as the load increases. Curve of the brake specific fuel consumption is shown in figure 4.5

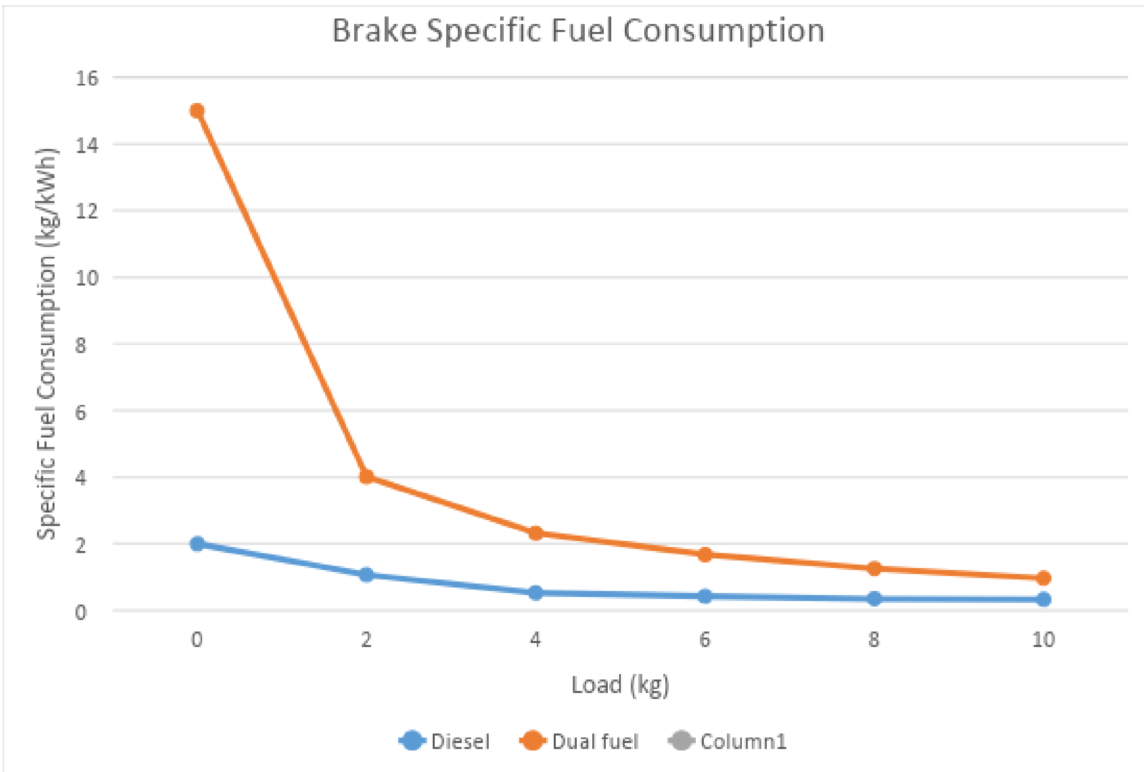

Fig. 4.4: Brake specific fuel consumption with a variation of load

Uma et at (2004) reported the diesel saving is 67-86% and **Ramdhas et al (2006)** reported the diesel saving is around 50%. Initially large particle size biomass consumes less diesel in comparison to other biomass size. At higher load diesel saving is same in both type of size distribution cases. Diesel saving is mainly depends on the injected fuel properties. [6, 24, 67]

4.1.5 Brake Specific Energy Consumption

This curve shows the same trend as the BSFC. It follows decreasing trends as the load increases. It starts with the highest value and then there is a sudden decrease in BSEC for the dual fuel mode at ≤33%. Reason of this is also same as that of the BSFC. It starts with a very high value and after the increase in supply of diesel by the governor, value goes down suddenly. After this, there is a very similar constant decrease in BSEC. CV of the dual fuel varies at every load value because of the variable gas composition of gas and diesel. Curve of brake specific energy consumption is shown in figure 4.6.

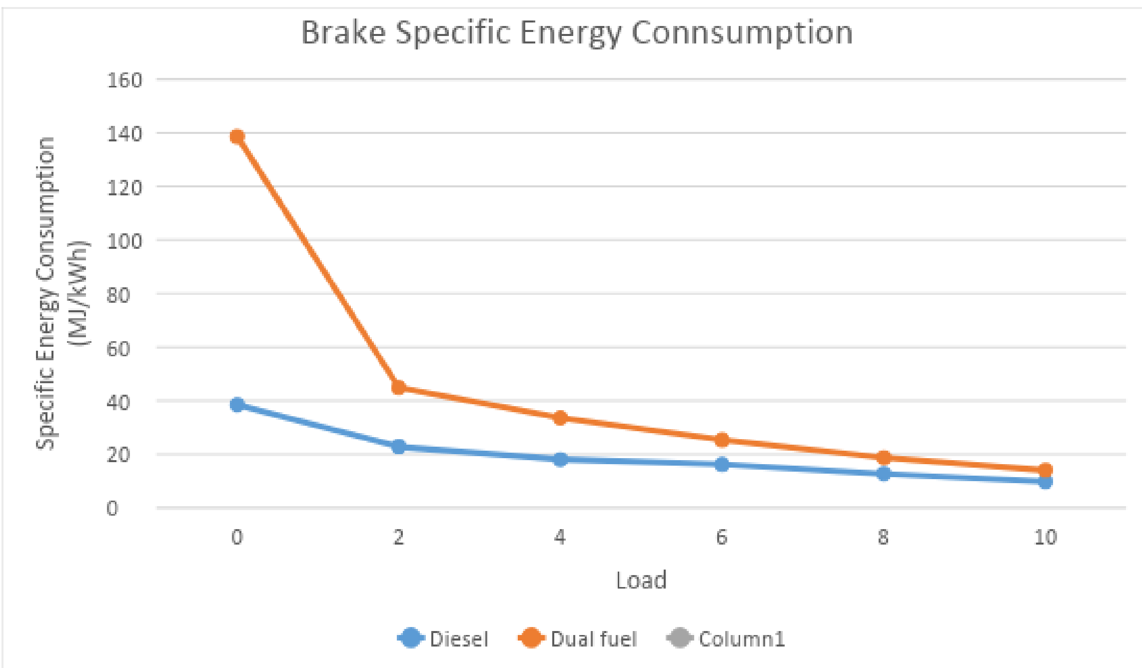

Fig. 4.5: Brake specific energy consumption with variation of load

4.2 Emission Characteristics

Emission characteristics of the dual fuel engine are recorded by the instrument "Maxicem portable gas analyzer" model ACE-8000 and this is based on the IR absorption principle. Different gases absorb different wavelength of different infrared radiation.

4.2.1 Hydrocarbon Emission

The HC emission curve shows increasing trends as the load increases. In the dual fuel mode, its value is higher as compared to the diesel fuel mode because there is more air supply in diesel fuel mode while in the dual fuel mode, some air is replaced by the producer gas. In diesel fuel mode, all the air is available only for combustion of diesel fuel and only liquid-gas reaction takes place, but in the dual fuel mode, diesel is mixed with the gas and two reactions, diesel-gas and gas-gas takes place. Gas-gas reaction's speed is higher than the liquid-gas reaction. So, very less amount of air remains for combustion of diesel due to which there is a higher HCs emission in dual fuel mode. In the producer gas, there are very high percentage of N_2 which is an inert gas and particle collision probability decreases because of that, chance of fuel molecule combustion also decreases. Curve of HC emission shown in figure 4.7.

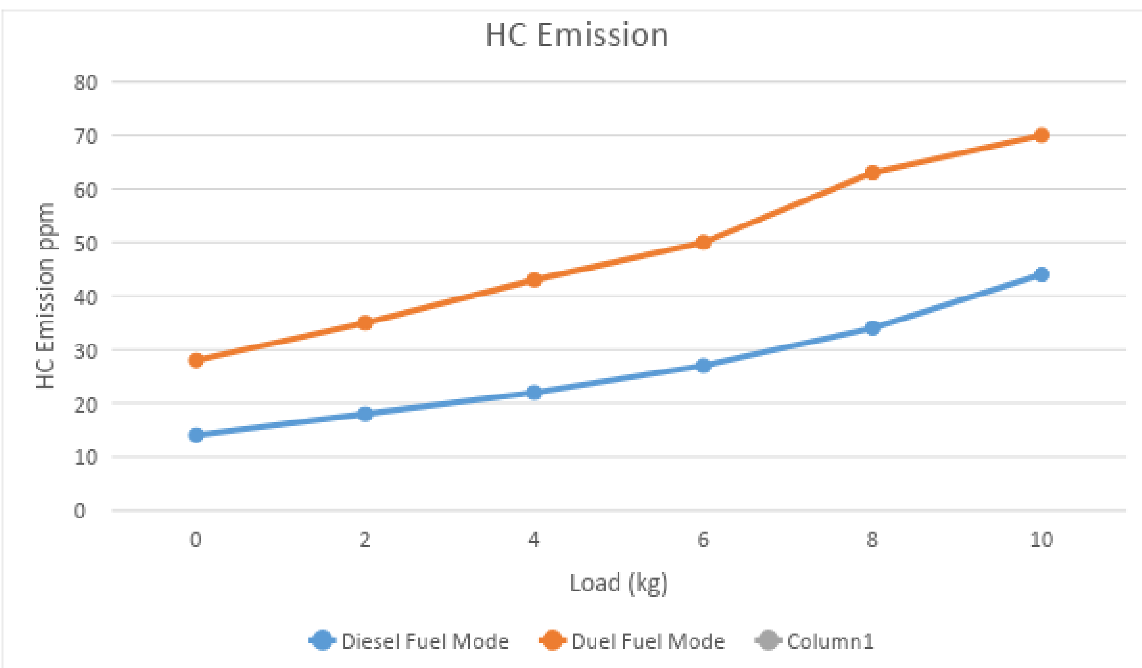

Fig. 4.6: HC emissions with variation of load

4.2.2 Carbon Mono Oxide Emission

The CO emission curve shows the increasing trend when load is increasing in both diesel and dual fuel mode. In dual fuel mode, emission of CO is higher as compared to the diesel fuel mode and it shows almost linearly increasing trend. Reason of this is explained earlier. Some part of the fuel does not participate in the combustion because of the insufficient oxygen in combustion chamber and poor mixing of the fuel, so CO emission increases. CO curve shown in figure 4.8. At maximum load CO emission is 0.026 volume percentage which is maximum.

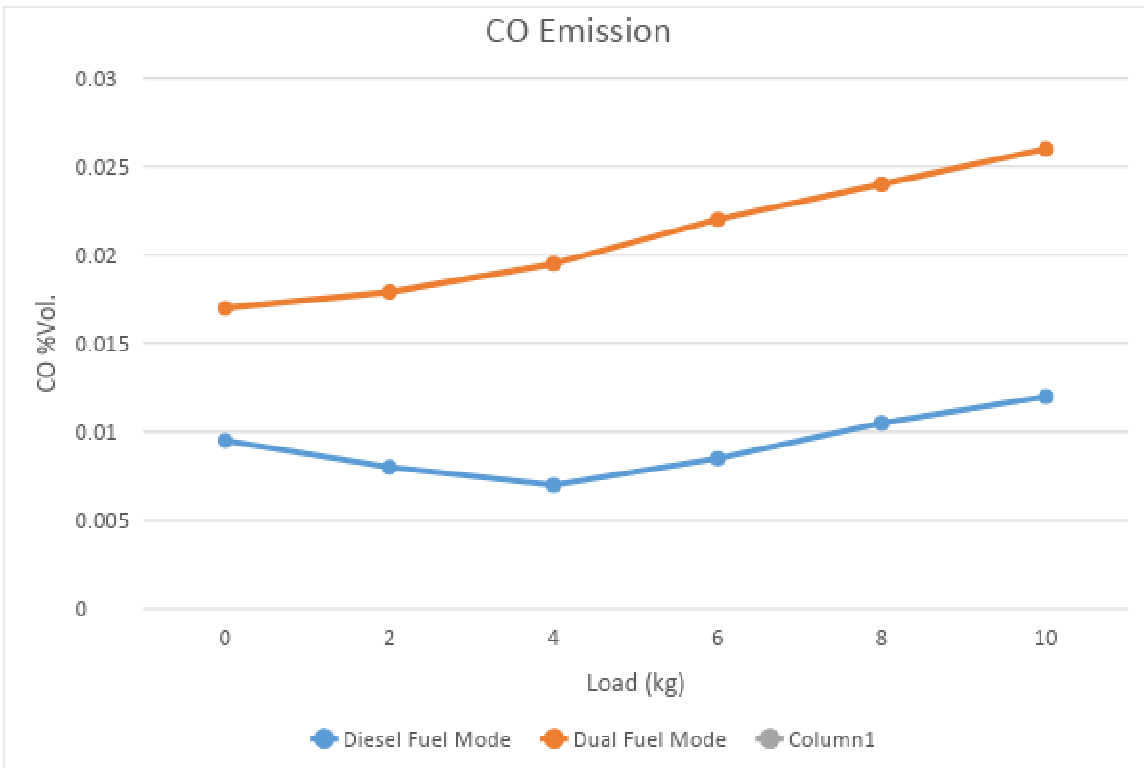

Fig. 4.7: CO Emission with variation of load

4.2.3 Exhaust Gas Temperature

Exhaust gas temperature shows an increasing trend in both diesel and dual fuel mode when load is increasing. Exhaust gas temperature is higher in diesel fuel mode as compared to the dual fuel mode because CV of the producer gas is lower (so the heat generated is low). One more reason is that amount of N_2 in the producer gas is very high as compared to diesel fuel. N_2 absorbs more sensible heat and because of this temperature of the exhaust gas temperature is lowered down. Highest exhaust gas temperature in dual fuel mode is 140°C and in the diesel fuel mode, it is 205°C. Exhaust gas temperature curve is shown in figure 4.9.

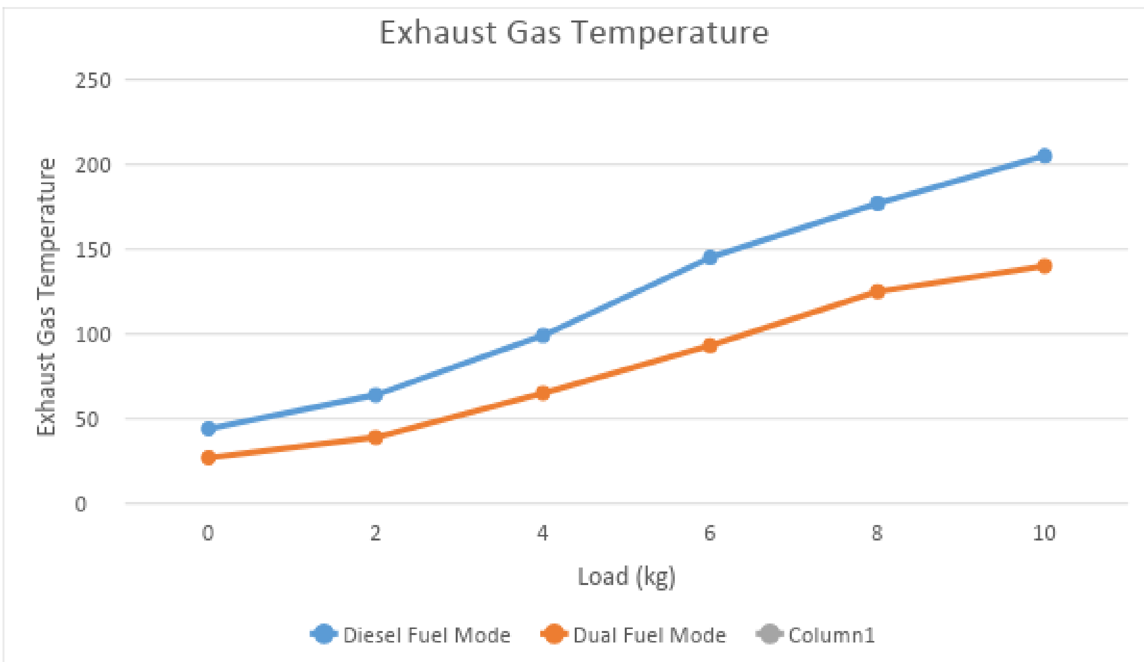

Fig. 4.8: Exhaust gas temperature with variation of load

4.2.4 Nitrogen Oxide Emission

NO_x emission shows an increasing trend as load increases in both the cases but slope is different. Value of NOx in diesel fuel mode is higher. The slope is also higher in this case as compared to the dual fuel mode. This is because the dual fuel mode temperature in the combustion chamber is lower as compared to the diesel fuel mode and NO_x emission depends on the temperature of the combustion chamber. By the curve we can see that the maximum NO_x emission in the exhaust gas is around 40ppm in dual fuel mode. So, the decrease in NO_x emission is around 67.8%. Curve of the NO_x emission is shown in the figure 4.10

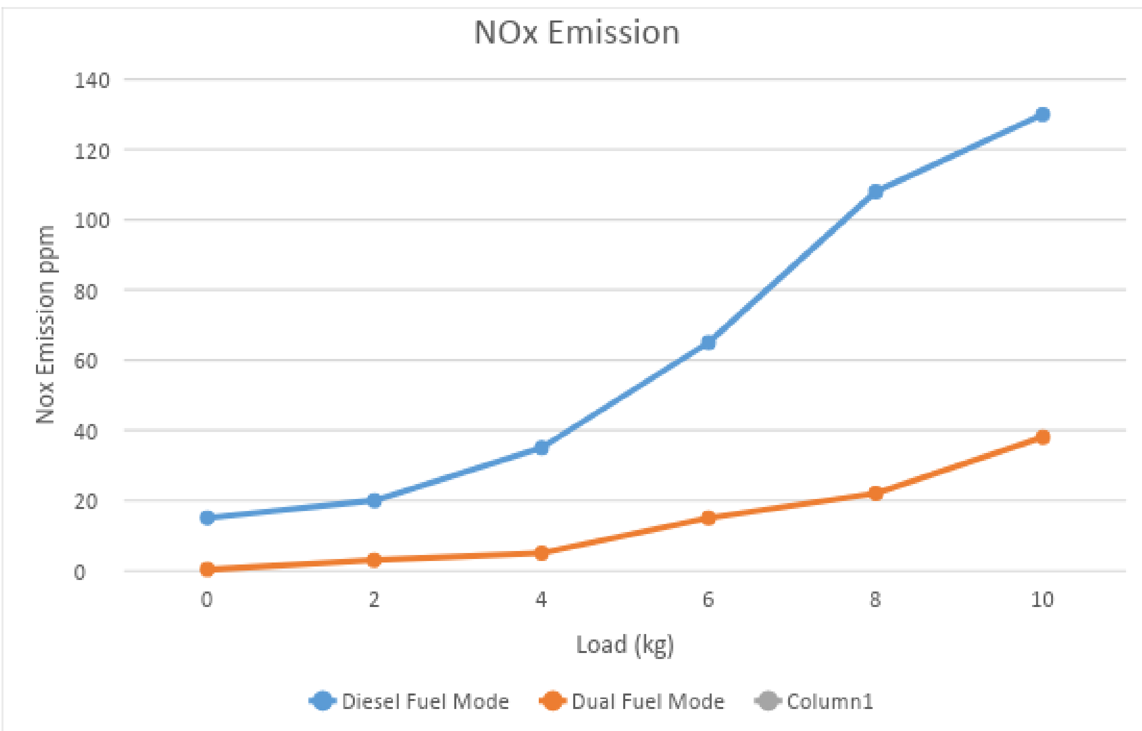

Fig. 4.9: NO_x emissions with variation of load

4.3 Noise Characteristics

For the noise measurement **CESVA Sound Level Meter and Spectral Analyzer** model **SC3 10** was used. The curve shows the increasing trend at the start of the engine in both fuel modes, but in dual fuel mode, at around >80% load it starts showing a decreasing trend. In the diesel fuel mode around >65% load. Noise is higher in dual fuel mode as compared to the diesel fuel mode and reason for this curve is the dependency of noise emission on the physical and chemical properties of the fuel. If the density and viscosity is high on the fuel, the noise is low and if the density and viscosity of the fuel are low, noise is high. In the dual fuel mode, the amount of diesel used is lesser as compared to pilot fuel mode because it has mixture of gas and liquid fuel and diesel has high density and viscosity. Because of this noise is high in dual fuel mode. Around 3.2dB, sound level increases in dual fuel mode. Curve of noise characteristics shown in figure 4.11

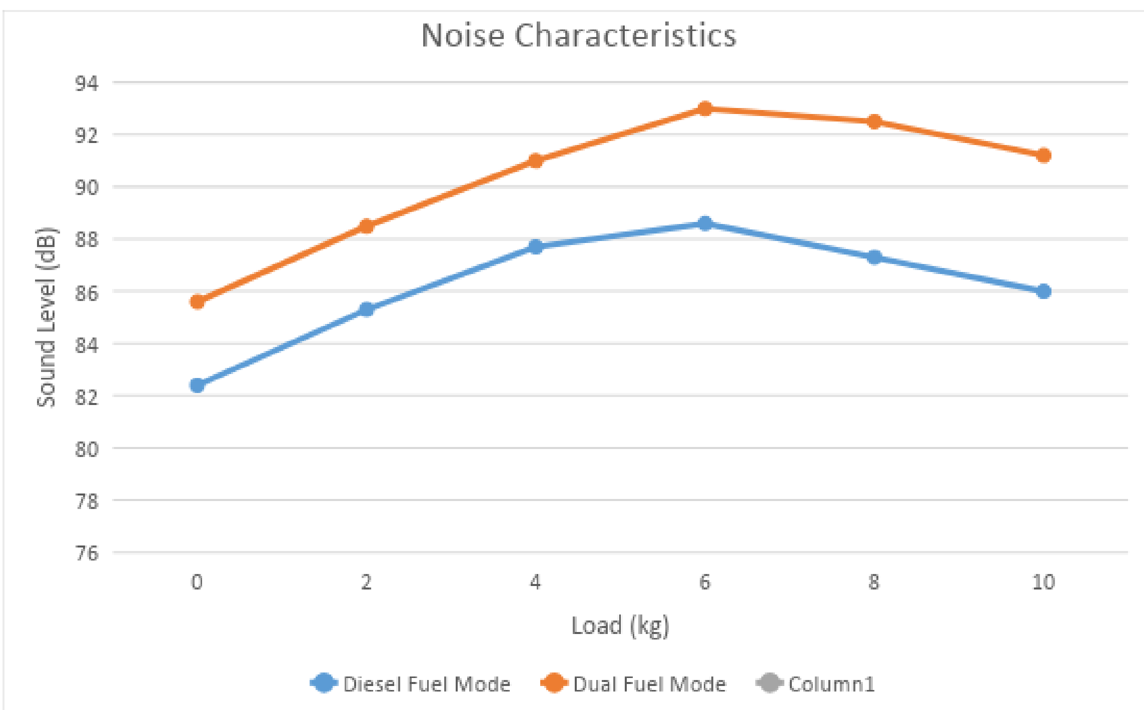

Fig. 4.10: Variation of noise level with variation of load

4.4 Proximate Analysis Comparison

Nobody has ever used the Pterospermum Acerifolium as the biomass fuel in the gasification of the biomass, so question rises on the Pterospermum Acerifolium weather it is useful for the gasification process or not. This problem can be solved by the comparison of the components present in the Pterospermum Acerifolium with the other components present in other biomass fuels. This comparison can be done by the comparison of the results of proximate analysis of fuels, if the results of proximate analysis of the Pterospermum Acerifolium is same or better with the other fuel than we can say it is a useful biomass for the gasification. Data of the proximate analysis of different fuel is given in the table 4.1. Which has taken from the different research papers.

Table 4.1: Data of Proximate Analysis [95, 96]

Biomass	Volatile matter + Moisture (%)	Ash (%)	Fixed Carbon (%)	Calorific Value (MJ/kg)
Sugarcane bagasse	85.06	2.92	12.02	18.34
Carpentry waste	81.25	1.04	17.71	18.77
Coconut shell	82.33	1.00	16.67	21.23
Cornstalk	79.70	3.98	16.32	18.26
Walnut shell	75.04	8.96	16.00	18.16
Sunflower stem	82.56	2.31	15.13	19.85
Soybean residue	77.48	5.36	17.16	18.27
Pterospermum Acerifolium	81.05	0.98	17.97	21.58

By the study of the results of proximate analysis, found that in Pterospermum Acerifolium the fixed carbon content and calorific value is high. Ash content in Pterospermum Acerifolium is very low as compare to other biomass. Density of the Pterospermum Acerifolium is also very high as compare to other biomass because it has wood like structure**.** Higher density fuel is preferred for the biomass gasification because of low density fuel causes problems like bridging and choking inside the gasifier. This comparison proves that Pterospermum Acerifolium is a good biomass fuel for gasification.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

This study is based on the production of the producer gas by the gasification of the biomass. Parameters studied in this study are the performance and exhaust emission and feasibility of using Pterospermum Acerifolium as a biomass fuel. By this study we can say diesel engine can operate successfully in dual fuel mode and Pterospermum Acerifolium gives good results in producing the producer gas by gasification. Following conclusions can be drawn from this study.

- Fruit of the Pterospermum Acerifolium is the wastage for society and its use in the production of producer gas is a good option of power generation from the waste.
- In dual fuel mode when producer gas from Pterospermum Acerifolium is mixed with the diesel, consumption of diesel is reduced to around 52%.
- Carbon monoxide emission is higher in dual fuel mode as compared to diesel fuel mode.
- NO_x level is reduced to 67.8% in dual fuel mode at higher load conditions and at lower load it is reduced by 20%.
- Slight increase in noise emission of 3.2 dB is observed.
- A reduction of 60% GHG emission is observed, so use of the Pterospermum Acerifolium is economical and environment friendly option for power generation.

Waste and low cost biomass are used for the production of the producer gas. Hence the power generation cost is very low in biomass gasification system as compared to conventional fuels. CO and HC emission is a little bit on the higher side, but it can be overcome by the slight modification in the design and installation of some cleaning mechanism of the exhaust gas. For small scale operation not such requirements in modification of gasifier system, but for the industrial use, some modifications are required in the design of the gasifier as well as a chopper, to chop the biomass in a fast rate.

Future Scope

As we all know India is a developing country energy demand is very high and to fulfill this energy demand, use of Pterospermum Acerifolium as biomass fuel can be a good option of power generation. It has the high carbon conversion efficiency as well as it will not pollute the environment. In near future environment safety is the biggest thread for the scientist, so the use of the biomass gasification will help to reduce environment pollution. This study consist all the important aspects. Still in order to improve the output of the present system following points can be expected in future.

- Pterospermum Acerifolium performance can be tested on various other biomass gasification techniques and implement the best technique in industrial sectors.
- Although biomass used by me is the high density biomass but by the some modification in the design of the gasifier, it can be useful for low density biomass.
- Multi cylinder engines can also use for the performance and emission test
- A long term endurance test can be carried out to study the wear and tear of the system
- To enforce regulation on producer gas- diesel fuel use a legal frame work should be there.
- To provide the knowledge of the gasification of biomass in rural areas regular information cum awareness programs should be conducted.

Apart from these issue some policy changes is also required to develop the gasification system in large scale like energy education and storing information should be provided in rural areas.

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