

# Design and development of downdraft gasifier for operating CI engine on dual fuel mode

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE DEGREE OF

**Master of Technology**  
In  
**Mechanical Engineering**

(Specialization: Thermal Engineering)

By

**VINAY SHRIVASTAVA**

ROLL NO 210ME3151



**DEPARTMENT OF MECHANICAL ENGINEERING**

**NATIONAL INSTITUTE OF TECHNOLOGY**

**ROURKELA 769008**

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*Guided by*

**DR. S. MURUGAN**

**DEPARTMENT OF MECHANICAL ENGINEERING**  
**NATIONAL INSTITUTE OF TECHNOLOGY**  
**ROURKELA 769008**



**NATIONAL INSTITUTE OF TECHNOLOGY  
ROURKELA (INDIA)**

**CERTIFICATE**

This is to certify that the thesis entitled, ” **Design and development of downdraft gasifier for operating CI engine on dual fuel mode**” submitted by **Mr. Vinay Shrivastava** in partial fulfillment of the requirements for the award of Master of Technology in Mechanical Engineering with Thermal Engineering specialization during session 2011-2012 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

It is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

**Dr. S. Murugan**

**(Associate Professor)**

**Date:**

**Department of Mechanical Engineering**

**Place: Rourkela**

**National Institute of Technology, Rourkela**

**Orissa, India**

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**DATE:**

**VINAY SHRIVASTAVA**

## **ABSTRACT**

Gasification is a thermo-chemical process which converts solid biomass into a mixture of combustible gases that can be used in various applications. In this project, a downdraft gasifier was designed and developed for running a single cylinder, 4-stroke, air cooled, direct injection diesel engine developing a power of 4.4 kW, at a rated speed of 1500 rpm on dual fuel mode. Wood chips and mustard oil cake in the ratio of 7:3 was used as a feed stock in the gasifier. An experimental study was also carried out on diesel fuel (DF) and producer gas (PG) on dual fuel mode. The producer gas was introduced in the inlet manifold of engine at 4lpm, 6lpm and 8lpm respectively. The performance and emission characteristics of the engine were studied at different loads for various gas flow rates. A reduction in the consumption of diesel fuel was observed when operated on dual fuel mode though there was a reduction in brake thermal efficiency. NO emission was found to be very low in dual fuel which is a great advantage of dual fuel mode over diesel fuel alone but, CO and HC emission for dual fuel mode was found to be higher than diesel.

**Key words: Biomass, Gasifier, Producer gas, Performance, Emission.**

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## NOMENCLATURE

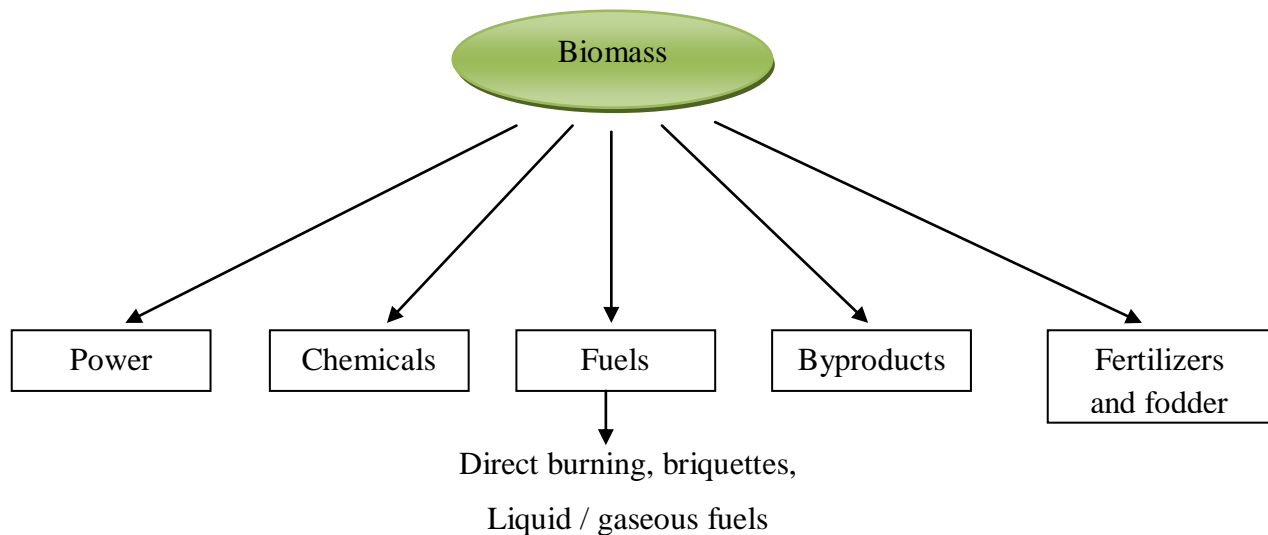
Sr. No.	Short form	Full name
1	DF	Diesel fuel
2	PG	Producer gas
3	BP	Brake power
4	BTE	Brake thermal efficiency
5	BSEC	Brake specific energy consumption
6	EGT	Exhaust gas temperature
7	CO	Carbon monoxide
8	HC	Hydrocarbon
9	CO <sub>2</sub>	Carbon dioxide
10	NO <sub>x</sub>	Oxides of nitrogen
11	NO	Nitric oxide
12	lpm	Litres per minute

# CHAPTER 1

## INTRODUCTION

## 1.1 General Introduction

Biomass is the oldest source of energy and currently accounts for approximately 10% of total primary energy consumption. Many of the developing countries has growing their interest in biofuel development and providing greater access to clean liquid fuels while helping to address the issues such as increase in fuel price, energy security and global warming concerns associated with petroleum fuels. Abundant biomass is available throughout the world which can be converted into useful energy. Biomass is considered as a better source of energy because it offers energy security, rural employability and reduced GHG emission. Biomass is traditionally available in the form of solid. Solid biomass include crops residues, forest waste, animal waste, municipal waste, food waste, plant waste and vegetable seeds. This biomass can be converted into heat and power by adopting appropriate method. Fig. 1 shows the utilization of biomass to get various different outputs [1].



**Fig.1. Utilization of biomass resources**

## 1.2 Biomass Energy in India

Biomass resources are potentially the world's largest and most sustainable energy sources for power generation in the 21<sup>st</sup> century. Over one third of total fuel energy in India is contributed by biomass. The current availability of biomass in India is estimated about 500 million metric tonnes per year. Ministry of New and Renewable Energy has estimated surplus biomass availability at about 120 – 150 million metric tonnes per annum covering agricultural and forestry residues corresponding to a potential of about 17,000 MW. This apart, about 5000 MW

additional power could be generated through bagasse based cogeneration in the country's 550 Sugar mills, if these sugar mills were to adopt technically and economically optimal levels of cogeneration for extracting power from the bagasse produced by them (Ministry of New and Renewable Energy). The details of the estimated renewable energy potential and cumulative power generation in the different states of country have been outlined in Table 1 [2], indicating that the available biomass has a potential to generate around 17,000 MW of electricity. The leading States for biomass power projects are Andhra Pradesh, Chhattisgarh, Maharashtra, Gujarat and Tamil Nadu.

**Table 1. State-wise/Year-wise List of Commissioned Biomass Power/Cogeneration Projects in MW (as on 31-03-2011)**

S.No.	State	2008-09	2009-10	2010-11	Total
1	Andhra				
2	Bihar	--	--	9.50	9.50
3	Chhattisgarh	9.80	43.80	32.00	85.60
4	Haryana	--	1.8	28.00	29.80
5	Karnataka	31.90	42.00	29.00	102.90
6	Maharashtra	71.50	33	184.50	289.00
7	Punjab	--	34.50	12.00	46.50
8	Rajasthan	8.00	--	42.00	50.00
9	Tamil Nadu	43.20	62.00	92.50	197.7
10	Uttarakhand	--	--	10.00	10.0
11	Uttar Pradesh	172.00	194.50	25.50	391.50
12	West Bengal	--	16.00	--	16.0
	<b>Total</b>	<b>345.40</b>	<b>447.60</b>	<b>465.00</b>	<b>2664.63</b>

Biofuels are predominantly used in rural households for cooking and water heating, as well as by traditional and artisan industries. Biomass delivers most energy for the domestic use (rural - 90% and urban - 40%) in India (NCAER, 1992). Woody biomass contributes 56 percent of total biomass energy. At present, biogas technology provides an alternative source of energy in rural India for cooking.

### **1.3 Biomass- Clean Energy Source**

Biomass is considered as one of the important sources of renewable energy. Biomass is an organic matter produced by plants (both terrestrial and aquatic), their derivatives and from animal and human waste. Biomass is considered as a renewable source of energy, because it is renewable in nature unlike fossil fuel like coal, oil and natural gas. Biomass can be converted into solid, liquid and gaseous fuel depending on their physical availability. Biomass can be considered as a carbon-neutral fuel, because plants and trees extract carbon-dioxide (CO<sub>2</sub>) from the atmosphere and store it while they grew up and when this biomass is used in various application like home, industries for energy production then they release CO<sub>2</sub> to atmosphere and at the same time it is balanced by capturing CO<sub>2</sub> for the growth of plant and trees. Whereas fossil fuels like gas, oil and coal can not be considered as carbon-neutral fuel because they release CO<sub>2</sub> which has been stored for millions of years [3]. Biomass is also considered as a form of solar energy as they absorb solar energy for growing up by photosynthesis process. Solar energy thus stored in the form of chemical energy is “Biomass”.

Solar Energy → Photosynthesis → Biomass → Energy Generation

Biomass energy resources are available from botanical plants, vegetation, algae, animals, animals and organisms living on land or in water. Biomass resources are generally classified into two categories.

- (1) Biomass from cultivated crops (Energy farms)
- (2) Biomass from waste organic matter.

Both the sources are of renewable source of energy. The biomass sources available in our country are shown in Table 2.

**Table 2. Biomass resources**

<b>Waste</b>	<b>Forest Products</b>	<b>Energy Crops</b>	<b>Aquatic plants</b>
1. Agriculture production waste 2. Agriculture process waste 3. Crop residue 4. Mill wood waste 5. Urban wood waste 6. Urban organic waste	1. Wood 2. Logging residue 3. Tree, shrub and wood residue 4. Sawdust, bark from forest clearing	1. Short rotation woody crops 2. Herbaceous wood crops 3. Grasses 4. Starch crops (corn and beet) 5. Sugar crops 6. Forage crops (grasses, alfalfa and clover) 7. Oilseed crops	1. Algae 2. Water weed 3. Water hyacinth 4. Reed and rushes

Biomass (depending on the energy density) can be cultivated to obtain energy in the energy farm. The cultivated biomass are trees, agriculture crops, aquatic crops etc. Agricultural crops, trees (wood chips, saw dust etc) are used to produce heat and electricity by direct combustion. They are also used to produce biogas by a set of process. Aquatic crops, algae, green plants are used to produce wood oil and charcoal by wood to oil process. Bio-energy can also be obtained from waste organic matter which is known as waste-to-energy technology. The organic waste includes agricultural waste, rural waste, forest waste, municipal waste, animal and human excreta etc. WTE process converts organic waste into useful energy forms such as heat, biogas, alcohol fuels, chemical etc. Agricultural wastes can be converted into heat by various processes such as combustion and bio-thermal reaction. Municipal, animal, human and rural waste can be converted into gaseous and liquid fuels by fermentation and biochemical processes. The moisture content in waste biomass is ranges from 50 to 90% [4]. Thus transporting bulky biomass to remote site for converting into useful energy is not economical hence bio-waste has to convert



into gaseous or liquid fuel on site by some conversion processes and then it can be used as a source of secondary energy. Dry biomass can be used directly to obtain energy by combustion, although dry biomass can be converted into liquid and gaseous fuel for later combustion. Wet biomass can be dried and burnt, but it requires a considerable amount of energy to drive off water and this diminishes the value of biomass as a fuel. Thus, it is more appropriate to convert wet biomass directly into premium fuels by wet processes like digestion or fermentation.

### **1.3.1 Solid biofuels**

Solid biofuel includes wood, straw and municipal waste etc. Wood can be used in the form of cut logs, wood chips and saw dust for domestic heating and to provide process heat in timber and furniture industries. It is a bulky fuel, has low ash and sulphur content so it can be easily burnt and reduces the problem of acid rain. Municipal refuse is messy to handle and has low and variable energy content about one third of coal. It is dried, sorted and shredded and then it can be burnt to obtain heat and power. Charcoal is one of the important solid biofuels and in some cases as an export product. It is produced through thermo-chemical transformation of biomass with oxygen deficiency (pyrolysis). In the pyrolysis process, more than half of the energy in the wood is lost but charcoal produced from this process has an advantage for the user as more even and cleaner combustion than fuel wood [5]. Wood chips can be used in all plant sizes. Chip quality generally depends on the type of wood used, the equipment used for making the chips, sorting techniques and moisture content. Dry chips can be stored but moist chips start to compost as they are left too long a period.

### **1.3.2 Liquid biofuel**

Alcohols and vegetable oils are the examples of liquid biofuel which can replace petrol and diesel respectively, because they are much cheaper and environment friendly. Ethanol and methanol can be blended with unleaded petrol and used in IC engine. Modifications required in the engine are increased compression ratio, altered injection timing and carburetion. Attention should be made because alcohol particularly methanol contains traces of water and corrosive organic impurities which can affect pipes, pumps and fuel tank of engine. Alcohol has a high octane rating, but lowers the calorific value than petrol. Methanol contains 25% less energy per gallon than ethanol and 50% less than petrol. But, alcohol improves engine performance and it is

cleaner fuel than petrol and diesel. They burn with high efficiency and at lower temperature and are free from lead and sulphur. This reduces noxious emissions dramatically.

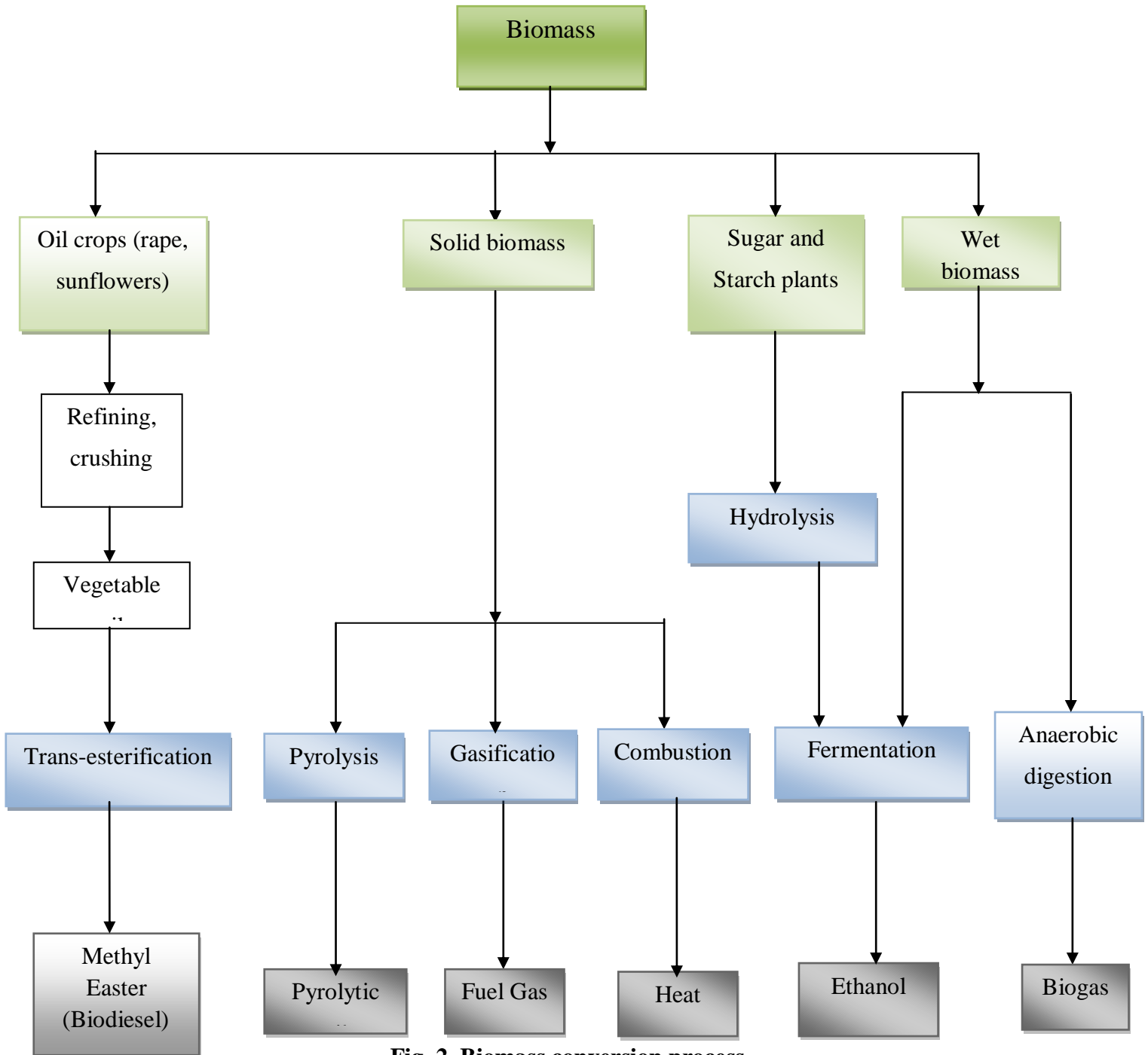
### **1.3.3 Gaseous biofuel**

Biogas, methane, fuel gas or producer gases are the examples of gaseous fuel obtained from biomass. Biogas is a mixture of methane and carbon dioxide with traces of hydrogen sulphide. Methane content varies from 50% to 70% depending on the sources of biomass. The energy content of biogas is about two-third of natural gas. It can be used in cooking application, stationary engine or turbine to produce heat and mechanical or electrical energy. At low pressure, biogas cannot be stored because of its low calorific value. Biogas can be stored by compressing it and its fuel quality can be improved by removing carbon dioxide by chemical treatment. Methane is a clean gas with high calorific value. It can be compressed for use in tractors and fork lift trucks. Fuel gas is produced by thermal degradation of biomass, also known as producer gas or syn gas. Main combustible components of producer gas are carbon monoxide, methane and hydrogen. Gas contains more than 70% of CO, H<sub>2</sub> and CH<sub>4</sub> known as synthetic gas or syn gas. Generally the composition and calorific value of fuel gas vary depending on the raw material used and the way it is produced. For example, the fuel gas produced from an air blown gasifier has a calorific value about 5MJ/m<sup>3</sup> whereas fuel gas produced from an oxygen fed system may be as high as 20MJ/m<sup>3</sup>. Transporting the low and medium calorific value gases are uneconomical, therefore, it is better to burn on site to produce heat and mechanical or electrical energy or converted into useful substance like methane and methanol.

## **1.4 Biomass Conversion Technology**

Wide variety of conversion technologies is available for the production of premium fuels from biomass. Conversion process generally depends on the physical condition of biomass and the economics of competing process. Biomass conversion technology can be basically grouped into three categories. (1) Direct combustion (2) Thermo-chemical conversion (3) Biochemical conversion. In direct combustion, oxygen supplied is generally higher than that of stoichiometric limit. In the thermo-chemical conversion method the biomass is raised to high temperature and depending on the quantity of oxygen supplied the process such as pyrolysis or gasification takes place. The biochemical conversion process is a low energy process and relies upon the action of

bacteria which degrade complex molecules of biomass into simpler ones. Production of biogas ( a mixture of  $\text{CH}_4$  and  $\text{CO}_2$ ) from animal dung by anaerobic digestion is a good example of biochemical process. Fig. 2 shows the conversion process of biomass [6]. A brief discussion of biomass conversion technology is described below.



**Fig. 2. Biomass conversion process**

### 1.4.1 Direct Combustion

Direct combustion or burning is one of the most common processes of biomass conversion technology. In combustion process, oxygen supplied is generally higher than that of stoichiometric limit. Combustion process can be applied to cultivated and waste biomass. Direct combustion requires biomass with moisture present around 15% or less therefore drying of biomass is required prior to combustion. The heat obtained from the combustion of biomass can be used for several useful processes such as cooking, industrial heat, steam generation, generation of electrical energy from steam etc. The energy route of combustion process is:



### 1.4.2 Pyrolysis

Pyrolysis process includes the heating of biomass at temperatures 500 – 900<sup>0</sup>C in a closed chamber or reactor in the absence of oxygen. It is an irreversible chemical change, which is due to heat supplied in the absence of oxygen. This process yield solid, liquid or gaseous fuel. In the absence of oxygen the energy splits the chemical bonds and leaves the energy which is stored in biomass. As the temperature rises the cellulose and lignin break down to simpler substances which are driven off leaving a char residue behind. This process has been used for centuries to produce charcoal. Main components evolve from biomass are H<sub>2</sub>, N<sub>2</sub>, CO, CO<sub>2</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub> and C<sub>7</sub>H<sub>8</sub>. Hydrogen and carbon monoxide can be converted into methanol, gasoline, diesel ammonia after proper treatment. The main advantage of this process includes compactness, simple equipment, low pressure operation, negligible waste product and high conversion efficiency of the order of 83%. Pyrolysis process can also be carried out by supplying small amount of oxygen (gasification), water (steam gasification), or hydrogen (Hydrogenation) in the reactor.

### 1.4.3 Gasification

In the gasification process, solid biomass are broken down to produce a combustible gas by the use of heat in an oxygen-starved environment. Heat for gasification is generated through partial combustion of the feed material. The resulting chemical breakdown of the fuel and internal reactions result in a combustible gas usually called "producer gas" [7]. The main combustible gases are H<sub>2</sub> and CO, but small amounts of methane, ethane and acetylene are also produced. Overall gasification efficiency is generally dependent on the specific gasifier used, fuel type, fuel moisture content and fuel geometry. Fuel gas from air blown gasifier has low calorific value

(around 5MJ/m<sup>3</sup>) and fuel gas from oxygen fed gasifier has a medium calorific value (10 – 20 MJ/m<sup>3</sup>). This gas can either be used onsite to produce heat, electrical or mechanical energy or can be converted into substitute like methane and methanol.

#### **1.4.4 Steam Gasification**

Methane is produced directly from woody matter by treatment at high temperatures and pressures with hydrogen gas. Steam is used as gasification agent, it can be produced by an industrial steam generator unit and is overheated up to 500°C. According to recent analysis steam gasification is the most efficient route for the production of methanol.

#### **1.4.5 Hydrogenation**

It is a chemical reaction between hydrogen molecule (H<sub>2</sub>) and another compound or element, ordinarily in the presence of a catalyst [8]. Typical hydrogenation reactions include the reaction of hydrogen and carbon monoxide to form methanol or hydrocarbons, depending on the choice of catalyst.

#### **1.4.6 Anaerobic digestion**

This method involves the microbial digestion of biomass. Anaerobic is a micro-organism that can live and grow in the absence of air or oxygen. The process takes place at low temperature 65<sup>0</sup>C and requires moisture content at least 80%. This produces gas which content mostly of CO<sub>2</sub> and CH<sub>4</sub> with minimum impurities such as hydrogen sulfide. CO<sub>2</sub> and impurities can be removed by further treatment. The main advantage of this process is that it utilizes biomass with moisture content as high as 99%. Small units are available which can be operated at individual farms. The limitation of anaerobic digestion is the dispose of large quantity of waste water after digestion.

#### **1.4.7 Fermentation**

Fermentation is the breakdown of complex molecules in organic compound under the influence of ferment such as yeast, bacteria, enzymes etc. Fermentation is a widely used technology for the conversion of grains and sugar crops into ethanol (ethyl alcohol). It can be mixed with gasoline to produce gasohol which is the mixture of 90% gasoline and 10% alcohol. After about 30 hours of fermentation, brew (beer) produced from sugar solution which contents 6-10% alcohol, this can be removed by distillation. After fermentation, the residue from grains and other feed stuffs contains high protein, which can be used as a feed supplement to cattle.

### **1.4.8 Hydrolysis and Ethanol Fermentation**

Hydrolysis is the process which converts cellulose to alcohols through fermentation. Ethyl alcohol can be produced from a variety of sugar by fermentation with yeasts. Molasses is diluted with water to sugar contents of about 20% by weight, acidified to pH 4.5 and then mixed with yeast culture (5% by volume) in a fermentor. Ammonia is used to reduce acidity. When 8-10 per cent alcohol is accumulated, then liquid is distilled, fractionated and rectified 2.5 liters of cane molasses produces about one litre of alcohol.

### **1.5 Objectives**

The main objective of the present work is to design and develop a down draft gasifier that uses 70% wood chips and 30% mustard oil cake as a feed stock to generate producer gas which will help to run a CI engine for power application. From the literature collection, it was understood that nobody has carried out this work with such feed stock.

The objectives of proposed work are:-

- To design and fabricate a down draft gasifier with effective cooling and cleaning device.
- To use of 70% wood chips and 30% mustard oil cake as feed stock in the down draft gasifier.
- To use of diesel as a primary fuel and producer gas as a secondary fuel.
- To introduce producer gas partially with air into the inlet manifold of 4-stroke single cylinder diesel engine and conduct the performance and emission test with varying loads in the diesel engine.

# CHAPTER 2

## LITERATURE SURVEY

A downdraft gasifier at laboratory scale was developed and tested for the composition of producer [9]. The construction of the gasifier was based on the design proposed by Bhattacharya et al. [10]. The various parts of the gasifier like reaction chamber, fuel hopper, gas outlet and air inlet were designed. The gasifier was ignited by a flame torch and the composition of the producer gas was found in close agreement with the desired composition.

An experimental study [11] was carried out on a 75kW downdraft biomass gasifier system to obtain temperature profile, gas composition, calorific value and trends for pressure drop across the porous gasifier bed, cooling-cleaning train and across the system as a whole in both firing as well as non-firing mode. In the reactor, both gas and biomass feedstock move downward as the reaction proceeds. While biomass flows because of gravity, air was injected with the help of a blower. Experiments were conducted to obtain fluid flow characteristics of the gasifier and also to obtain the temperature profile in the reactive bed, the gas composition and calorific value. For non-firing gasifier, the extinguished bed showed greater pressure drop as compared to a freshly charged gasifier bed. The pressure drop across the porous bed was found to be sensitive with change in flow rate. When used in firing mode, the higher temperature in the bed led to better conversion of non-combustibles component in the resulting gas and thus improved the calorific value of the product gas.

An experimental study was carried out on producer gas generation [12] from wood waste in a downdraft biomass gasifier. They used sesame wood or rose wood as biomass. They observed that biomass consumption rate decreased with an increase in the moisture content and it increased with an increase in the air flow rate. The performance of the biomass gasifier system was evaluated in terms of producer gas composition, the calorific value of producer gas, gas generation rate, zone temperatures and cold gas efficiency. Thermocouples were placed inside the gasifier at different locations to measure the temperature of various zones of gasifier. They found the producer gas composition using gas chromatograph.

Characteristics of hydrogen produced [13] from biomass gasification was studied. They used a self-heated gasifier as the reactor and char as the catalyst. The steady temperatures of the pyrolysis zone, combustion zone and reduction zone were recorded. Equivalence ratio(ER) was defined as the actual oxygen to fuel ratio divided by the stoichiometric oxygen to fuel ratio



needed for complete combustion. The temperature of the neck was found to increase with feeding rate for similar ER values. For increasing the production capacity, accelerating the feed rate is essential, but excessively high feeding rate would result in a higher gas yield and a shorter gas residence, thus degrading gas quality. The temperature increased with feeding rate but hydrogen yield decreased with feeding rate.

The thermo-chemical reaction in gasification [14] may vary with varying parameters and the size of biomass. For a particle size below 1mm diameter, thermo-chemical reaction shows a sharp increase in the fuel conversion which could be used in conventional entrained flow gasifier. A reduction in the fuel particle size led to an improvement in the gas quality and thus to a higher producer gas heating value. Maximum fuel conversion was obtained for the smallest particle size tested (0.5mm). The thermo-chemical characterization of the char-ash residue showed that as the fuels particle size was reduced, the release of volatile matter during pyrolysis stage along with particle carbonization, gradually increased, which suggest that pyrolysis reaction took place to a great extent. For fuel particle size of 1mm, the reaction of char gasification became more relevant which contribute in the improvement of conversion of fuel and the composition of producer gas.

It is necessary to cool biomass-based producer gas to ambient temperature, and clean it of tar and particulates before it could be used as a fuel [15]. The unit gave a clean gas with tar+dust content below the limit of  $150 \text{ mg/nm}^3$  as long as the inlet gas tar+dust content was below about  $600 \text{ mg/nm}^3$ . The system was being tested to supply gas to a dual-fuel engine, and solve any operating problems in this application. It was developed further to study its maintenance requirements, and increase the number of hours of continuous use of the sand filter with no operator attention. The system was mainly developed for small scale gasifier–engine system applications. It can be scaled up to larger sizes to provide a compact unit. The scale up can be done by increasing the cross-sectional areas of the various beds and the water flow rate in proportion to the producer gas flow rate.

For prediction of gasification process in downdraft gasifier, an equilibrium modeling [16] was been used. The composition of the producer gas, the calorific value was determined by the modeling. The effects of moisture content in wood and temperature in the gasification zone on

the calorific value were investigated. In addition to wood, the prediction were also made for peddy husk, paper and municipal waste and it was found that wood and paper are the two most efficient biomass to produce syngas. It had high CO, H<sub>2</sub>, CH<sub>4</sub> content with higher CV. The result of equilibrium modeling showed that the H<sub>2</sub> content in the producer gas increased with moisture content for all the material considered and CO content decreased as the moisture content in the producer gas increases. Methane content in the producer gas increased with increase in moisture content but calorific value of the producer gas also decreased.

Experiments were conducted on three different types of downdraft gasifier [17] single stage, Conventional two-stage, and an innovative two-stage air and premixed air/gas supply approach. The innovative two-stage approach had two nozzle locations, one for air supply at combustion zone and the other located at the pyrolysis zone for supplying the premixed gas (air and producer gas). The producer gas was partially bypassed to mix with air and supplied to burn at the pyrolysis zone. The result showed that producer gas quality generated by the innovative two-stage approach improved as compared to conventional two-stage. The higher heating value (HHV) increased from 5.4 to 6.5 MJ/Nm<sup>3</sup>. Tar content in producer gas reduced to less than 45 mg/Nm<sup>3</sup>. This method can lower tar content sufficiently to feed the gas directly to internal combustion engine. The gas efficiency and capacity were also improved around 15% and 40% respectively when compared to a single-stage gasifier.

The performance of the gasifier generally depends on certain key operating parameter and design feature. Experimental results of the design under various conditions [18] had produced data that was then used to calibrate a computer program, developed to investigate the impact of those parameters and features on conversion efficiency. The program consisted of two sub-models of the pyrolysis and gasification zones, respectively. The pyrolysis sub-model was used to determine the maximum temperature and the composition of the gas entering the gasification zone. The gasification zone sub-model was calibrated using data gathered from the experiments. It was found that a wood chip size of 3–5cm with moisture content below 15% (d.b.) should be used in this gasifier. Feed material with a fixed carbon content of higher than 30% and heat losses of more than 15% should be avoided. Moisture content and heat loss had greater effects on reactor temperature and hence on the conversion efficiency. The study concluded that the length of the gasification zone is a vital design parameter for downdraft gasifier. A longer length

enables the gasifier to operate at its maximum efficiency. For the above parameters, the gasification zone should be 33 cm long to achieve an acceptable conversion efficiency.

The effect of hydrogen content in producer gas was investigated on the performance and exhaust emissions of a supercharged producer gas–diesel dual-fuel engine [19]. For this experiment, two different composition of producer gas were used, one with low hydrogen content (13.7%) and other with high hydrogen content (20%). The experiment was carried out for maximum power output and maximum thermal efficiency by keeping constant injection pressure and injection quantity for different fuel–air equivalence ratios and at various injection timings. The experimental strategy was to optimize the injection timing to maximize engine power at different fuel–air equivalence ratios without knocking and within the limit of the maximum cylinder pressure. It was found by experiments that better combustion, engine performance, and exhaust emissions (except  $\text{NO}_x$ ) were noticed with the high  $\text{H}_2$ -content producer gas than with the low  $\text{H}_2$ -content producer gas, especially under leaner conditions. Within the optimum fuel–air equivalence ratio, HC and CO emissions with the high  $\text{H}_2$ -content producer gas were 10–25% lower than that with the low  $\text{H}_2$ -content producer gas. These still need to be reduced. The exhaust gas temperature (about  $250^\circ\text{C}$  to  $500^\circ\text{C}$ ) and  $\text{O}_2$  concentration in exhaust gases (2–10%) favored the use of an oxidation catalyst. An oxidation catalyst could be used to reduce CO and HC in the exhaust gases below regulated limits.  $\text{NO}_x$  emissions with the high  $\text{H}_2$ -content producer gas were very high. It was suggested that EGR could be provide to reduce  $\text{NO}_x$  emissions.

A downdraft moving-bed gasifier was coupled with reciprocating internal combustion engine (SI engine) [20]. The producer gas was mixed with air in order to get a stoichiometric mixture to fuel the RICE. A new parameter called engine fuel quality (EFQ) was developed by the author to predict the engine performance working with such a fuel. Factors that affect the engine power are the heating value, the stoichiometric air-fuel ratio and volume correction factor of the mixture. EFQ parameter indicated that the power of engine fuelled with producer gas is of the order of two-thirds of the corresponding conventional fuel. Two zone thermodynamic models were used to predict engine performance. Thermodynamic model results included the mass burned fraction, the pressure and temperature evolution and the associated value of indicated mean pressure and engine efficiency.

An experimental study was carried out on a compression ignition reciprocation engine with higher compression ratio (17:1) which was restricted to lower compression ratio up to 12:1 [21]. Producer gas with low calorific value was used as a engine fuel. Experiment shows that engine ran smoothly at compression ratio 17:1 without any tendency of auto-ignition. Experiments were also conducted on multi-cylinder spark ignition engine modified from diesel engine at varying compression ratios from 11.5:1 to 17:1 by retaining the combustion chamber design. At highest compression ratio, maximum brake power efficiency of 17.5kWe was obtained with overall engine efficiency of 21%. Since combustion chamber was originally meant for diesel operation, hence higher heat loss to the cylinder wall was noticed. Heat loss to the coolant could be reduced up to 10% by using bowl-in piston combustion chamber design which improves the overall efficiency by 3%.

Effect of injection system parameters such as injection pressure, injection timing and nozzle tip protrusion was investigated on the performance and emission characteristics of a twin cylinder water cooled CIDI engine [22]. Biodiesel, derived from pongamia seeds was blended with diesel and used as fuel in this work. The experiments were designed using a statistical tool known as design of experiments (DoE) based on response surface methodology (RSM). The resultant models of the response surface methodology were helpful to predict the response parameters such as brake specific energy consumption, brake thermal efficiency, carbon monoxide (CO), hydrocarbon (H<sub>2</sub>), smoke opacity and nitrogen oxides (NO<sub>x</sub>). Experimental results show that advancing the injection timing from 18<sup>0</sup> bTDC to 30<sup>0</sup> bTDC helped to reduce the CO, HC and smoke emissions with increase in NO<sub>x</sub> emission. Increasing the injection pressure contributed for better BTE with lesser BSEC at all injection timings with lower CO, HC and smoke emissions and higher NO<sub>x</sub> and at too high injection pressure, the results were negated. Lesser BSEC with high BTE was noticed at moderate nozzle tip protrusion, but shorter and/or longer protrusion led to poor BSEC, BTE with higher CO and HC emissions. Also, with moderate protrusion and advanced injection timing, high injection pressure yielded better performance than their individual contribution.

Experiments were conducted to study the performance of a diesel engine (four stroke, single cylinder, 5.25 kW) with respect to its thermal efficiency, specific fuel consumption and diesel substitution by use of diesel alone and producer gas-cum-diesel (dual fuel mode) through a

downdraft gasifier [23]. The moisture content of biomass was kept at 8%, 12%, 16%, and 21% respectively for engine speed as 1600rpm and with variable engine loads. The gas producer system coupled with diesel engine was found to perform satisfactorily by using three types of biomass such as wood chips, pigeon pea stalks and corn cobs. Thermal efficiency of engine on dual fuel mode was found slightly lower than that of diesel mode. For the same amount of energy output, the specific diesel consumption was found to be 60 to 64 % less in dual fuel mode than that in diesel mode. The average diesel substitution in diesel engine was found in the range of 62 to 64 percent using three types of biomass fuels.

An experimental study was carried out by using hingan shell as the feedstock for gasifier to generate producer gas [24]. The gasifier-engine system was allowed to operated on diesel and on esters of vegetable oil of hingan in liquid fuel mode operation and then on liquid fuel and producer gas combination in dual fuel mode operation. The performance and emission characteristic of the CI engine was analyzed by running the engine in liquid fuel mode operation and in dual fuel mode operation at varying load conditions. It was found that specific energy consumption in the dual fuel mode of operation was higher at all the load condition than diesel and liquid fuel mode. The brake thermal efficiency of the engine using diesel or hingan oil methyl ester (HOME) was found to be higher than that of dual fuel mode operation. 60% diesel was substituted by hingan shell producer gas in dual fuel mode operation. The emissions parameters such CO, HC, NO<sub>x</sub>, CO<sub>2</sub> and smoke were found to be higher in dual fuel mode of operation as compared to that of liquid fuel mode.

# CHAPTER 3

## GASIFICATION TECHNOLOGY

### 3.1 Gasification

Gasification is a thermo-chemical process by which carbonaceous (hydrocarbon) materials (coal, petroleum coke, biomass, etc.) can be converted to a synthesis gas (syngas) or producer gas by means of partial oxidation with air, oxygen, and/or steam. The device which performs this work is known as gasifier. Gasifier is a chemical reactor where various complex chemical and physical processes take place. A hydrocarbon feedstock (biomass) is fed into a high-pressure, high-temperature chemical reactor (gasifier) containing steam and a limited amount of oxygen. As biomass flows through the reactor it gets dried, heated, pyrolysed, partially oxidized and reduced. Under these “reducing” conditions, the chemical bonds in the feedstock are severed by the extreme heat and pressure and producer gas is formed. The main constituents of producer gas are hydrogen (H<sub>2</sub>) and carbon monoxide (CO). In short, the task of gasifier is to pyrolyze the biomass to produce volatile matter, gas and carbon and to convert the volatile matter into permanent gases, CO, H<sub>2</sub> and CH<sub>4</sub>. A typical composition of syngas produced from wood gasification on volumetric basis is given in the Table 3 [25].

**Table 3. Composition of producer gas**

<b>Compound</b>	<b>Symbol</b>	<b>Gas (Vol. %)</b>	<b>Dry gas (Vol. %)</b>
Carbon monoxide	CO	21	22.1
Hydrogen	H <sub>2</sub>	14.5	15.2
Methane	CH <sub>4</sub>	1.6	1.7
Heavier hydrocarbon	HC	0.3	0.4
Carbon dioxide	CO <sub>2</sub>	9.7	10.2
Nitrogen	N <sub>2</sub>	48.4	50.8
Water vapour	H <sub>2</sub> O	4.8	-

Producer gas derived from biomass can be used in IC engine with some modifications. Spark ignition (SI) engine can be made to run entirely on producer gas and compression ignition (CI) engine replaces 60% - 80% fuel oil by using producer gas.

## **3.2 Gasification – The Conversion Alternative**

Digestion, gasification, incineration and steam generation are some of the available processes for the conversion of biomass into energy [26]. But, gasification is the best conversion alternative in the following view:

- Gasification offers high flexibility in terms of various biomass materials as the feedstock.
- Gasification has thermo-chemical conversion efficiency in the range of 70% to 90% which is the highest among various alternative.
- Gasification output capacity, especially in the high output ranges, is controlled only by availability of adequate feed materials rather than other technical consideration.
- The area requirement for gasification equipment is the lowest per unit output of energy in the form of heat and/or electricity.
- The gasification equipment has high turn down ratios comparable to biogas and higher than steam turbine systems.
- Gasification outputs are suitable as a fuel to all types of internal combustion engines with capacity derating in the range of 15% to 30%.

## **3.3 Classification of Biomass Gasifier**

Gasifiers are classified as per the type of bed i.e. (1) fixed bed and (2) fluidized bed.

### **3.3.1 Fixed bed gasifiers**

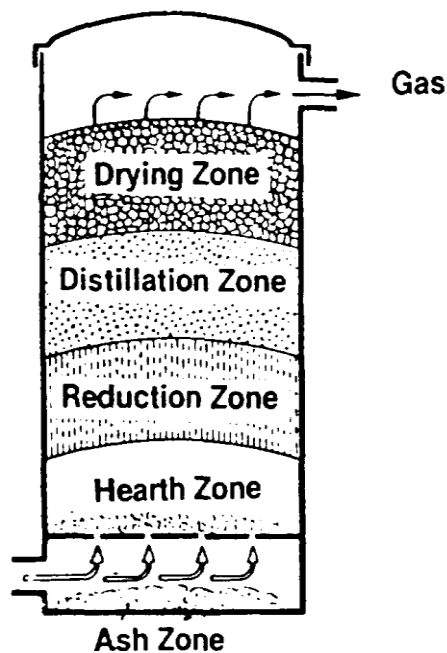
Major concern of the present study is on fixed bed gasifier. It is also classified as per the direction of the gas flow. Gasifier is a vertical flow packed bed reactor through which oxygen or air for combustion is passed through it which may pass downward or upward or across the bed depending upon the type of gasifier. When the air or oxygen is passed upward and gases leave at the top of gasifier this is known as updraft gasifier, when air passed downward and gases leave at bottom of gasifier this is known as downdraft gasifier and when air passed across the bed and gases leaves across the bed this is known as crossdraft gasifier. The types of fixed bed gasifiers are described below.

#### **3.3.1.1 Up Draft Gasifier**

The geometry of the updraft gasifier is shown in Fig. 3. Biomass is fed into the top while air enters below the combustion zone through grate and flows upward through bed. The grate is



mounted at the base of gasifier, air and steam reacts there with charcoal from biomass to produce very hot  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . This  $\text{CO}_2$  and  $\text{H}_2\text{O}$  react endothermically with char to form  $\text{CO}$  and  $\text{H}_2$ . The ascending, hot, reducing gases pyrolyze the incoming biomass. The producer gas has no ash but contains tar and water vapour because of passing of gas through unburnt biomass. Usually 5% to 20% of tars and oils are produced at temperature too low for significant cracking and are carried out in the gas stream. The remaining heat dries the wet biomass so that none of the energy is lost as sensible heat in the gas. The advantage of updraft gasifier over other gasifier is its high conversion efficiency up to 80% but it produces tar with producer gas which is the major feedback of updraft gasifier. Tar content producer gas cannot be use in engine application, it may corrode the engine parts like piston, valve and fuel line.

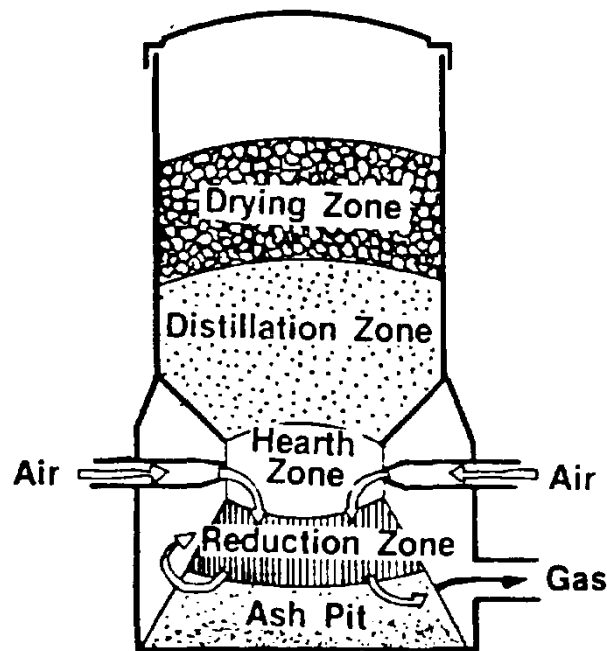
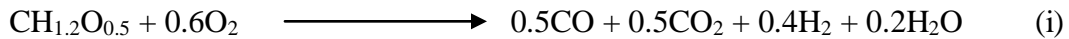


**Fig. 3. Updraft gasifier [27]**

### **3.3.1.2 Downdraft Gasifier**

In the downdraft gasifier, the upper cylindrical part of gasifier acts as a collection device for wood chips or other biomass fuel. The geometry of the downdraft gasifier is shown in Fig. 4. Below this cylindrical part of gasifier, there is a radially directed air nozzle that permits air to be drawn in to chips as they move down to be gasified. This nozzle constitutes combustion and reduction zone as shown in Fig. 4. Air contacts the pyrolyzing biomass before it contacts with

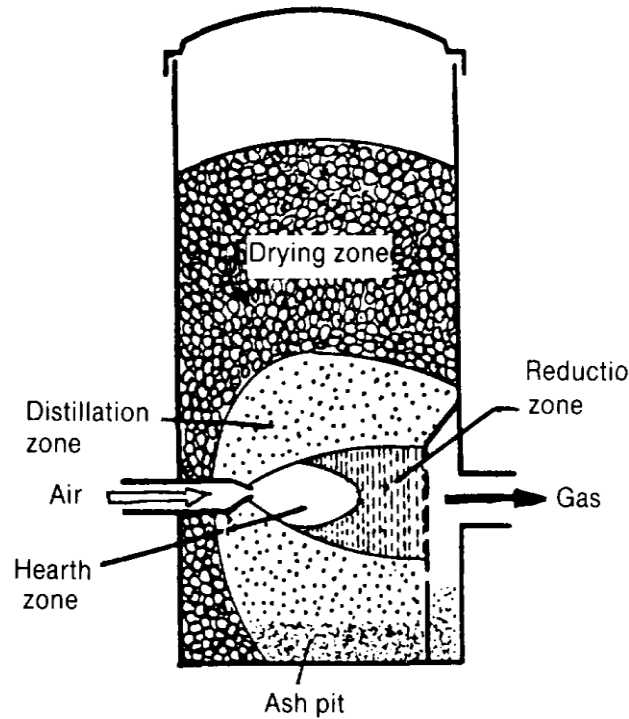
char and support a flame. The limited air supply in the gasifier is rapidly consumed, so that the flame gets richer as pyrolysis proceeds. At the end of pyrolysis zone, the gases consist mostly of  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{CO}$  and  $\text{H}_2$ . The throat ensures that the gaseous products pass through the hottest zone where most of the tar cracked into gaseous hydrocarbon. Thus produces relatively clean gas. For the application of producer gas in CI engine, downdraft gasifier is more suitable as it produces very less tar. If the chemical formula of biomass is taken as approximately  $\text{CH}_{1.2}\text{O}_{0.5}$  then partially combustion can be represented approximately by the reaction given below.



**Fig. 4. Downdraft gasifier**

### 3.3.1.3 Crossdraft Gasifier

The crossdraft gasifier is shown in Fig. 5. Air enters at high velocity through a water cooled nozzle mounted on one side of the firebox, induces substantial circulation and flows across the bed of fuel and char. The gas is produced in the horizontal direction in front of the nozzle and passes through a vertical grate into the hot gas port on the opposite side. This produces very high temperature in a very small volume and results the production of very low tar gas. However, the cross draft gasifier is not commonly used.



**Fig. 5. Crossdraft gasifier**

### 3.3.2 Fluidized Bed Gasifier

Fluidized bed gasification system is used for the fuel which has high ash contents and the ash has low melting point. In fluidized bed gasifiers the air is blown upwards through the biomass bed. The bed under such conditions behaves like boiling fluid and has excellent temperature uniformity and provides efficient contact between gaseous and solid phase. Generally the heat is transferred initially by hot bed of sand. Normally the operation temperature of the bed is maintained within the range of 750-950<sup>0</sup>C, so that the ash zones do not get heated to its initial deformation temperature and this prevents clinkering and slagging. The major advantage of fluidized bed gasifier over downdraft is its flexibility with regard to feed rate and rate of consumption but it produces more dust and tars as compared to downdraft gasifier [29]. This puts a heavy load on cleaning and cooling train.

Fixed bed gasifiers are suitable to use for appropriate applications. Updraft gasifier has higher conversion efficiency, but it produces more tar than downdraft gasifier. Advantages and disadvantages of various types of fixed bed gasifiers are shown in Table 4 [28].

**Table 4. Advantages and disadvantages of various types of fixed bed gasifier**

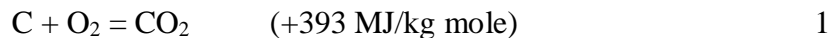
Sr. No.	Gasifier types	Advantages	Disadvantages
1.	Updraft Gasifier	<ol style="list-style-type: none"> <li>1. Small pressure drop</li> <li>2. Good thermal efficiency</li> <li>3. Little tendency towards slag formation</li> </ol>	<ol style="list-style-type: none"> <li>1. Great sensitivity to tar and moisture and moisture content of fuel</li> <li>2. Relatively long time required for start up of IC engine</li> <li>3. Poor reaction capability with heavy gas load</li> </ol>
2.	Downdraft Gasifier	<ol style="list-style-type: none"> <li>1. Flexible adaptation of gas production to load</li> <li>2. Low sensitivity to charcoal dust and tar content of fuel</li> </ol>	<ol style="list-style-type: none"> <li>1. Design tends to be tall</li> <li>2. Not feasible for very small particle size of fuel</li> </ol>
3.	Crossdraft Gasifier	<ol style="list-style-type: none"> <li>1. Short design height</li> <li>2. Very fast response time to load</li> <li>3. Flexible gas production</li> </ol>	<ol style="list-style-type: none"> <li>1. Very high sensitivity to slag formation</li> <li>2. High pressure drop</li> </ol>

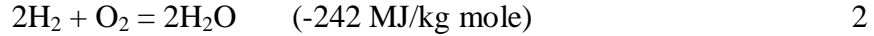
### 3.4 Reaction Chemistry of Gasification

The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. The producer gas is formed by the partial combustion of solid biomass in a vertical flow packed bed reactor. In the conventional theory of producer gas, gasification reaction takes place in four zones. They are oxidation, reduction, pyrolysis and distillation zones.

#### 3.4.1 Oxidation

In the oxidation zone, the oxygen in the air-stream reacts with the carbon and hydrogen in the fuel to reduce carbon and hydrogen to form carbon dioxide and water. Carbon dioxide is obtained from carbon and water is obtained from the hydrogen in the fuel.

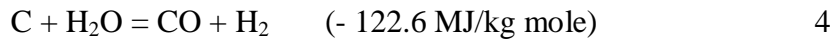
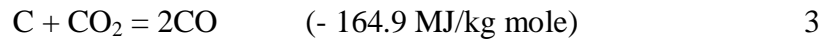




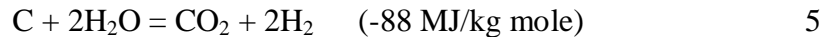
Reaction (1) is known as combustion reaction. The oxidation reaction is exothermic and this heat is supplied to the neighbouring zones i.e. reduction zone.

### 3.4.2 Reduction zone

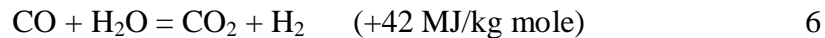
The partial combustion products  $\text{CO}_2$ ,  $\text{H}_2\text{O}$  obtained from oxidation zone are now passed through reduction zone. Here  $\text{CO}_2$  and  $\text{H}_2\text{O}$  are reduced to form carbon monoxide ( $\text{CO}$ ) and hydrogen ( $\text{H}_2$ ) by absorbing heat from the oxidation zone. Oxidation zone raise the temperature of reduction zone to promote the carbon/steam gasification reaction which has higher activation energy. This reaction requires temperature of  $900^\circ\text{C}$  and above. Over 90% of  $\text{CO}_2$  is reduced to  $\text{CO}$  at temperatures above  $900^\circ\text{C}$ . It is an endothermic reaction.



Reaction (3) is known as Boudouard reaction. Reaction (4) is the water gas reaction and it is very important in gasification as it can enrich the gas manufactured with hydrogen, thus enhancing its calorific value. The other reaction with carbon/steam gasification occurs at lower temperature between  $500\text{-}600^\circ\text{C}$ .



A further steam reaction in gas producer with excess of steam is water gas shift reaction. This should be avoided as it reduces the cold gas efficiency, though it reduces the carbon monoxide which is highly toxic in fuel gas distribution for public use.



Other reaction occurs in char at temperature about  $500^\circ\text{C}$  are



Reaction (7) is known as methane reaction and it is an exothermic reaction.

### 3.4.3 Pyrolysis zone

In pyrolysis zone, up to the temperature of  $200^\circ\text{C}$  only water is driven off and between the temperature  $200$  to  $280^\circ\text{C}$  carbon dioxide, acetic acid and water are given off. The real pyrolysis, starts between  $280$  to  $500^\circ\text{C}$ , produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between  $500$  to  $700^\circ\text{C}$  the gas production is small and contains hydrogen. From the reason mentioned above, updraft gasifier

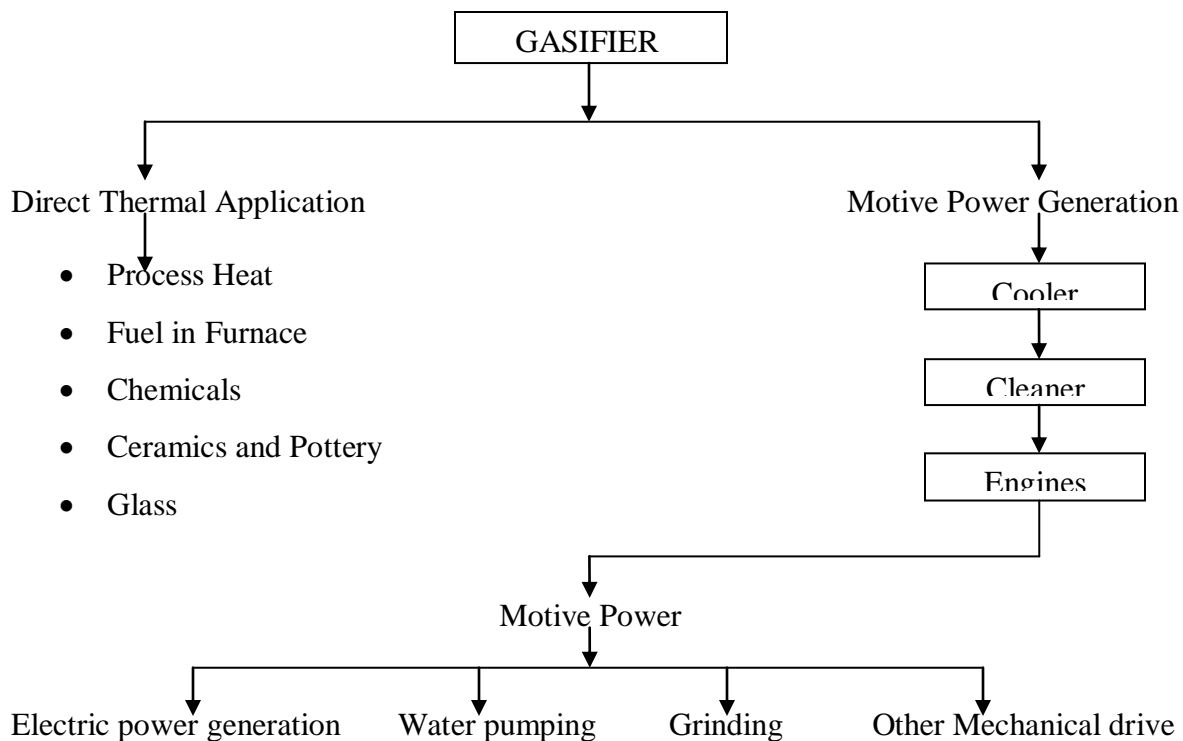
produces much more tar than downdraft one because in downdraft gasifier the tars have to go through combustion and reduction zone and are partially broken down.

### 3.4.4 Distillation zone

In the distillation zone, raw fuel like tar is preheated and carbonized giving of condensable and non-condensable gases.

### 3.5 Applications of Gasifier

Gasifier can be used in the direct or indirect thermal applications. Direct thermal applications are process heat, chemicals etc and the indirect thermal application is motive power generation to produce electrical or mechanical energy etc. When the gasifier is used in direct thermal application for example process heat, there is no requirement of after treatment of producer gas, but when gasifier is used in motive power generation, after treatment of producer gas is very essential because producer gas contain  $\text{CO}_2$ , tar, oxide of sulphur, soot and dust particle which can be proof harmful for the engine and can reduce engine life by corroding engine components. Hence, better cooling and cleaning of producer gas is required before feeding the producer gas in motive power generation. A block diagram of gasifier application is shown in Fig. 6.



**Fig. 6. Applications of gasifier**

# CHAPTER 4

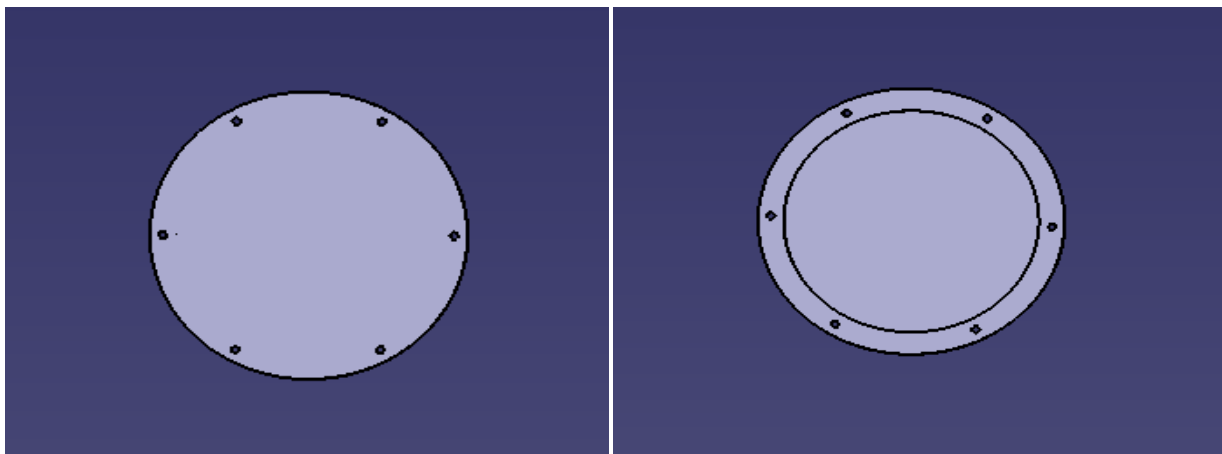
## DESIGN AND DEVELOPMENT OF DOWNDRAFT GASIFIER

## 4.1 Components of gasifier

In the present work, downdraft gasifier is used for producer gas generation, because it produces less tar compared to updraft gasifier. Since the gasifier has to couple with diesel engine for performance and emission and combustion test hence producer gas from gasifier must contain as less tar as possible because higher tar content fuel gives rise to corrosion effect which is a major cause of damage to engine components like piston, valve and fuel pipe lines etc. Hence downdraft gasifier is the most appropriate for the above application. All the components of downdraft gasifier are designed in CATIA software. Main components of downdraft gasifier and their design are described below.

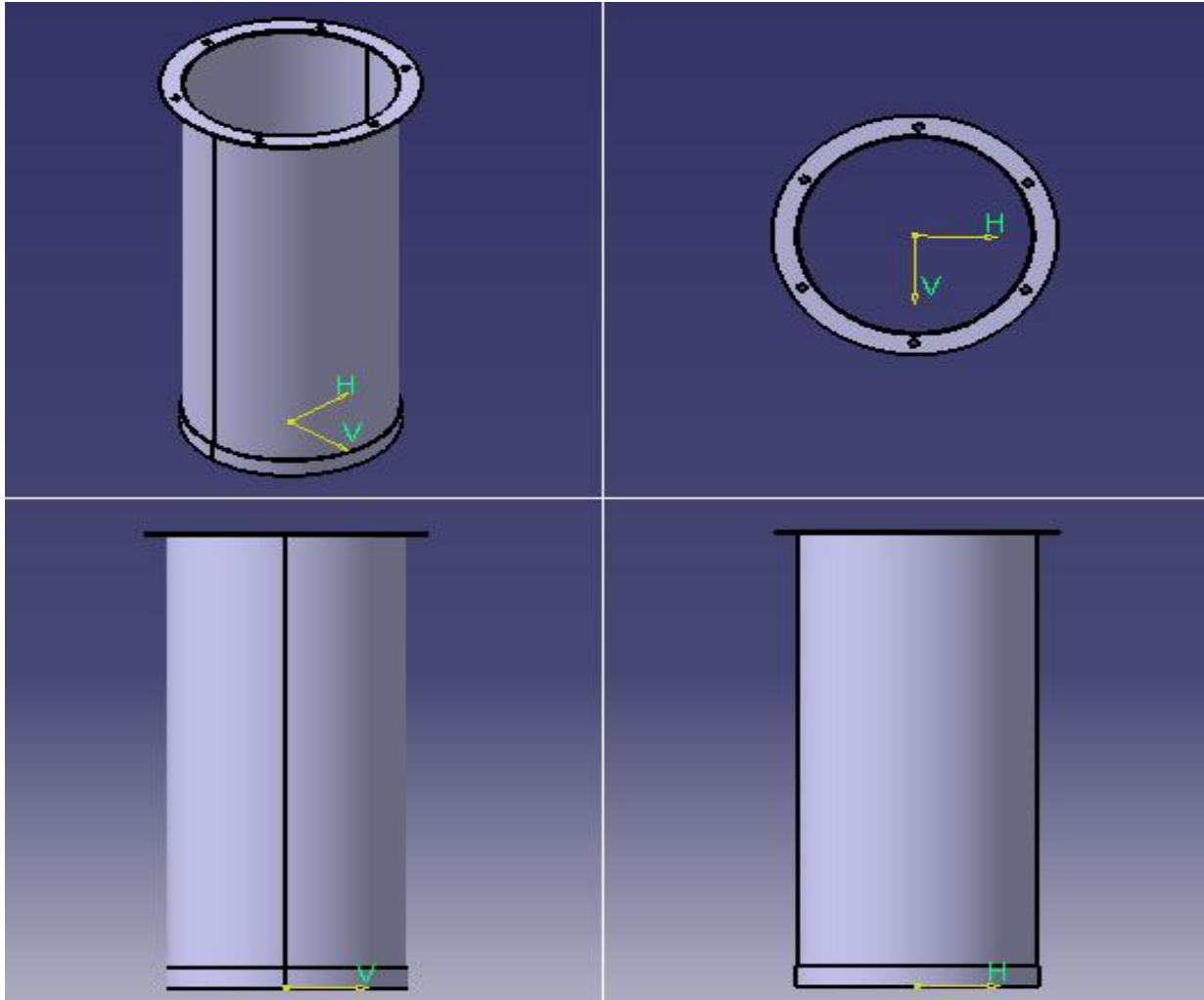
### 4.1.1 Hopper

The purpose of a hopper is to store the biomass for continuous feed to reaction chamber. It is mounted above the reactor of gasifier. The fuel storage hopper is made up of 2mm thick mild steel. The diameter and height of fuel hopper is chosen to be 250mm and 550mm respectively. Round shaped hopper has been chosen to prevent the problem of biomass being stuck. Two flat rings of 250mm internal diameter and 300mm external diameter with thickness of 3mm are fabricated. One ring is welded at the top of hopper and the other one is welded with a circular plate of 300mm diameter. 6 holes of 80mm diameter are drilled in both the plates to cover up the hopper with the help of nut and bolts. Fig. 7 and Fig. 8 show the design of hopper and cover plate in front, side, top and isometric view respectively.



**Fig. 7. Top and bottom view of cover plate**





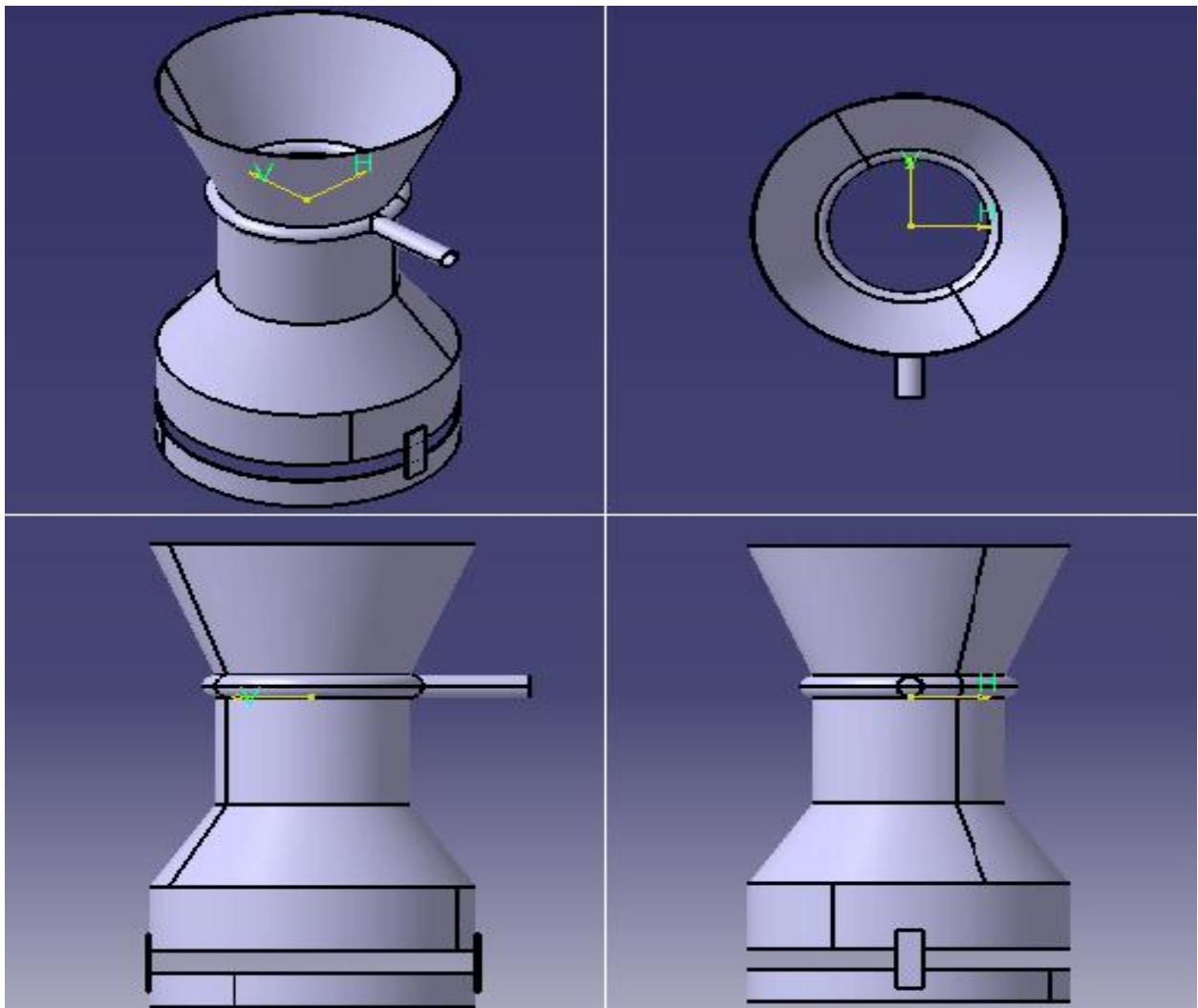
**Fig. 8. Isometric, top, front and side view of hopper**

#### **4.1.2 Gasification Zone**

This is the main component of gasifier. The main reaction of gasification like oxidation, reduction and distillation takes place in this zone. It is in the shape of vertical convergent and divergent nozzle (from top to bottom direction) and made by 2mm thick mild steel. Upper diameter of divergent section is 150mm and the lower diameter is of 250mm with 80mm height. A cylinder of 150mm diameter and 100mm height is welded at the top of divergent section. A circular pipe of  $\frac{3}{4}$  inch (approximately 20mm) diameter is made round with internal diameter 220mm and external diameter 260mm. 8 hole of 6cm diameter is drilled in the inner side of circular pipe in inclined downward direction as shown in Fig. 9. This round circular pipe is connected to a  $\frac{3}{4}$  inch diameter and 90mm long pipe. Air is inducted in the reactor through the

holes in round shaped pipe with the help of external source like blower. A convergent section with 250mm upper diameter and 150mm lower diameter with 80mm height is welded at the top of the round circular pipe.

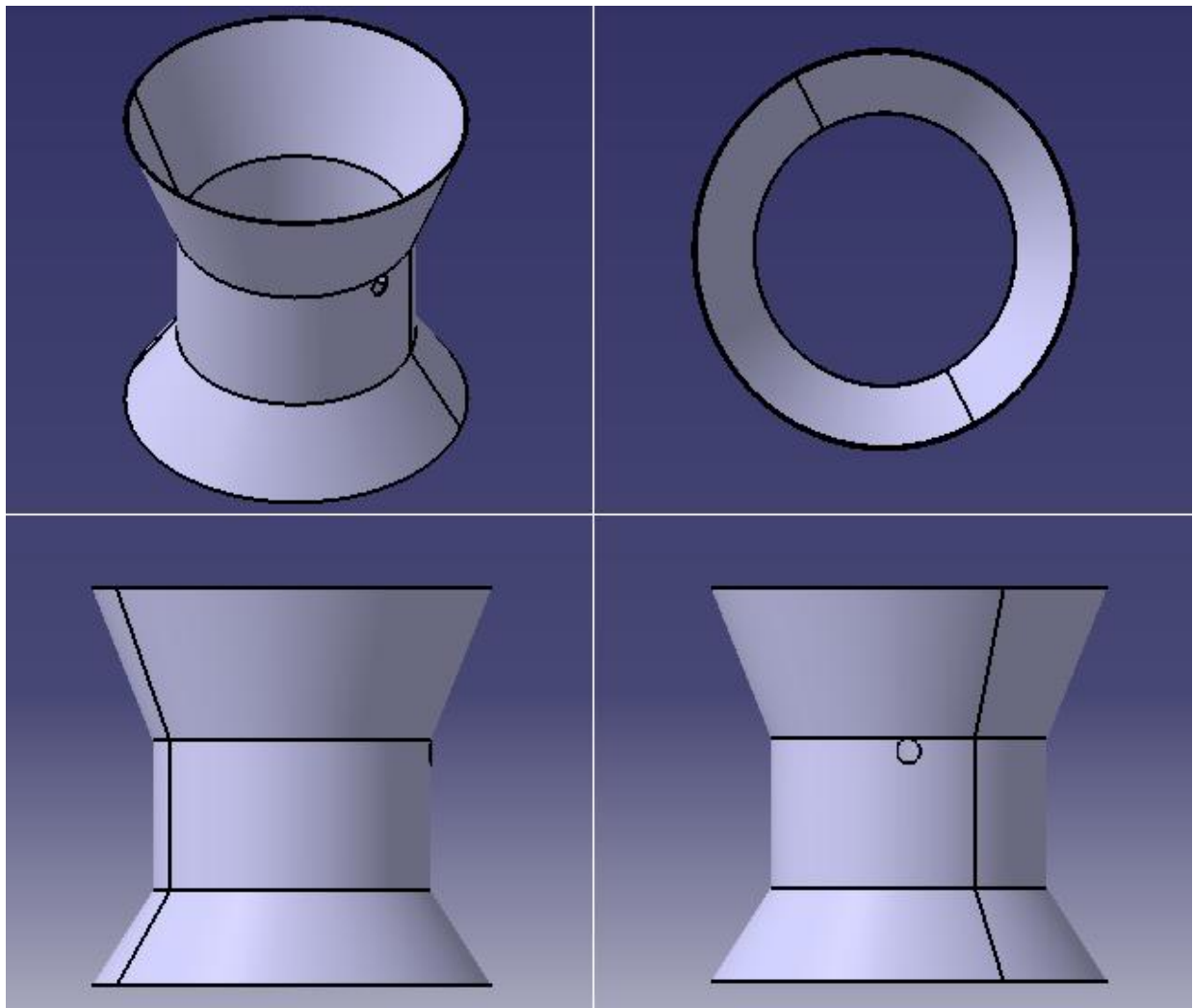
Two circular strips with diameter 250mm and height 50mm and 20mm respectively are combined in such a way that they maintain a gap of 20mm between them. At one end they are joined with the help of hinge and on the other end with the help of hook. This gap is made for shaking the grate so as to dropping the burnt biomass down, this grate can be removed by opening the hook. The whole convergent and divergent gasification zone is welded at the top of these two coupled round strips. A complete design of gasification zone is shown in Fig. 9.



**Fig. 9. Isometric, top, front and side view of gasification zone**

### 4.1.3 Casing of gasification zone

Producer gas from gasification zone contains tar and in order to reduce the amount of tar content in producer gas, it must pass through a hot region. Due to various chemical reactions in gasification zone, the body of gasification zone becomes hot thus it would be more beneficial to pass producer gas from the outer surface of gasification zone to reduce tar concentration. Thus a gasification zone casing is fabricated in convergent and divergent shape so as to pass the producer gas through the gap between gasification zone and its casing as shown in Fig. 10.



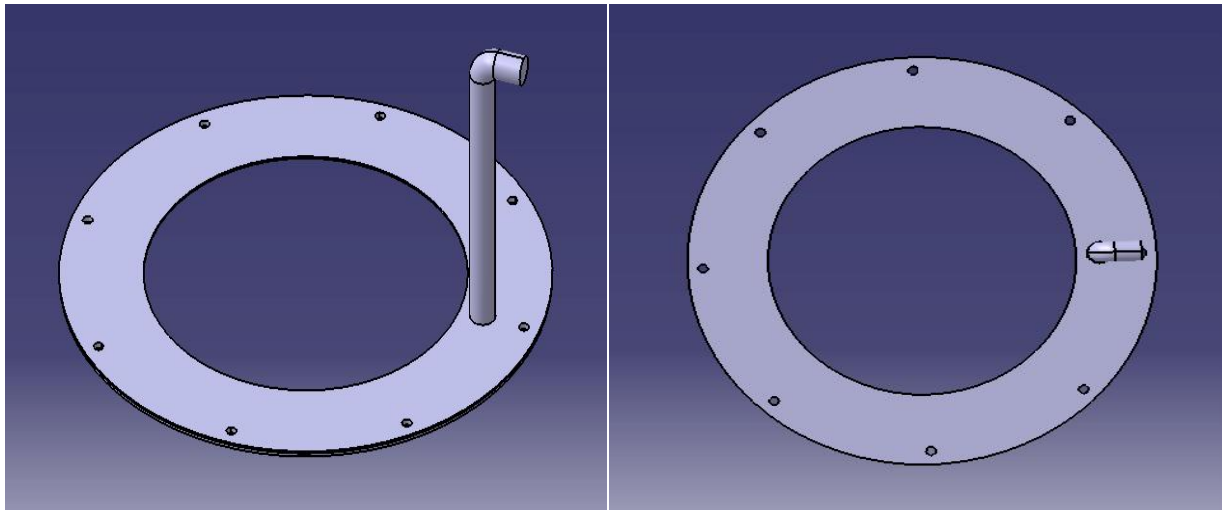
**Fig. 10. Isometric, top, front and side view of gasification zone casing**

The divergent section of casing has 230mm upper diameter, 330mm lower diameter and 50mm height. A cylinder of 230mm diameter and 120mm height is welded at the top of divergent

section. A hole of  $\frac{3}{4}$  inch is made at the top of cylinder wall. Now convergent section with 330mm upper diameter, 230mm lower diameter and 80mm height is welded at the top of cylinder, so as to form a complete casing of gasification zone. An isometric, top, front and side view of gasification zone casing is shown in Fig. 10.

#### 4.1.4 Gas outlet

A flat round strip of 250mm internal diameter, 380mm external diameter and 2mm thick with 8 equally spaced hole of 80mm diameter is designed to cover the gap between gasification zone and outer casing of gasification. A hole of 20mm diameter is made in this round flat strip at a radius of 270mm from the same centre. This hole is made to provide outlet to producer gas. Another strip of 380mm external diameter, 330mm internal diameter and 3mm thick with 8 equally spaced hole of 80mm diameter is welded over the other one so as to fix it with bottom cylinder with the help of nut and bolts. Fig. 11 shows the isometric and top view of the gas outlet pipe and cover plate.

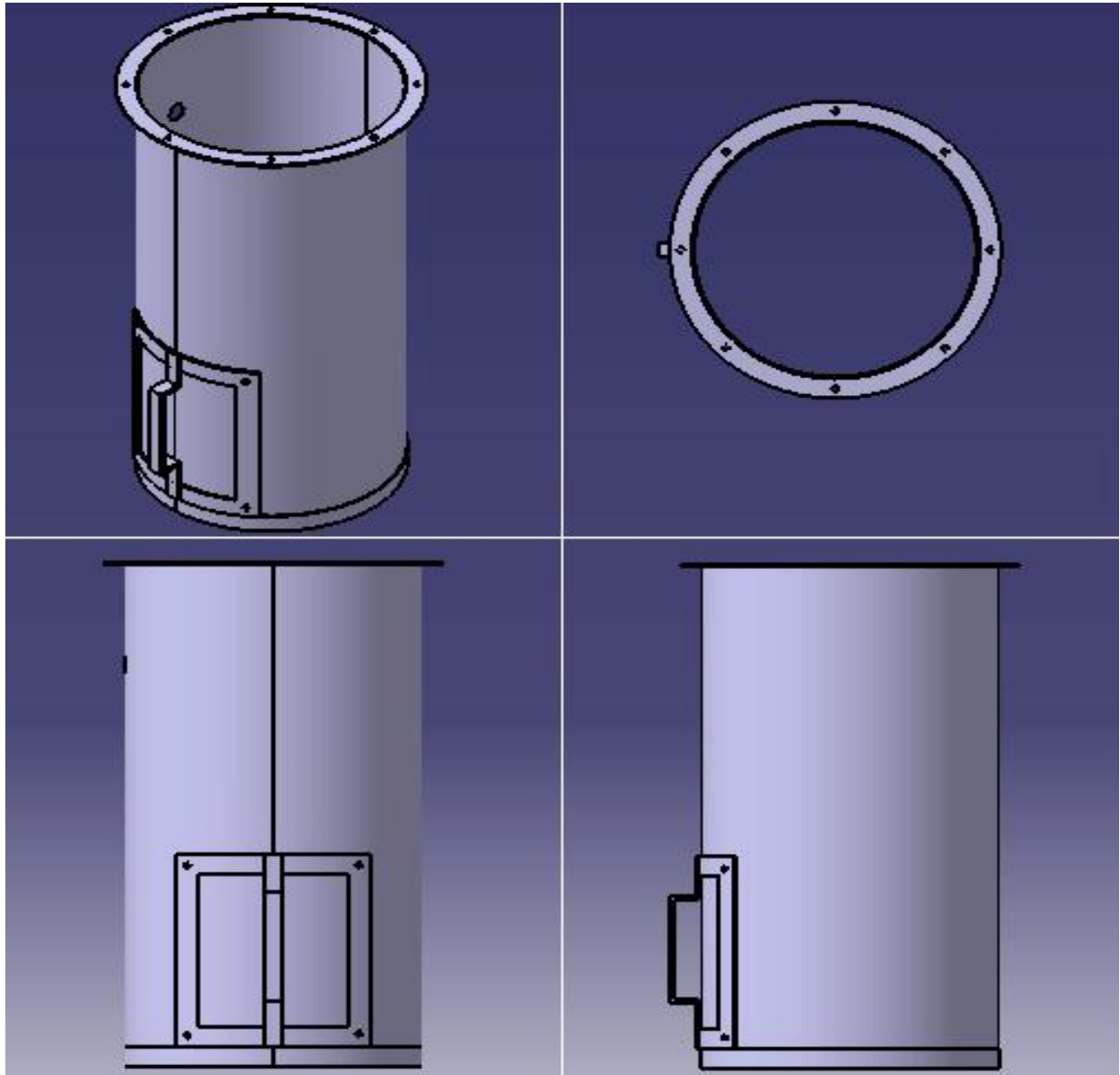


**Fig. 11. Isometric and top view of gas outlet and cover plate**

#### 4.1.5 Outer Cylinder

A cylinder is made to cover the whole gasification assembly. The height and diameter of cylinder are 600mm and 330mm respectively. 120mm from the top of cylinder, one hole of 20mm is made on the wall of cylinder for inducting air into gasification zone. A flat round strip of 330mm internal diameter, 380mm external diameters and 30mm thickness is welded at the top of the

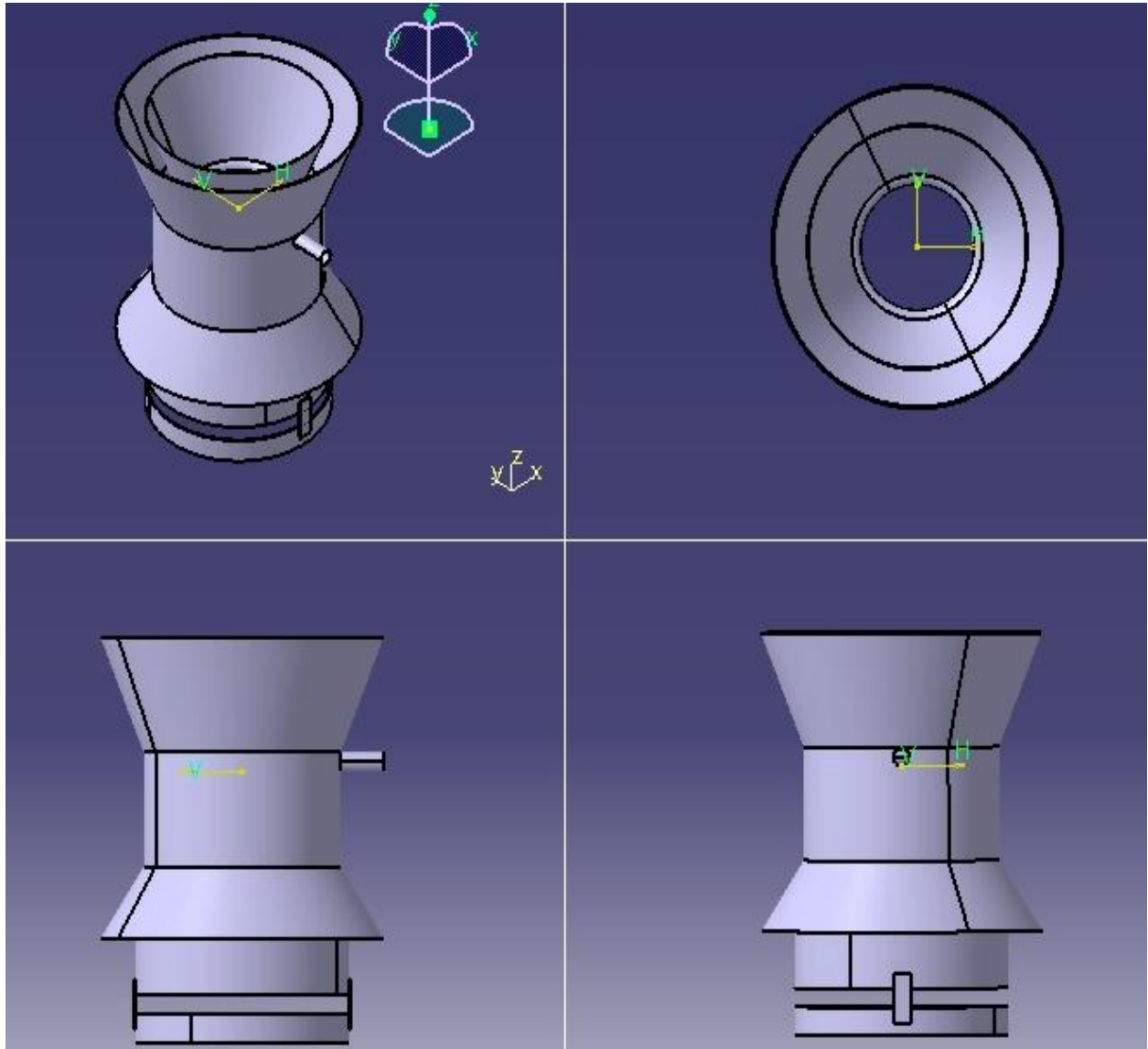
cylinder. 8 hole of 80mm diameter is drilled in this strip so as to tight it with gas outlet strip with the help of nut and bolts. A hole of 2mm diameter is made on the wall of cylinder at a height of 250mm from the bottom of cylinder for shaking the grate. A gate 230mm height is made at the bottom of cylinder wall to remove ash. 4 holes of 80mm diameter are made on the four corners of gate to tighten the gate with cylinder wall with the help of nuts and bolts. Fig. 12 shows the design of outer cylinder.



**Fig. 12. Isometric, top, front and side view of outer cylinder**

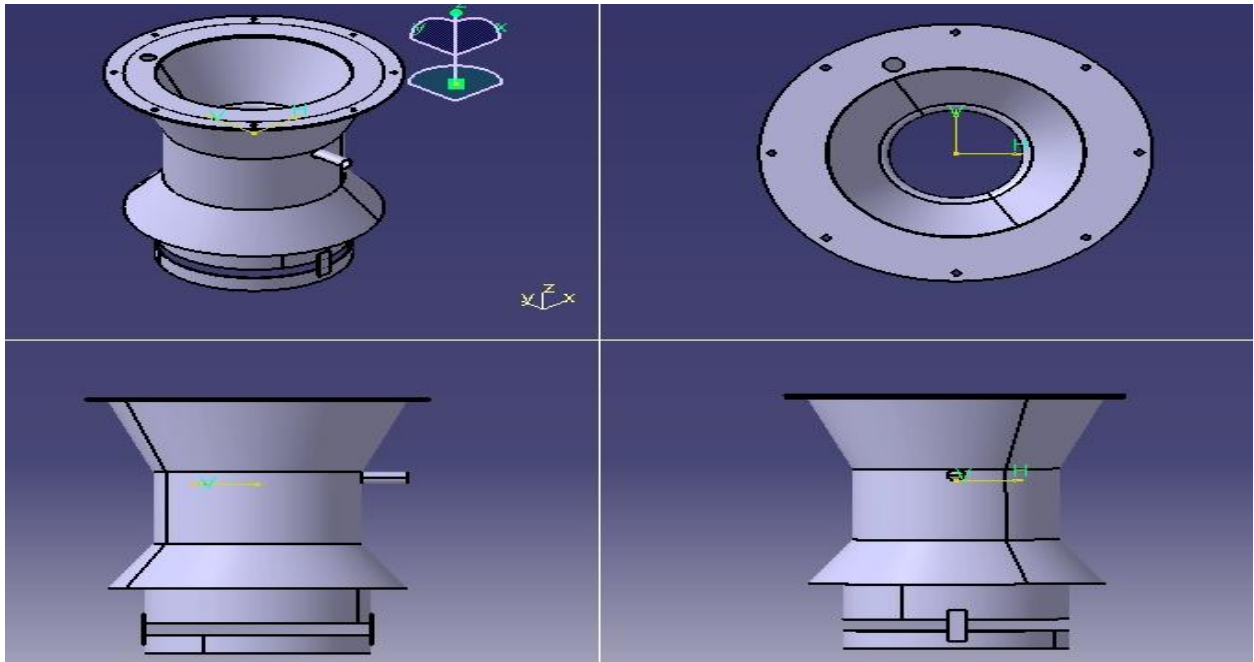
## 4.2 Assembling of Gasifier Component

In order to assemble the gasifier components, first of all gasification zone is placed inside the casing of gasification zone as shown in Fig. 13.



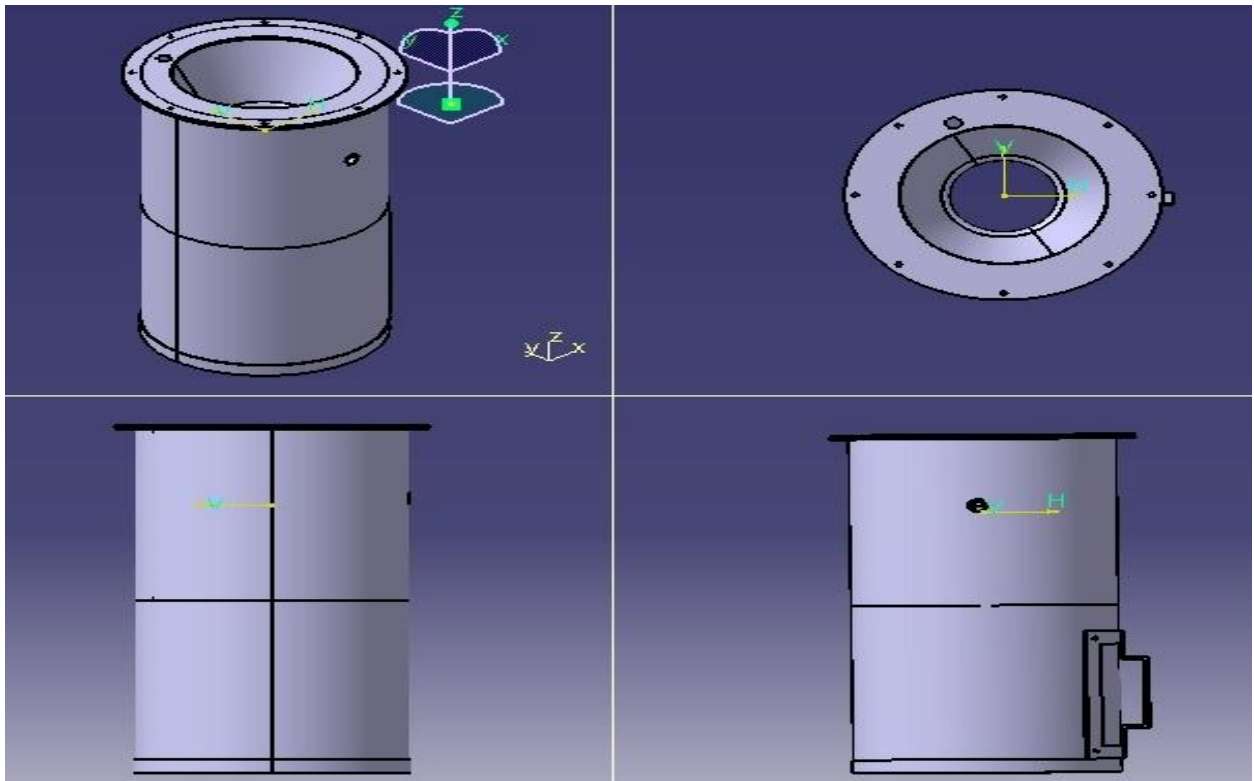
**Fig. 13. Assembling of gasification zone and casing**

Now gas outlet plate is welded at the top of the gasification zone. The complete assembly of gasification zone, casing and gas outlet cover plate is shown in Fig. 14.



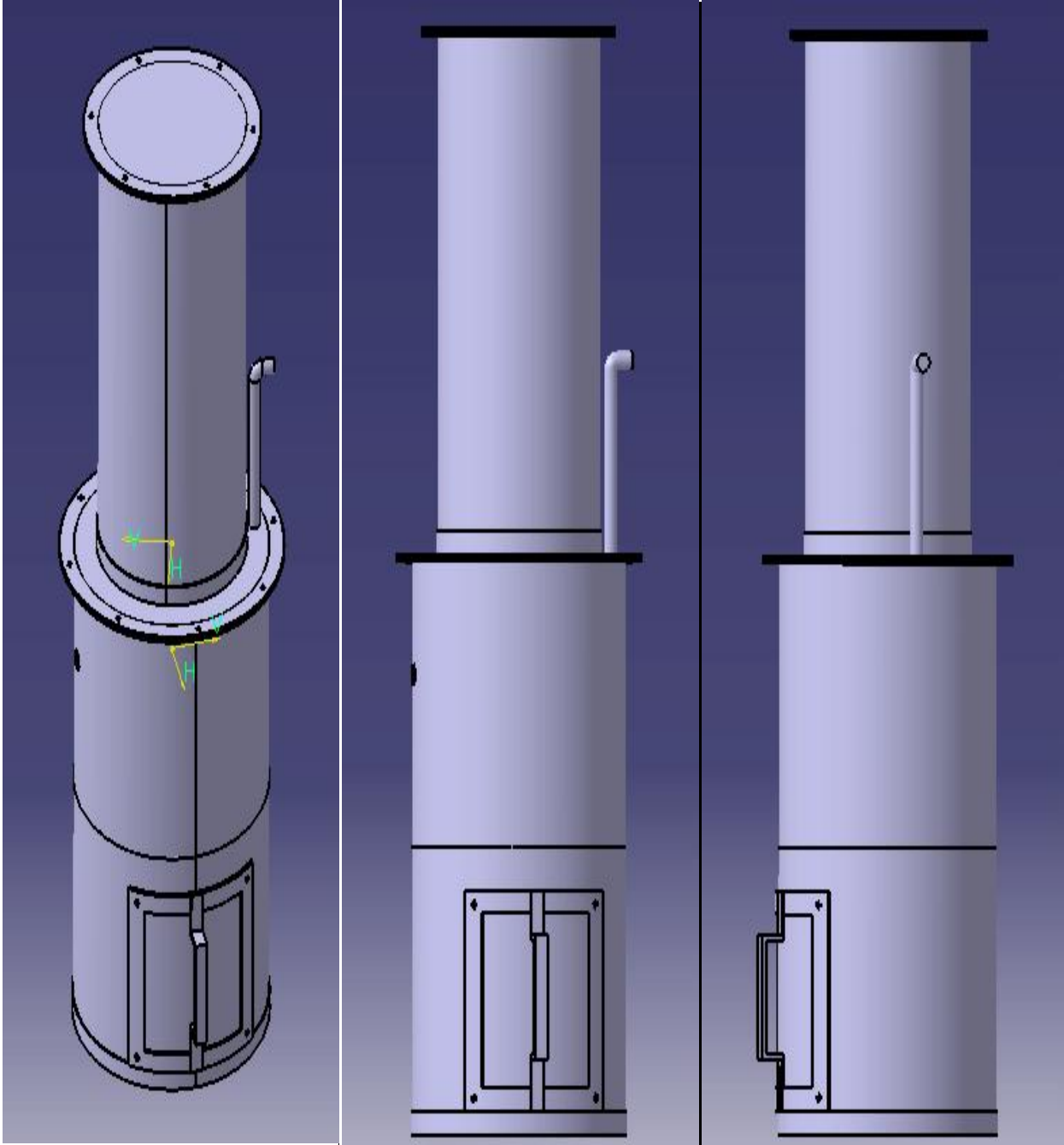
**Fig. 14 assembling of gasification zone, casing and gas outlet**

Now the above shown assembly is placed inside the outer cylinder and tightens with the help of nut and bolts as shown in Fig. 15.



**Fig. 15 Outer cylinder and complete gasification zone assembly.**

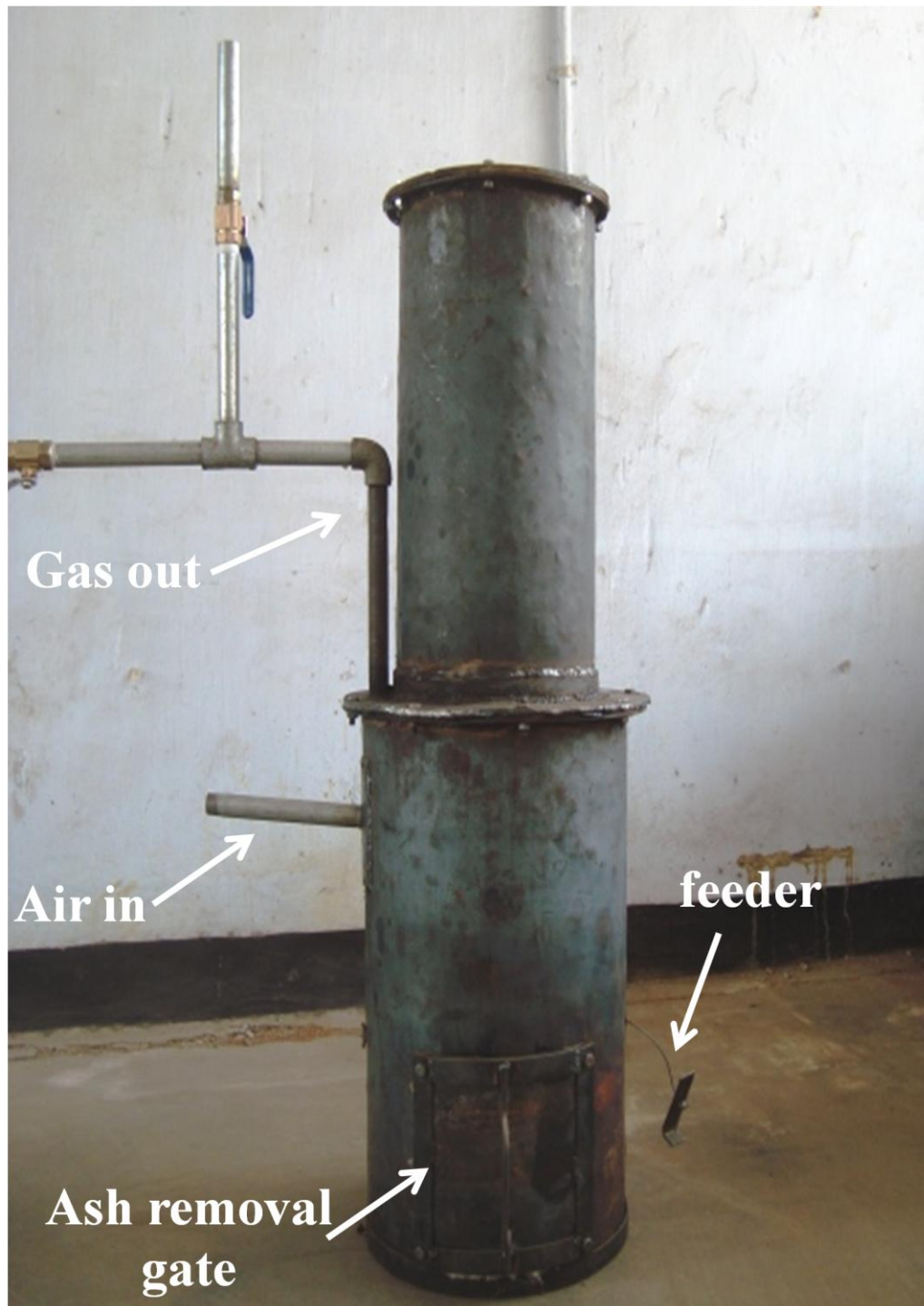
Hopper with its cover plat is now welded at the top of the above assembly as shown in Fig. 16 making the design of complete gasifier unit. Isometric, top, front and side view of the complete gasifier unit is shown in Fig. 16.



**Fig. 16. Isometric, front and side view of complete gasifier**



Fig. 17 shows the fabricated downdraft gasifier.



**Fig. 17. Fabricated Downdraft Gasifier**

### 4.3 Feed stock for gasification

Wood chips and mustard oil cake shown in Fig. 18, is used as a feed stock for gasification. It is a renewable source of energy and easily available at large scale. Wood chips can be collected from furniture shop, and it is one kind of waste for shop keeper and they used to through it as it is. Mustard oil cake can be produced by extracting mustard oil from the mustard seeds by transesterification process. Generally it is used to feed the cattle, because of its higher nutrition content. In the present study wood chips and mustard oil cake is used for feed to gasifier. The ultimate analysis of the properties of wood chips and mustard oil cake [30] are shown in Table 5.

**Table 5. Properties of wood chips and mustard oil cake**

<b>S. No.</b>	<b>Property</b>	<b>Wood Chips</b>	<b>Mustard oil cake</b>
1.	Carbon (%)	48.6	47.47
2.	Hydrogen (%)	6.5	5.73
3.	Oxygen (%)	40	38.91
4.	Nitrogen (%)	7.26	6.16
5.	Sulphur (%)	0.05	1.74
6.	Ash content (%)	3.90	7.70
7.	Moisture content (%)	6.57	6.02
8.	Volatile matter (%)	86.2	84.02
9.	GCV (MJ/kg)	18.06	20.5



**Fig. 18. Wood chips and mustard oil cake**

# CHAPTER 5

## EXPERIMENTAL SETUP

AND

## METHODOLOGY

## 5.1 Engine specification

A single cylinder, four stroke air-cooled and naturally aspirated DI diesel engine designed to develop a power of 4.4kW at 1500 rpm was used for the experimental study. A detail of engine specification is shown in Table 6.

**Table 6. Engine specification**

<b>Model</b>	<b>Kirloskar TAF 1</b>
Brake power (kW)	4.4
Rated speed (rpm)	1500
Bore (mm)	87.5
Stroke (mm)	110
Compression ratio	17.5:1
Nozzle opening pressure (bar)	200
Injection timing, (°CA)	23
Cooling system	Air cooled

Diesel was used as a pilot fuel to run the diesel engine in this study. The physical and combustion properties of diesel fuel are shown in Table 7.

**Table 7. Physical and Combustion Properties Diesel fuel**

<b>S.No.</b>	<b>Properties</b>	<b>Diesel fuel</b>
1.	Formula	$C_{12}H_{26}$
2.	Density, kg/m <sup>3</sup> (At 1 atm & 20 <sup>0</sup> C)	840
3.	Auto ignition temp (K)	527
4.	Stoichiometric air fuel ratio, (kg/kg)	14.5
5.	Flammability limits (Volume %)	0.6-5.5
6.	Lower calorific value (kJ/kg)	42,500

The air flow in the intake manifold of engine was measured by a pressure drop across a sharp edge orifice of the air surge chamber and by sensors. Fuel consumption was determined by using calibrated burette with an accuracy of 0.1CC. The pressure time history of cylinder was measured by a pressure transducer, which was mounted on the cylinder head. The crankshaft

position was obtained using a crankshaft angle sensor to determine cylinder pressure as a function of the CA. The CA signal was obtained from an angle-generating device mounted on the main shaft. A laptop is provided with data acquisition system to collect the data from all sensors and stored for offline calculations. The exhaust gas constituents CO, CO<sub>2</sub>, HC, NO, O<sub>2</sub> were measured by AVL gas analyzer and smoke density can be measure by AVL smoke meter. The technical specification of the exhaust gas analyzer used in this study is given in Annexure.

## 5.2 Gasifier unit

Gasifier unit consists of a downdraft gasifier, heat exchanger, cleaning cum cooling kit, drum and a flow meter. Fig. 18 shows the general sketch of gasifier used in present research work.

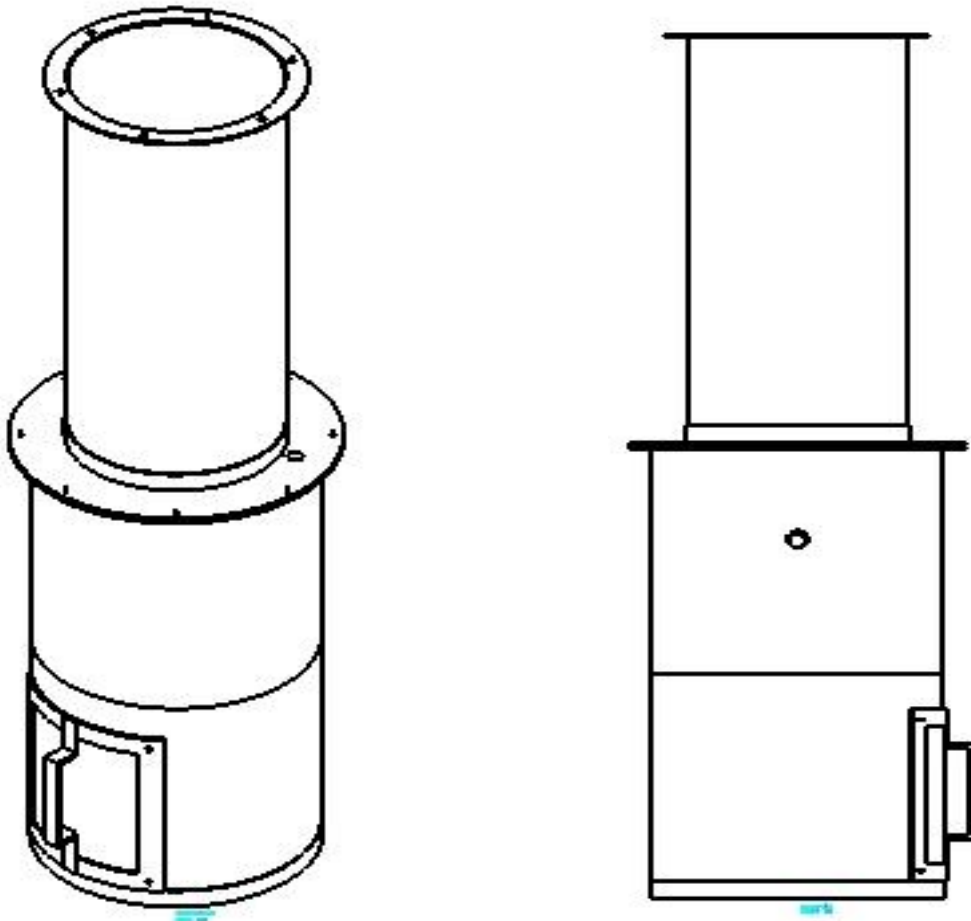
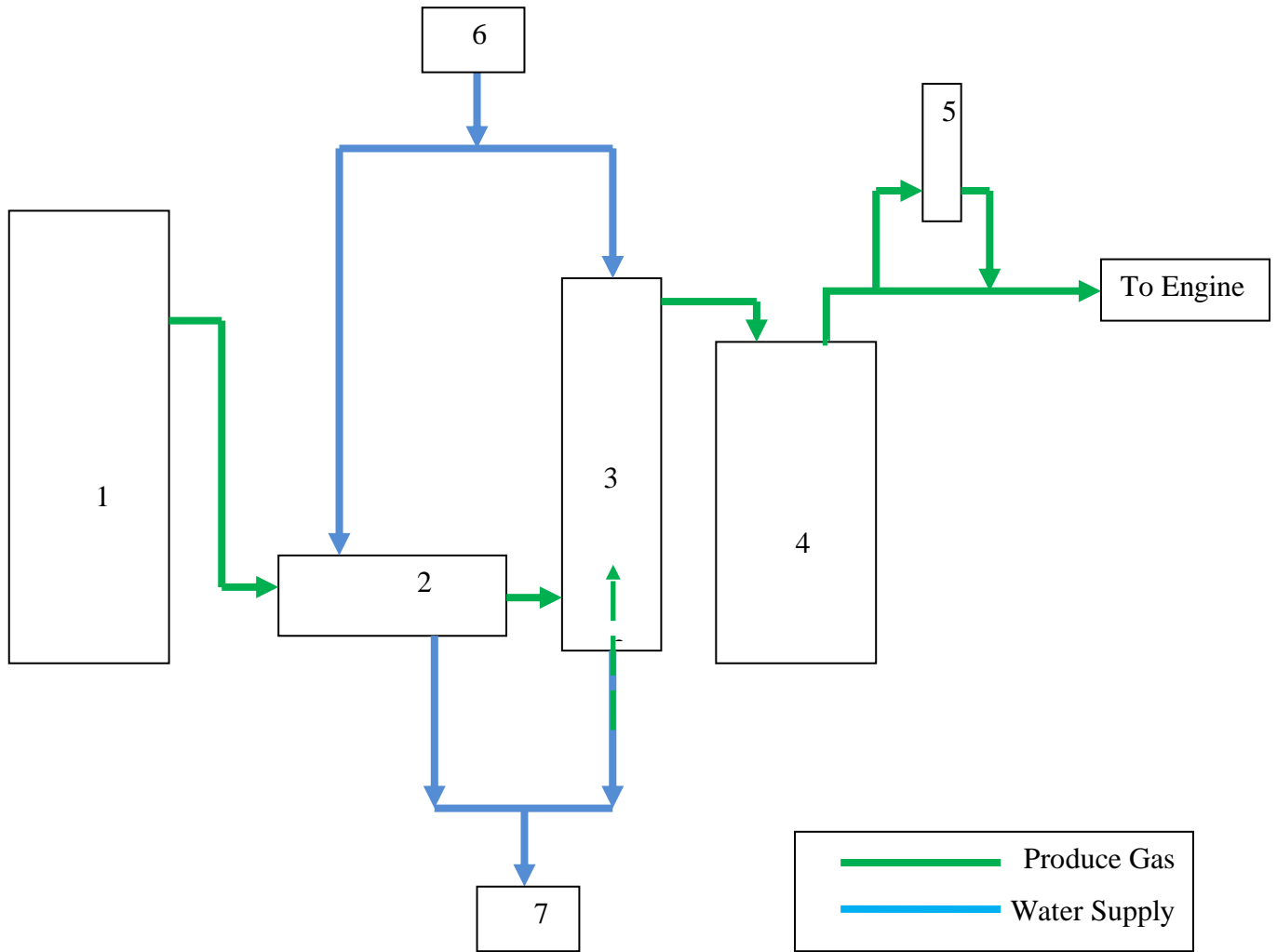


Fig. 19. General sketch of gasifier

Coal was used to initiate the gasification process, 10 – 12 pieces of coal was poured into the gasifier and with the help of oil and dry cow dung, it had been ignited. Air was inducted with the help of blower, the flow of air could be regulated as per the requirement. When coal reaches at its red heat level, a mixture of wood chips and mustard oil cake in the ratio of 7:3 by weight was poured into the hopper and the hopper cover was tightened by nut and bolts. The blower supplied air in such a way that the biomass burnt partially and generates producer gas. This producer gas thus passed through the gap between gasification zone and casing of gasification zone. Here most of the heavier particles get stuck and tar present in producer gas gets creaked. Now this producer gas was allowed to pass through heat exchanger unit so as to reduce the temperature of producer gas. Producer gas from here passed through cleaning cum cooling unit where it was cleaned as well as cooled. The physical and combustible properties of producer gas are shown in Table 8. Before inducting producer gas into the inlet manifold of engine, it was temporarily stored in a drum in order to provide backup to the engine. Between drum and engine intake manifold, a gas flow meter was introduced to meter the volume of flowing producer gas in terms of litre per minute. This flow meter can be regulated as per the requirement of supply. Fig. 19 shows the block diagram of gasifier unit.

**Table 8. Physical and Combustion Properties of Producer gas**

<b>S.No.</b>	<b>Properties</b>	<b>Producer gas</b>
1.	Density, kg/m <sup>3</sup> (At 1 atm & 20 <sup>0</sup> C)	1.287
2.	Stoichiometric air fuel ratio, (kg/kg)	1.12:1
3.	Flammability Limits	N/A
4.	Lower Calorific Value (kJ/kg)	5000



**Fig. 20. Block diagram of gasifier unit**

Table 9 shows the description of gasifier unit.

**Table 9. Description of gasifier unit**

Sr. No.	Description	Sr. No.	Description
1.	Gasifier	5.	Gas flow meter
2.	Heat exchanger	6.	Water in
3.	Cleaning cum cooling system	7.	Water out
4.	Drum		



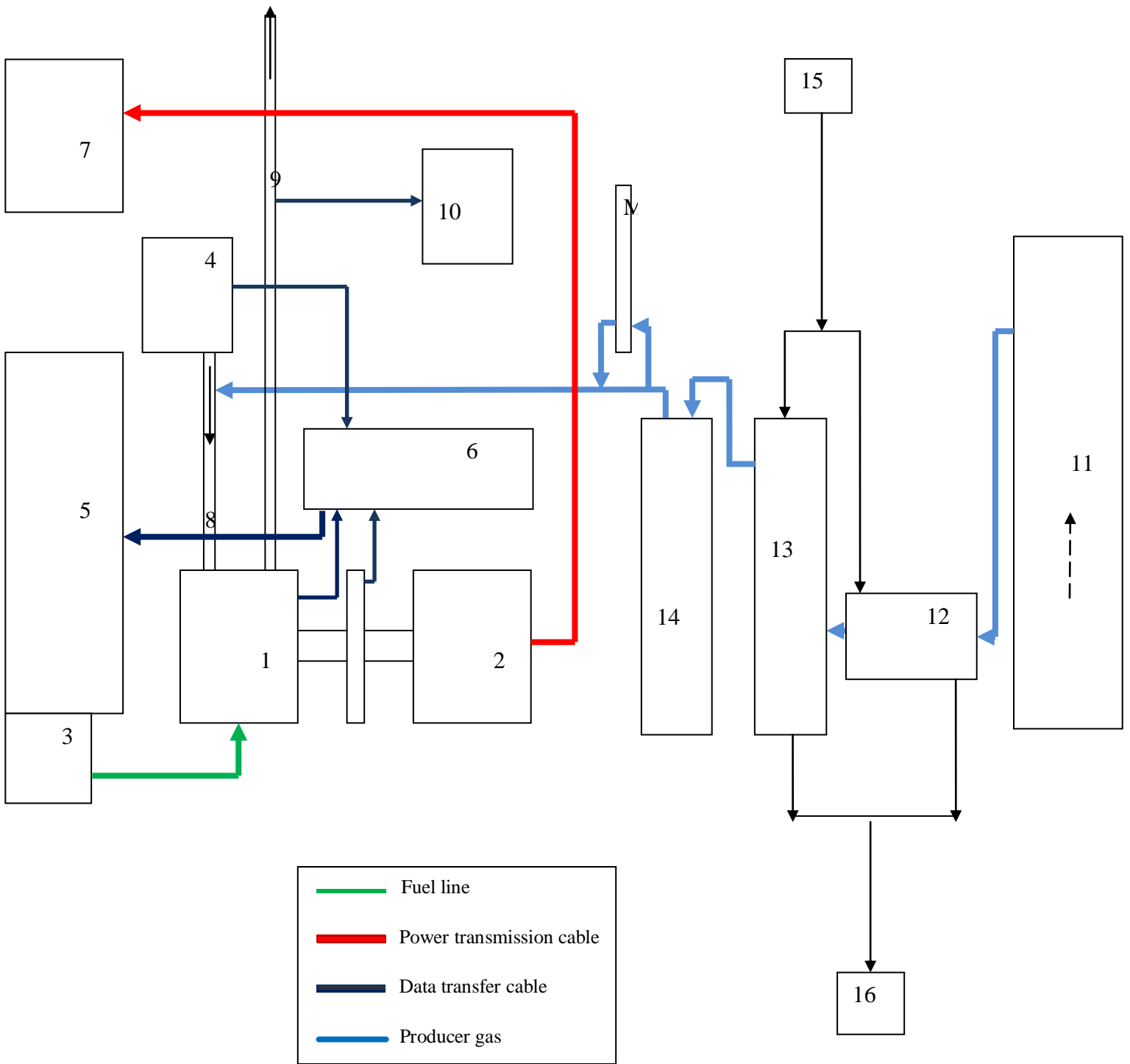
## 5.2 Engine Coupled with Gasifier

To finalize the experimental setup, engine was coupled with gasifier unit. Fig. 20 shows the block diagram of engine coupled with gasifier. To conduct the experiment, first of all engine was run on diesel fuel only and various readings for emission and performance test were taken at no load, 1kW, 2kW, 3kW and 4.5kW. Now producer gas from gasifier unit was allowed to pass with air in intake manifold of engine. The gas flow meter was maintained at 4 litres per minute (lpm). The engine was allowed to run for a while and after that first load of 1kW was put on electric load cell than 2kW, 3kW and 4.5kW were added on electric load cell and various readings were taken respectively to obtain emission and performance characteristic of engine at diesel and 2lpm of producer gas. Similarly for next experiment, the gas flow meter was maintained at 6lpm and 8lpm and various reading were taken respectively to obtain emission and performance characteristics at varying load.

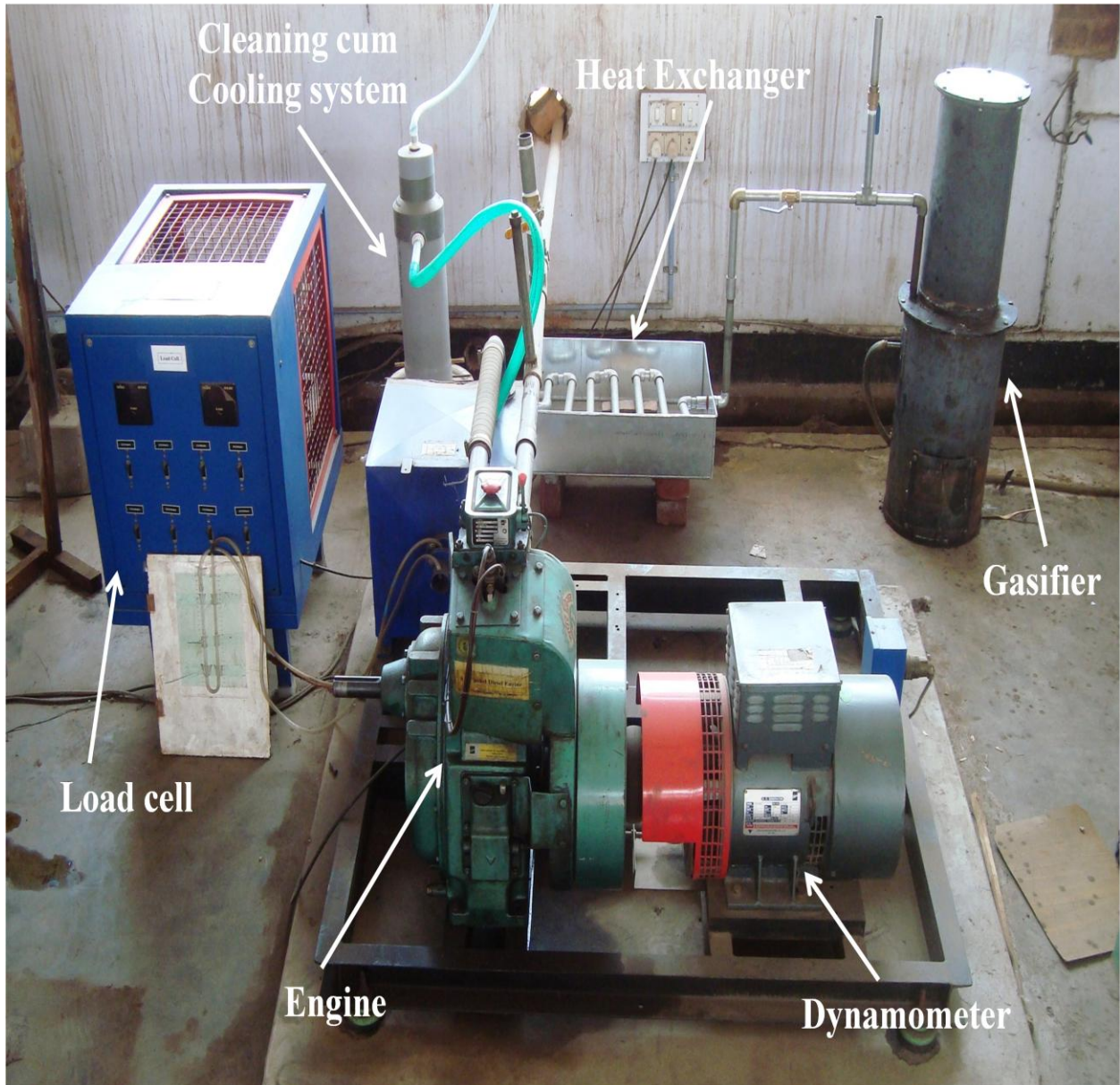
Descriptions of various components of engine coupled with gasifier unit are shown in Table 10.

**Table 10. Description of engine coupled with gasifier unit**

Sr. No.	Description	Sr. No.	Description
1.	Engine	10.	Exhaust gas analyzer
2.	Electric Dynamometer	11.	Gasifier Unit
3.	Fuel tank	12.	Heat exchanger
4.	Air box	13.	Cleaning cum cooling
5.	Data acquisition system	14.	Drum
6.	Data receiver unit	15.	Water in
7.	Electric load cell	16.	Water out
8.	Intake pipe	M.	Gas flow meter
9.	Exhaust pipe		



**Fig. 21. Block diagram of engine coupled with gasifier**



**Fig. 22. Complete picture of engine coupled with gasifier unit**

# CHAPTER 6

## RESULT AND DISCUSSION

In the present work, the performance and emission tests were conducted on diesel engine at dual fuel mode i.e. diesel (DF) as primary fuel and producer gas (PG) at 4lpm, 6lpm and 8lpm as secondary fuel respectively. The fuel terms are denoted as DF+PG4lpm, DF+PG6lpm and DF+PG8lpm, where the mass flow rates of producer gas is indicated after PG. The results of the performance and emission test are described below.

## **6.1 Performance of Diesel Engine in Dual Fuels Mode**

Liquid fuel economy is one of the major factors when operating the gasifier CI engine system. The engine performance with diesel (D) and producer gas (PG) is evaluated in terms of brake thermal efficiency (BTE), brake specific fuel consumption (BSEC) and exhaust gas temperature (EGT) along with emission characteristics at no load, 1kW, 2kW, 3kW and 4.5kW of brake power.

### **6.1.1. Brake Thermal Efficiency (BTE)**

Fig. 23 shows the effect of brake power at brake thermal efficiency at varying load condition. The BTE of the dual fuel mode for engine is lower than that of diesel. A considerable reduction in brake thermal efficiency is observed in dual fuel mode as compared to DF mode at all loads. The maximum efficiency achieved by diesel fuel was 27.5% where as in dual fuel mode maximum efficiency achieved was 26%, 25% and 24.5% for D+PG4lpm, D+PG6lpm and D+PG9lpm respectively. The reduction in BTE is due to the lower calorific value of producer gas, which contains more combusted mixture that enters into the engine. Producer gas evolved from the engine is at higher temperature and therefore density of producer gas is reduced, which in turn reduces the mass flow rate of producer gas and air required for combustion, resulting in lowering the oxygen level required for combustion. This insufficient oxygen in the combustion chamber is the cause of incomplete combustion [31].

### **6.1.2 Brake Specific Energy Consumption (SEC)**

Fig. 24 shows the variation between specific energy consumption and brake power. Brake specific fuel consumption is not a very reliable parameter to compare the two fuels having different calorific values and density, hence brake specific energy consumption is preferred to compare the performance of CI engine. The specific energy consumption in dual fuel mode is calculated from the fuel consumption and calorific value of diesel and producer gas. Specific

energy consumption in dual fuel mode was found to be higher than that of diesel mode at all load conditions. BSEC is inversely proportional to BTE hence as the brake thermal efficiency is reducing by using of producer gas with air, the BSEC will decrease with corresponding flow rate of producer gas.

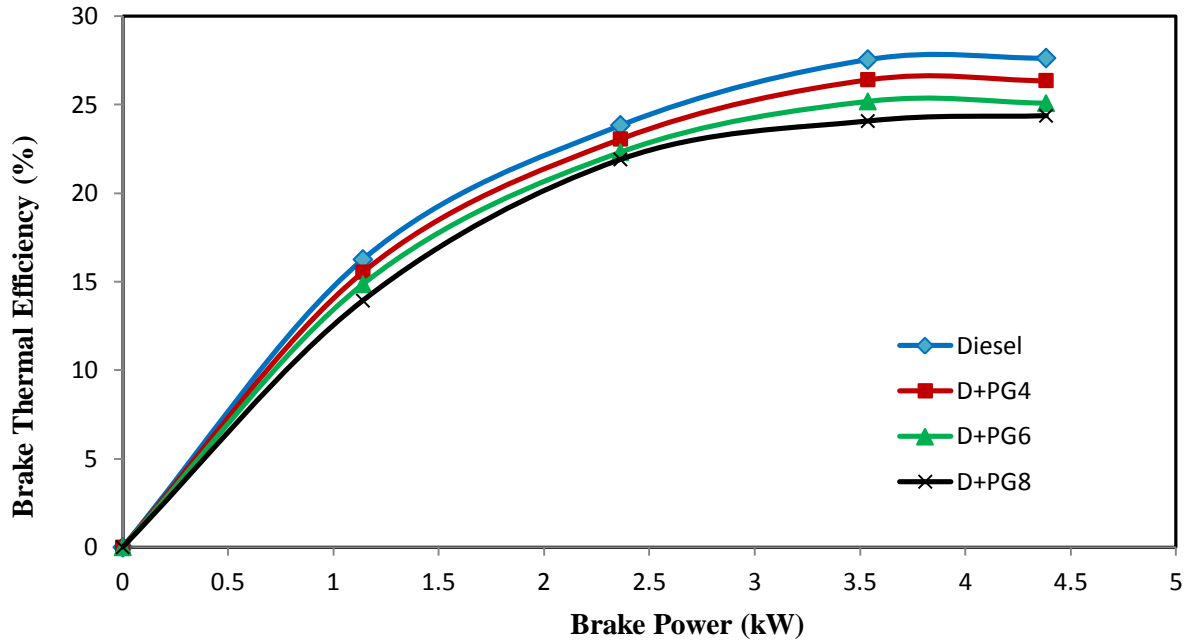


Fig. 23. Effect of brake power on brake thermal efficiency in dual fuel mode

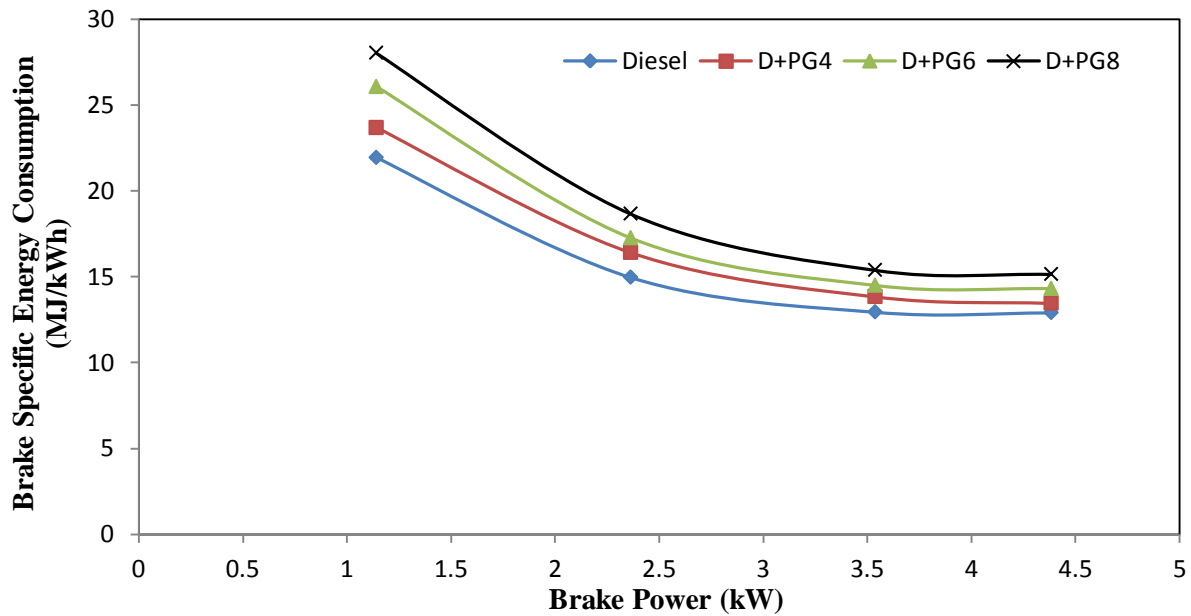


Fig. 24. Effect of brake power on specific energy consumption in dual fuel mode

### 6.1.3 Exhaust Gas Temperature

The variation of exhaust gas temperature with brake power is shown in Fig. 25. The exhaust gas temperature of diesel at full load is found to be 330°C while the exhaust gas temperature at full load for D+PG4, D+PG6 and D+PG8 are found to be 365, 378 and 388°C respectively. EGT for dual fuel mode is always higher than DF, this is due to the excess energy supplied to the engine [32]. The EGT can be reduced by increasing the density of fuel mixture for combustion in engine. Higher the exhaust gas temperature in the combustion chamber is an indication of increase in  $\text{NO}_x$  emission because at temperature more than 1100°C, nitrogen reacts with oxygen to produce  $\text{NO}_x$ .

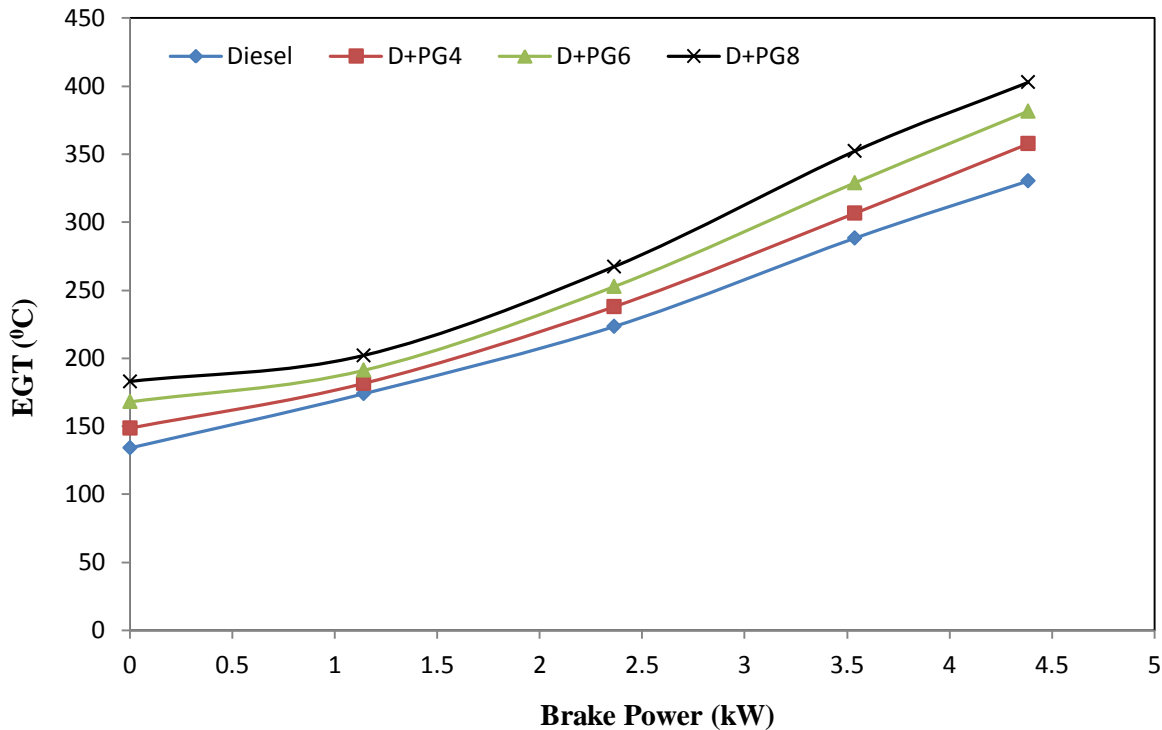


Fig. 25. Effect of brake power on exhaust gas temperature in dual fuel mode

## 6.2 Emission Characteristics of diesel engine in Dual Fuel Mode

Emission from the engine reflects the quality of combustion takes place inside the engine. The different emission parameters measured during diesel and dual fuel (D+PG) mode operation are discussed as follows.

### 6.2.1 Carbon monoxide (CO) emission

There are two major cause of formation of CO emission, the first one is the incomplete combustion due to insufficient amount of oxygen supplied in combustion chamber and the second one is the insufficient time in the cycle for completion of combustion. The variation of CO emission of the engine with DF and dual fuel mode is depicted in Fig. 26. With increase in load, an increase in CO emission was observed. Much higher values of CO emission are recorded in dual fuel mode as compared to diesel fuel mode. The higher concentration of CO emission in the dual fuel mode is due to incomplete combustion. The mixture of high temperature PG and air flow to the engine reduces the amount of oxygen required for complete combustion. This creates incomplete combustion and increases the CO emission.

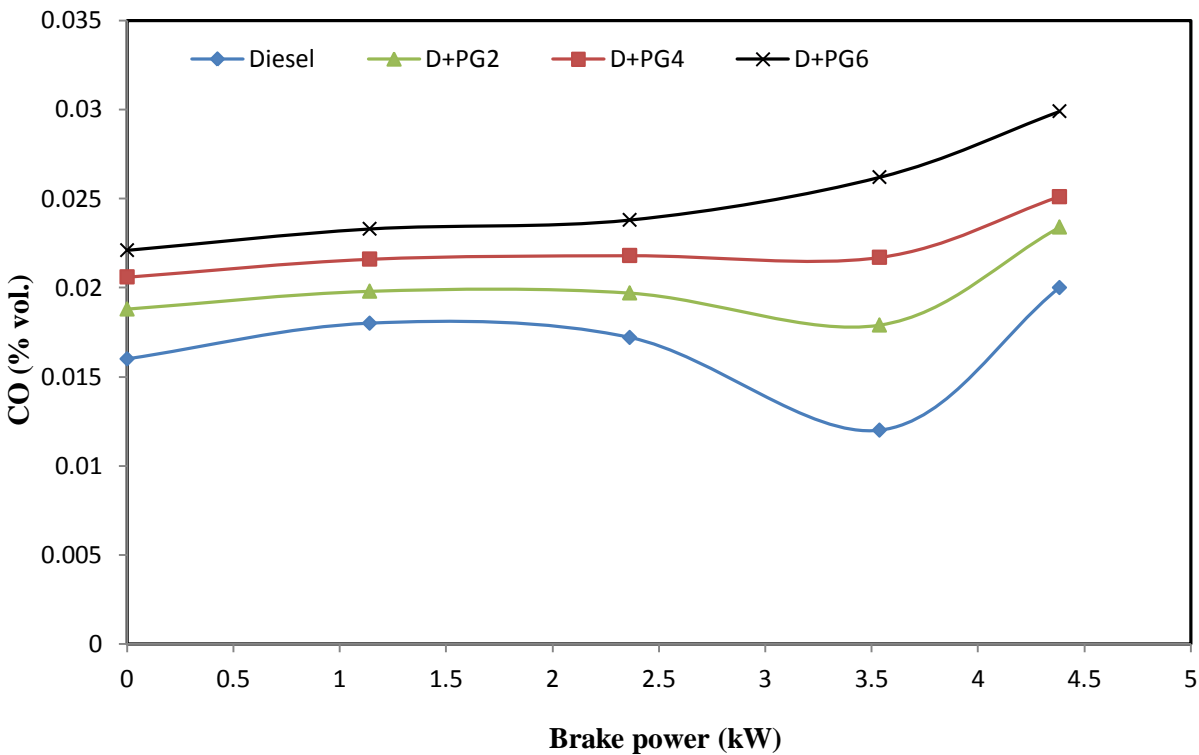
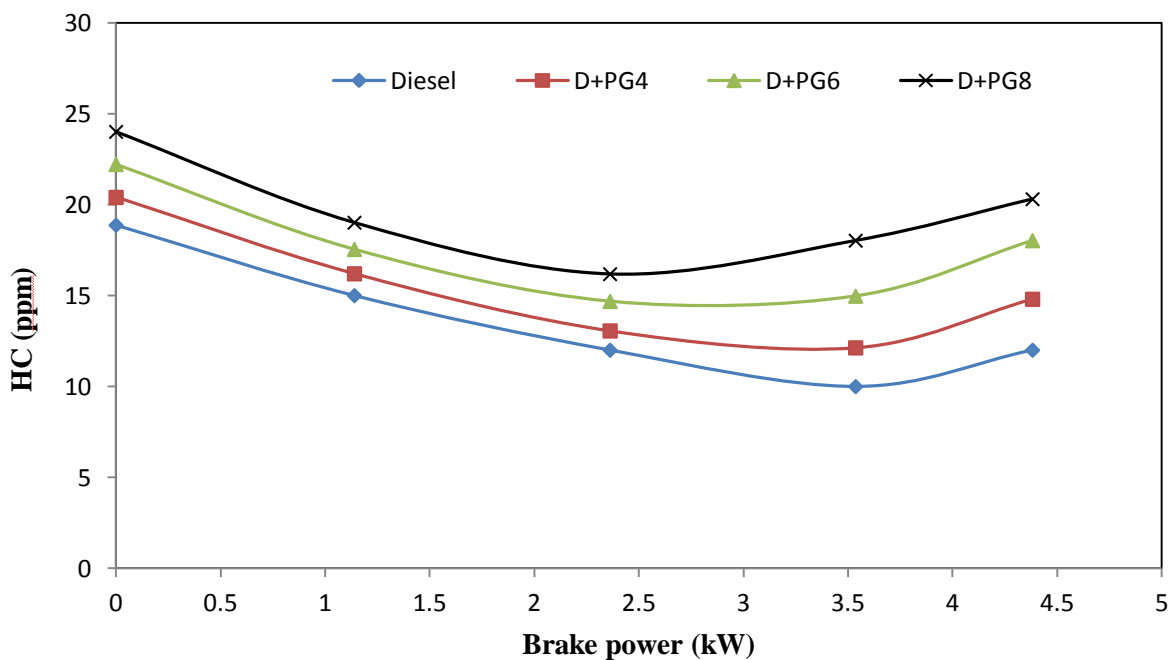


Fig. 26. Effect of brake power on CO emission at varying load in dual fuel mode



### 6.2.2 Hydro carbon (HC) emission

As shown in Fig. 27, there is always an increase in hydrogen carbon (HC) emission when there is an increment in loads. Unburnt hydrocarbon emissions are the direct result of incomplete combustion. The unburned hydrocarbons and their derivatives that readily vaporize are termed as volatile organic compounds (VOCs). The VOCs react with oxides of nitrogen in the presence of sunlight to form oxidants and photochemical smog [33]. This emission arises when a part of the fuel inducted into the engine escapes combustion. During ignition delay period, fuel air mixtures becomes too rich to ignite and combust contribute to HC emissions.

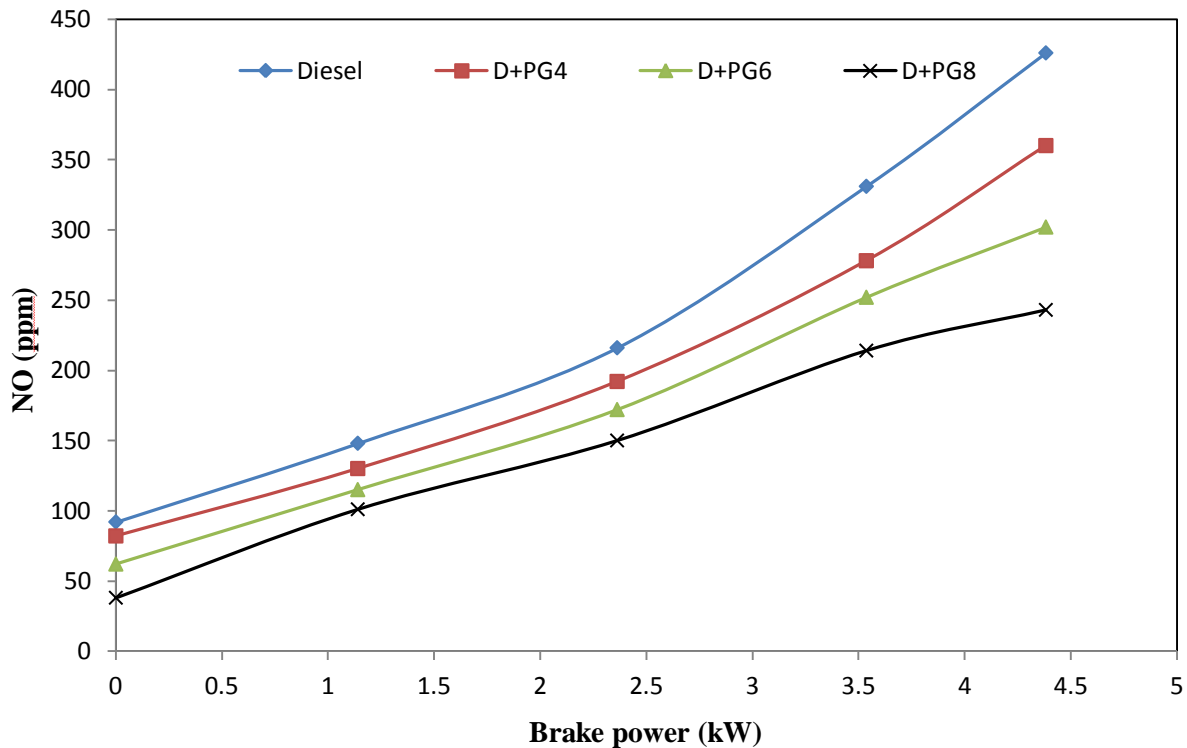


**Fig. 27. Effect of brake power on HC emission at varying load in dual fuel mode**

### 6.2.3 Nitric oxide (NO) emission

Higher temperature and availability of oxygen are the two main reasons for the formation of NO<sub>x</sub>. Nitrogen is inert at low temperature, but at temperature higher than 1100<sup>0</sup>C nitrogen reacts with oxygen and form oxides of nitrogen [34]. Thus NO emission depends upon combustion chamber temperature which in turn depends on the applied load. From the Fig. 28, it was observed that the NO emission increases with increase in load for all the fuels i.e. diesel and D+PG fuel. This is due to the high temperature in combustion chamber obtained at high load

thus reacting nitrogen with oxygen to form  $\text{NO}_x$ . At low brake power, insignificant difference in  $\text{NO}$  emission was recorded while operating the engine on diesel fuel mode and dual fuel mode but, as brake power increases the variation of  $\text{NO}$  emission increases between Diesel and D+PG fuel.  $\text{NO}$  emission was higher in diesel fuel mode than dual fuel mode, which is an excellent advantage of dual fuel mode. Also organic nitrogen from the air causes  $\text{NO}_x$  formation. Producer gas do not have organic nitrogen, it has only atmospheric nitrogen, which inorganic nitrogen [35].

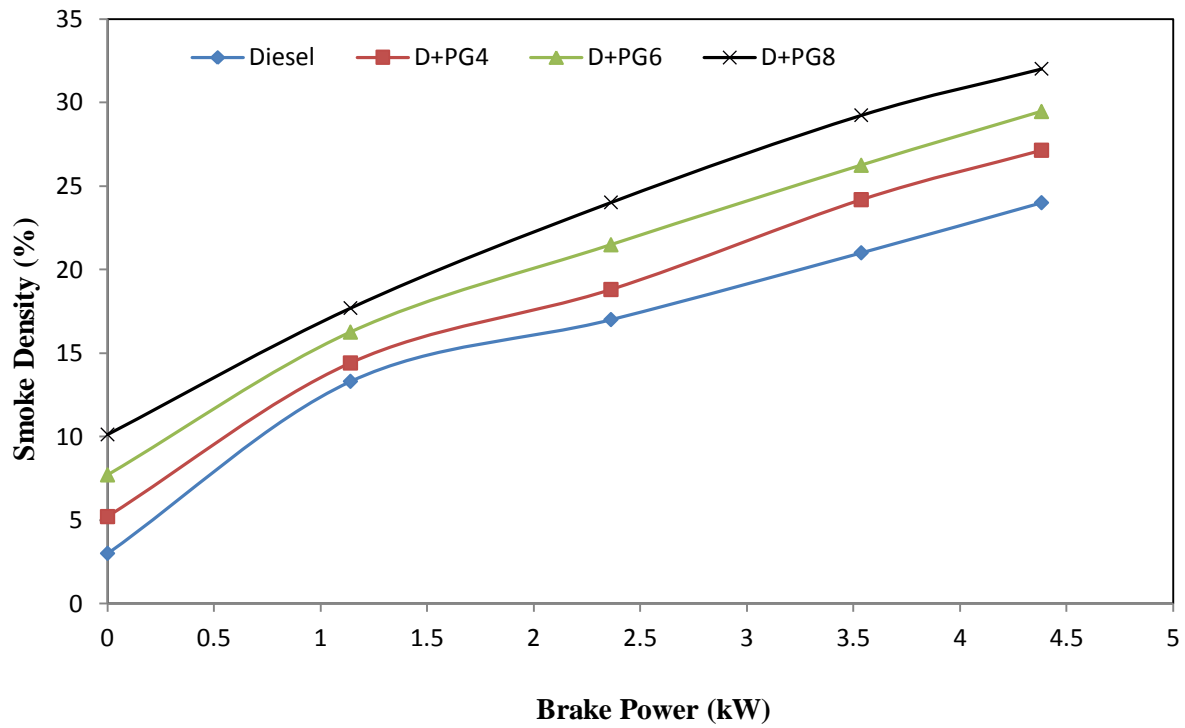


**Fig. 28. Effect of brake power on  $\text{NO}$  emission at varying load in dual fuel mode**

### 6.2.3 Smoke density

Smoke density increases as the brake power increases, it is applicable for all types of fuel used in diesel engine. The cause of smoke is incomplete combustion which may be due to incorrect air-fuel ratio or may be due to improper mixing of fuel with air. As shown in Fig. 29, significant difference is observed between smoke density of various fuels at no load and full load, but the change was very insignificant when first load was given to engine. This is due to the lack of oxygen at no load and full load than the oxygen available at first load. In diesel fuel mode operation the smoke density attained a maximum value of 25% where as it is 32% in dual fuel

mode for D+PG8 at full load. In dual fuel mode of operation, the smoke density is observed to be higher than that of the DF for all combination of PG.



**Fig. 29. Effect of brake power on smoke density at varying load in dual fuel mode**

# CHAPTER 7

## CONCLUSION

## 7.1 Conclusion

The performance and exhaust emission characteristics were investigated experimentally in a single cylinder, 4-stroke air cooled DI diesel engine operating with gasifier on a dual fuel mode and following conclusion were made on the basis of present work.

- Higher amount of diesel fuel can be saved by replacing diesel with producer gas although there would be a reduction in brake thermal efficiency which is due to lower heating value of producer gas and insufficient amount of oxygen supply.
- NO emission was found to be very low in dual fuel which is a great advantage of dual fuel mode over diesel fuel alone.
- CO and HC emission was observed very high in dual fuel mode which gives an indication of insufficient oxygen in combustion chamber.

## 7.2 Future scopes

In the present energy scenario, variety of alternative fuel has been developed for replacing fossil fuels. Producer gas has been proven a better substitute for diesel fuel for the application in stationary diesel engine. In the present work, considerable reduction in diesel fuel was observed when operated in dual fuel mode. Furthermore reduction in NO<sub>x</sub> was also observed in dual fuel mode which is very toxic and harmful emission, but other emission like CO, HC and smoke was found to be higher in dual fuel mode. This can be reduced by supplying additional oxygen into the inlet manifold of engine. This task can be done by providing super charger. Producer gas with high content of CO<sub>2</sub> and dust particle also makes a cause in the increase in emission, hence an efficient filter must be provided for better cleaning of producer gas before inducting producer gas into inlet manifold of diesel engine. Proper mixing of air and producer gas is required to obtained complete combustion.

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# ANNEXURE

## TECHNICAL SPECIFICATION OF SMOKE METER

### Range/Accuracy/Resolution

	<b>OPACITY</b>	<b>ABSORPTION</b>	<b>RPM</b>	<b>Oil Temperature</b>
Measuring range	0–100 %	0–99.99 m-1	400–6000 1/min	0–150 oC
Accuracy & Repeatability	± 1 % of full scale	Better than ± 0.1 m-1	± 10	± 3 oC
Resolution	0.1 %	0.01 m-1	± 1	± 1 oC

<b>Application</b>	:	For free-acceleration test only.
<b>Calibration</b>	:	Automatic (self-calibration immediately after switch-on or at the press of a key).
<b>Display</b>	:	Digital
Standard	:	LED (7 segment), 4x15 (mm)
Optional	:	LCD
<b>Alarming signal</b>	:	Equipment is not working.
<b>Linearity check</b>	:	48.4%-53.1%/ 1.54m-1-1.76m-1 of measurement range (manual).
<b>Probes</b>	:	Set of probes of three different size (10, 16 & 27 mm internal dia)
<b>Hose pipes</b>	:	material length
Standard		Rubber 4.0 meter
Optional		Rubber 2.5/5.0 meter
<b>Smoke inlet</b>	:	Through a control valve.
<b>Smoke temperature at entrance</b>	:	250 °C (maximum)
<b>Measuring chamber</b>		
Length	:	430±5 mm
Heating	:	Thermostatically controlled.
<b>Light source</b>	:	Halogen Lamp, 12 V/5W (Color temperature: 3000±150 K)
<b>Sensor</b>	:	Selenium Photocell (size – φ 45 mm)

**Built-in printer** : Dot matrix printer, 24 column

**Ambient operating conditions**

Temperature : 0-50 °C

Humidity : 90% at 50 °C (non-condensing)

**Dimension** : width x height x depth

Basic unit 437C : 600 x 260 x 370 mm

RPM module : 93 x 140 x 33 mm

Dispeed 490 : 277 x 48 x 184 mm

**Weight:**

Unit : 24 kg

RPM module : 0.45 kg

Dispeed 490 : 1.18 kg

Hose pipe (4m) + probes : 8 kg

**Power consumption:**

Overall equipment : 600 W

Measuring chamber heating : 500 W (at 220V)

**Storage temperature** : -30<sup>0</sup>C to +65<sup>0</sup>C

**Protection type** : IP 52

## TECHNICAL SPECIFICATION OF GAS ANALYSER

### (A) Details of Instruments

Sr. No.	Instrument	Measurement	Make and model	Measurement technique / method
1.	Load cell	Loading device	Indian make	Load cell
2.	Burette	Fuel consumption	Indian make	Solenoid type
3.	Temperature indicator	Exhaust gas measurement	Indian make	Thermocouple
4.	Exhaust gas analyser	NO	AVL 444 Digas analyser	Chemiluminescence
		HC		FID
		CO		NDIR
5.	Pressure transducer with charge amplifier	Cylinder pressure	Kistler 5395A	Piezoelectric pickup
6.	Crank angle encoder	Crank angle	Indian make	Magnetic pick up type

**(B) Range, Accuracy and Uncertainty**

<b>Sr. No.</b>	<b>Instrument</b>	<b>Range</b>	<b>Accuracy</b>	<b>Uncertainty</b>
1.	Load indicator	250-6000 W	$\pm 1$ W	0.2
2.	Temperature indicator	0-900	$\pm 1$ oC	0.15
3.	Burette	1-30cc	$\pm 0.2$ cc	1.5
4.	Speed sensor	0-10,000 rpm	$\pm 10$ rpm	$\pm 1$
5.	Exhaust gas analyser	NO-0-5000 ppm	$\pm 50$ ppm	1
		HC-0-200000 ppm	$\pm 10$ ppm	0.5
		CO-0-10%	0.03%	1
6.	Smoke meter	0-100%	$\pm 1$ %	1
7.	Pressure transducer	0-110bar	$\pm 1$ bar	0.15
8.	Crank angle encoder		$\pm 1$	1