TO STUDY THE BIOMASS PROPERTIES FOR A DUAL FUEL ENGINE

Thesis submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering

in

THERMAL ENGINEERING

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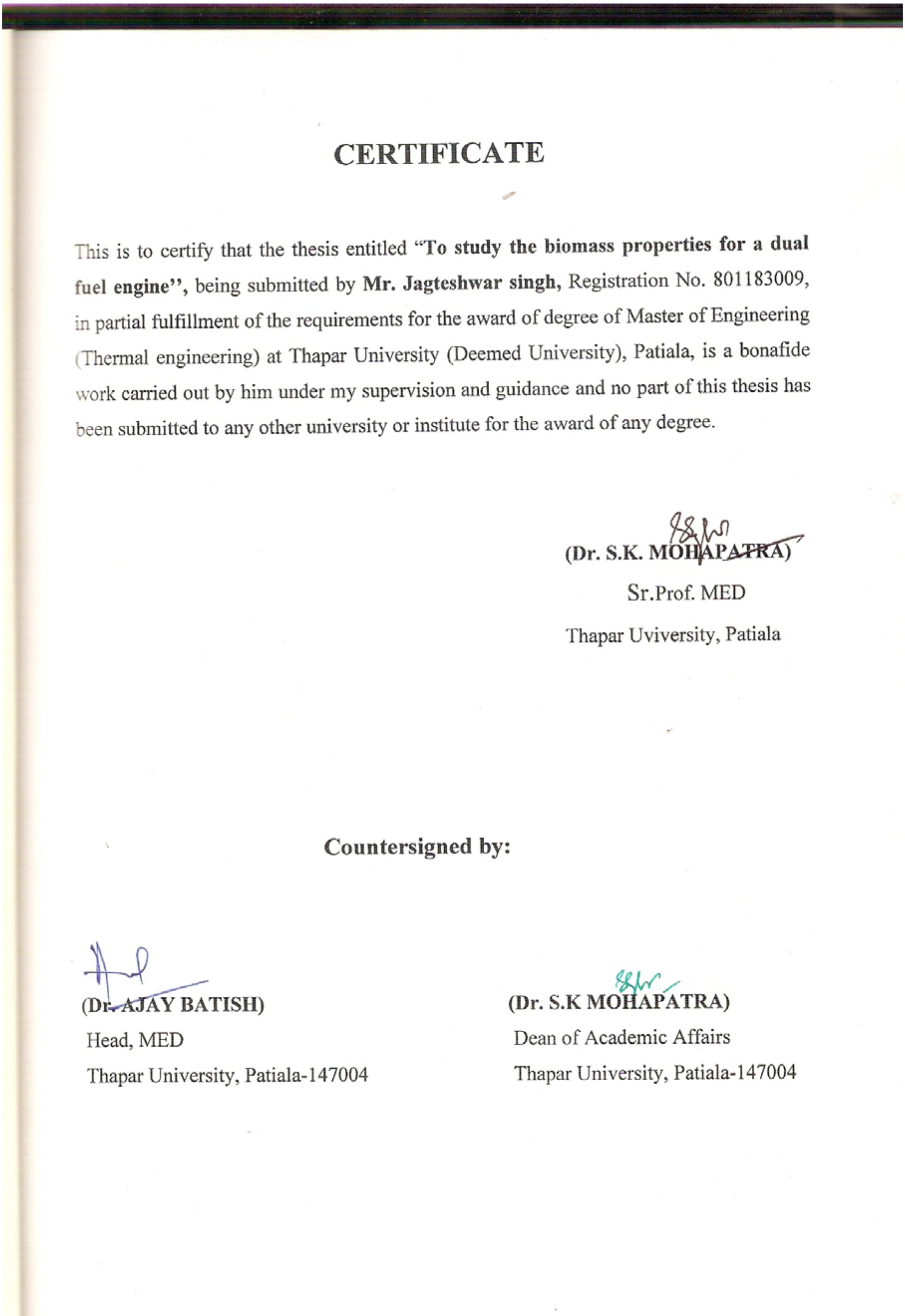

CERTIFICATE

This is to certify that the thesis entitled **“To study the biomass properties for a dual fuel engine’’**, being submitted by **Mr. Jagteshwar singh,** Registration No. 801183009, in partial fulfillment of the requirements for the award of degree of Master of Engineering (Thermal engineering) at Thapar University (Deemed University), Patiala, is a bonafide work carried out by him under my supervision and guidance and no part of this thesis has been submitted to any other university or institute for the award of any degree.

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ABSTRACT

The current trend of energy consumption, in which fossil fuel is the main energy provider, has reached a level where other resources must be unearthed to ensure there is a constant supply for utilization. The rise in fuel prices recently has affected economic activity and only worsens the global energy scenario. Electricity generation is possible in new applications like biomass gasification. Among the all possible gasifiers, fluidized bed gasifiers are very appropriate in much respect. As major occupation of people in Punjab is agriculture. So a major source of biomass comes from this field. For this experiments are performed by taking three samples of biomass i.e cotton stalk, sugarcane bagasse and mustard stalk. It is performed for various openings of the gasifier valve at different loads; the loads are taken as 2 kW, 4 kW and 6 kW. The openings are three revolutions of gasifier valve, six revolutions and maximum possible revolutions. As predicted with the use of producer gas the consumption of diesel decreases considerably and subsequently the cost of operation also decreases. From the comparison of the three biomass samples it is clear that the cotton stalk stands out to be the better fuel option. With a wide range of applications the gasifier arrangement has a great potential to reduce the gap between energy requirement and supply of energy.

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CHAPTER 1

INTRODUCTION

The current trend of energy consumption, in which fossil fuel is the main energy provider, has reached a level where other resources must be unearthed to ensure there is a constant supply for the utilization. The amount of remaining reserves has led to the situation of finding a solution. Best example is the sudden increase of economic activity in India, which has raised the nation's energy consumption to a record high. Coal is an abundant source of energy but more efficient energy utilization methods and energy conservation programs should be considered to ensure sustainability. The recent rise in fuel prices has affected economic activity and only worsens the global energy scenario.

One such energy is biomass, which is available in abundance in World and India. Electricity generation is possible in new applications like biomass gasification. This technology is an efficient and environmental friendly method for heat and power production. Among the all possible gasifiers, fluidized bed gasifiers are very appropriate in much respect.

1.1.1 Definition of biomass

A non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms .This also includes products, by-products, residues and agricultural waste, forestry and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes.

As major occupation of people in Punjab is agriculture. So a major source of biomass comes from this field. A major part of biomass is ligno-cellulose. Ligno-cellulosic material is the nonstarch, fibrous part of plant materials. Ligno-cellulosic biomass is not a part of human food chain and therefore, its use for gasification does not threaten the world's food supply. A good example of ligno-cellulosic biomass is a woody plant, straw or cereal plants, husk, scrap, slash, etc. So let's classify common sources of biomass, its scenario and some of its important properties while using it for gasification.

1.1.2 Common sources of biomass

- Agricultural: food grains, bagasse (crushed sugarcane), corn stalks, straw, seed hulls, nutshells, and manure from cattle, poultry and hogs.
- Forest: trees, wood waste, wood or bark, saw dust, timber slash, and mill scrap.
- Municipal: refuse-derived fuel (RDF), food waste, waste paper and yard clippings.
- Energy: poplars, willows, switch grass, alfalfa, prairie bluestem, corn, and soybean, canola, and other plant oils.
- Biological: biological waste, aquatic species, animal waste.

1.1.3 Biomass scenario in Punjab

In the significant development, which could enable the Punjab Government to overcome the acute shortage of electricity, the Punjab Energy Development Agency (PEDA) has allocated six projects to the private companies to produce 66MW of power from biomass. Not only this, the PEDA has also decided to set up 10 projects on its own to produce 120 MW of electricity to enable PSPCL to overcome the shortage of power. For this PEDA has taken up its case with the World Bank demanding Rs.700 crores for funding the projects.

Table 1.1 Renewable energy comparisons in India and Punjab **[1].**

Energy Sources	Country Potential	State Potential	Power Generation	Exploited Potential
Biogas plants	12 Millions (nos)	424700 (nos)	164 MW	9.2 MW
Biomass	17000 MW	1000 MW	1000 MW	20.5 MW
Solar energy	$5x10^{15}$ kWh/yr	2228.5 kWh/yr		
Small hydro	10,000 MW	140 MW	140 MW	13.6 MW
Municipal solid waste	27.4 Million tonnes/yr	3.5 Million tonnes/yr.	100 MW	
Co-generation (sugar)	5000 MW	140 MW	140 MW	10 MW
Co-generation (other industry)	1000 MW	150 MW	150 MW	

Table 1.1 above shows the comparison between India and Punjab in terms of renewable energy sources and power generation. It also indicates the potential which is present in the country and in the state, also the exploited potential of different renewable energy resources.

1.1.4 Biomass Conversion

The bulky and inconvenient form of biomass is a major barrier from a rapid shift from fossil to biomass fuels. Unlike gas or liquids, biomass cannot be stored, or transported easily. This provides the major motivation for the conversion of solid biomass into liquid or gaseous fuel. Biomass can be converted into liquid fuels (ethanol, biodiesel, methanol, vegetable oil, etc), gaseous fuels (biogas (CH_4, CO_2), producer gas (CO, H_2, CH_4, CO_2, H_2), syngas (CO, H_2), substitute natural gas (CH_4) and solid fuels like (charcoal, torrefied biomass).

Biomass can be converted into liquid, gaseous and solid fuels through one of the two major routes:

- Biochemical route
    - Digestion (anaerobic/aerobic)
    - Fermentation
- Thermo chemical route
    - Pyrolysis
    - Gasification (using air, O_2, steam, CO_2 as a fluidizing medium)
    - Liquefication
    - Combustion

We all have some elementary knowledge of biochemical route like fermentation in the presence on enzymes and microorganisms which doesn’t require external heat source and takes place in the absence of oxygen. These processes are relatively very slower as compared to thermo chemical processes. Whereas thermo chemical processes is a new field. It requires some heat source in order to carry on the chemical reactions. Naturally it is relatively faster than biochemical process. To compare biochemical route and thermo chemical route we take an example of biomass conversion into ethanol.

Table 1.2 Comparison of biochemical and thermo chemical routes of biomass conversion into ethanol **Basu [2].**

	Biochemical **(Sugar Fermentation)**	**Thermo chemical**
Feedstock	Sugarcane, starch, corn	Cellulosic stock, wood, municipal solid waste
Reactor Type	Batch	Continuous
Reaction Type	2 Days	7 minutes
Water-Usage	3.5-170 liter / liter ethanol	<1 liter/liter ethanol
By-Product	Distiller's dried grain	Syngas/Electricity
Yield	450 liter/tonn	265-490 liter/tonn
Technology Maturity	>100 in U.S. Plant	Pilot Plant

So let's explain the thermochemical route (specially the gasification part) in some detail in the coming subheadings.

1.1.5 Thermo chemical conversion

In thermo chemical conversion, the entire biomass is converted into gases, which are then synthesized into desired chemicals or used directly. It has four broad pathways:

1) Combustion: - Combustion involves high-temperature conversion of biomass in excess air into carbon dioxide and steam. The burning of forest wood taught humans how to cook and how to be warm. Chemically, combustion is an exothermic reaction between oxygen and the hydrocarbon in biomass. Here, the biomass is converted into two major stable compounds: H_2O and CO_2.

2) Pyrolysis:-In contrast to combustion, pyrolysis takes place in total absence of oxygen, except in cases where partial combustion is allowed to provide the thermal energy needed for this process. It is a thermal decomposition of the biomass into gas, liquid, and solid. It has three variations:

- Torrefaction, or mild pyrolysis
- Slow pyrolysis
- Fast pyrolysis

3) Gasification: - Gasification converts biomass or organic materials to producer gas via partial oxidation. It occurs in three stages and begins with drying, where inherent moisture in the biomass is removed. It is then followed by pyrolysis where volatile gases are released. Then finally gasification process takes place, here partial oxidation of residues and volatiles occur. Gasification of biomass has three major motivations:

- To increase heating value of the fuel by rejecting non combustible components like nitrogen and water.
- To remove sulphur and nitrogen such that when burnt the gasified fuel does not release them into atmosphere.
- To reduce the carbon-to-hydrogen (C/H) mass ratio in the fuel. Higher the hydrogen content of the fuel, lower the vaporization temperature and higher the probability of the fuel being in gaseous state.

Four mediums air, steam, carbon dioxide, and a steam-oxygen mixture can be used for gasification; they may have different effects on tar formation and conversion. The ratio of fuel to medium is an important parameter that influences the product of gasification, including tar. This parameter is expressed differently for different mediums.

Table 1.3 Gasification medium and characteristics parameters **Basu [2].**

Medium	**Parameter**
Air	ER= ratio of air used to stoichiometric air
Steam	Steam-to-biomass (S/B) ratio
Carbon dioxide	CO_2-to-biomass ratio
Steam and oxygen	Gasifying ratio (GR) : (steam + O_2)-to-biomass ratio

4) Liquefaction: - Liquification of solid biomass into liquid fuel can be done by pyrolysis, gasification as well as through the hydrothermal process. In the latter process, biomass is get converted into an oily liquid by contacting the biomass with water at elevated temperatures (300–350 °C) with high (12–20 MPa) for a period of time.

1.1.6 Properties of biomass

The gasification of biomass depends on number of factors. Each type of gasifier will operate satisfactorily with respect to stability, gas quality, and efficiency and pressure losses only within certain ranges of the fuel properties. So let’s go through some of these properties:

1. **Ignition Temperature**: - Ignition temperature is an important property of any fuel because the combustion reaction of the fuel becomes self-sustaining only above it. In a typical gasifier, a certain amount of combustion is necessary to provide the energy required for drying and pyrolysis and finally for the endothermic gasification reaction.

The ignition temperature is generally lower for higher volatile matter content fuel. Because biomass particles have higher volatile matter content than coal, they have a significantly lower ignition temperature, **[2]**.

2. **Heating value**:- Higher heating value (HHV) is defined as the amount of heat released by the unit mass or volume of fuel (initially at 25°C) once it is combusted and the

products have returned to a temperature of 25°C. It includes the latent heat of vaporization of water. HHV can be measured in a bomb calorimeter.

Lower heating value (LLV) is defined as the temperature of the exhaust flue gas of a boiler is generally in the range 120 to 180 °C. The products of combustion are rarely cooled to the initial temperature of the fuel, which is generally below the condensation temperature of steam. So the water vapour in the flue gas does not condense, and therefore the latent heat vaporization of this component is not recovered. The effective heat available for use in the boiler is a lower amount, which is less than the chemical energy stored in the fuel.

3. **Moisture content**: - Moisture content is defined as:

$$M.C_{dry} = \frac{wet\ weight - dry\ weight}{dry\ weight} X100\ \%$$

Alternatively, the moisture content on the wet basis is defined as:

$$M.C_{wet} = \frac{wet\ weight - dry\ weight}{wet\ weight} X100\ \%$$

High moisture contents reduce the thermal efficiency since heat is used to drive off the water and consequently this energy is not available for the reduction reactions and for converting thermal energy into chemical bound energy in the gas. The high moisture content results in low gas heating values. Downdraught gasifiers need reasonably dry fuels (less than 25 percent moisture dry basis) **[2]**.

4. **Volatile matter content**: - The volatile matter of the fuel is the condensable and non condensable vapour released when the fuel is heated. Its amount depends on the rate of heating and the temperature to which it is heated. As a general rule if the fuel contains more than 10 percent volatile matter it should be used in downdraught gas producers.

5. **Ash content**: - Ashes can cause a variety of problems particularly in up or downdraught gasifiers. Clinker formation in the reactor, caused due to melting and agglomeration of ash, will greatly add to the amount of labour required to operate the gasifier. If no special measures are taken, slagging can also lead to excessive tar formation and complete blocking of the reactor. At worst there is a possibility of air-channelling which can lead to a risk of explosion, especially in the updraught gasifiers. Whether or not slagging occurs depends on the ash content of the fuel, melting characteristics of the ash, and temperature patterns in the gasifier. The local high temperatures in voids in fuel bed in the oxidation zone, caused by bridging in the bed, may cause slagging even using fuels with a high ash melting temperature. In general, no slagging is observed with fuels having the ash contents below 5-6 percent. Severe slagging can be expected for fuels having ash contents of the range of 12 percent and above. For fuels with ash contents between the range of 6 and 12 percent, the slagging behaviour depends on the ash melting temperature, which is influenced by the presence of trace elements giving rise to the formation of low melting point eutectic mixtures.

6. **Particle size and size distribution**: - Up and downdraught gasifiers are limited in the range of fuel size acceptable in the feed stock. Fine grained or fluffy feedstock can cause flow problems in bunker section of the gasifier as well as with an inadmissible pressure drop over the reduction zone and a high proportion of dust in the gas. Large pressure drops can cause reduction of the gas load of downdraught equipment, which results in low temperatures and tar production.

Excessively large sizes of particles or pieces give rise to reduce reactivity of fuel, which results in startup problems and poor gas quality, and transport problems through the equipment. Large range in size distribution of the feedstock will generally aggravate the above phenomena. Also, too large particle sizes can cause gas channeling problems, especially in up draught gasifiers.

Acceptable fuel sizes for gasification systems depend to a certain extent on the design of the units. In general, the wood gasifiers operate on wood blocks and wood chips ranging from 8 x 4 x 4 cm. to 1 x 0.5 x 0.5 cm. Charcoal gasifiers are generally fuelled by charcoal lumps ranging between 1 x 1 x 1 cm. and 3 x 3 x 3 cm. Fluidized bed gasifiers are normally able to handle the fuels with particle diameters varying between the range of 0.1 and 20 mm

1.1.7 Advantages of biomass

1. Highly abundant: - India produces about 320 million tonnes of agriculture residue every year. Fuel wood is another major source of biomass in India. The consumption of fuel wood in India is estimated to be about 227 million tonnes per year. About 40% of primary energy consumption is come from biomass and related fuel.

2. Cheap: - Compare to fossil fuels (LDO, FO, DIESEL), most biomass fuels are much cheaper. In India fire wood merely costs INR 1.5 ($.04) and agriculture residue is almost free. Thus using biomass as a fuel can lead to tremendous cost savings.

3. Renewable:- If plantation of species like prosopis, casurina, eucalyptus, or other energy trees is taken up, one hectare of land can generate up to 30 tonnes of wood on a sustainable basis (the trees are not to be cut down). The trimming can be used as a fuel).

4. Clean: - There is no sulphur in biomass. Thus the use of biomass as fuel generates only CO_2 and water vapour. No sulphur compounds that leads to acid rain are generated. The carbon cycle where in plants take CO_2 (released on burning of fuel) from the atmosphere and then convert it to the biomass and thus reducing the amount of CO_2 in the atmosphere and thus reducing the green house effect. Generation of fossil fuels take million of years. Thus whenever we burn any fossil fuels, we are adding more and more CO_2 to the atmosphere which is leading to global warming. On the other hand when we use any agro-waste, we typically use the waste generated in that season. During the next season when the new crop is grown, the CO_2 is again gets fixed to biomass.

5. Green: - A biomass becomes more of a commonly used fuel, simple supply and demand will leads to greening more and more areas and thus adding to the green cover of the planet.

1.1.8 Gasifiers and process of gasification

The process of gasification to produce the combustible from organic feeds was used in blast furnaces about over 180 years ago. The possibility of using this gas for the heating and power generation was soon realized and then emerged in Europe as producer gas systems, which used charcoal and peat as feed material. At turn of the century petroleum gained wider use as a fuel, during both world wars and especially World War II, shortage in the petroleum supplies led to widespread re-introduction of gasification. By the year 1945 the gas was being used to power trucks, buses and agricultural and industrial machines. It is also estimated that there were close to 9000,000 Vehicles running on producer gas all over the world. After World War II the lack of strategic impetus and the availability of cheap fossil fuels led to general decline in the producer gas industry. Whereas, Sweden continued to work on producer gas technology and the work was accelerated after 1956 Suez Canal crisis. A decision was made to include gasifiers in Swedish strategic emergency plans. Research for suitable designs of wood gasifiers, essentially for transport use, was carried out at the National Swedish Institute for Agricultural Machinery Testing. The contemporary interest in small scale gasifier R&D, for the most part dates from 1973 oil crisis. The U.S. research in this area is reviewed by Goss. The manufacturing also took off with increased interest shown in gasification technology. At the present there are about 64 gasification equipment manufacturers all over the world. A major breakthrough came in biomass gasification came from the Envirotherm atmospheric CFB (circulating fluidized bed) technology was originally developed by lurgi for alumina calcination and later, during the 1980s, it was adapted for the combustion of coal. Lurgi gasifiers use a moving bed design and operate below the ash melting point of the feed. The feed does not have to be finely milled; only crushed. In fact, one of the disadvantages of the Lurgi process is its inability to handle fine feed. The feed is fed into the top of the gasifier via lockhoppers. Oxygen is injected at the bottom of the gasifier and reacts with the feed which has been pre-heated by the hot syngas rising through the feed bed. Ash drops off the bottom of the bed and is depressurized via a lockhopper. The process was originally developed by Lurgi GmbH in the 1930s in Germany. A key disadvantage of the Lurgi process in IGCC applications is the production of hydrocarbon liquids in addition to syngas. BG Technologies USA, Inc., has licensed gasification technology from Ankur Scientific Energy Technologies Pvt, Ltd., of

India for the worldwide distribution. Ankur Scientific has over 400 installations worldwide using this technology for processing of the soy husks, cocunut shells, cotton stalks, rice hulls, maize cobs, wood chips, palm nut shells, and sawdust. The BG Technologies electric system consists of a biomass gasifier, gas cleaning unit and cooling unit, and a diesel generator set. The diesel generator is operated under dual fuel mode using diesel and producer gas from the gasifier which reduces diesel consumption by about 70%. The main objective of this system is to displace some of the fuel requirement for the diesel generator. As we all know that a gasifier is essentially a chemical reactor where various complex physical and chemical processes take place. Biomass gets dried, heated and pyrolysed, partially oxidized and reduced in this reactor as it flows through it. The gasification process follows the following sequence:

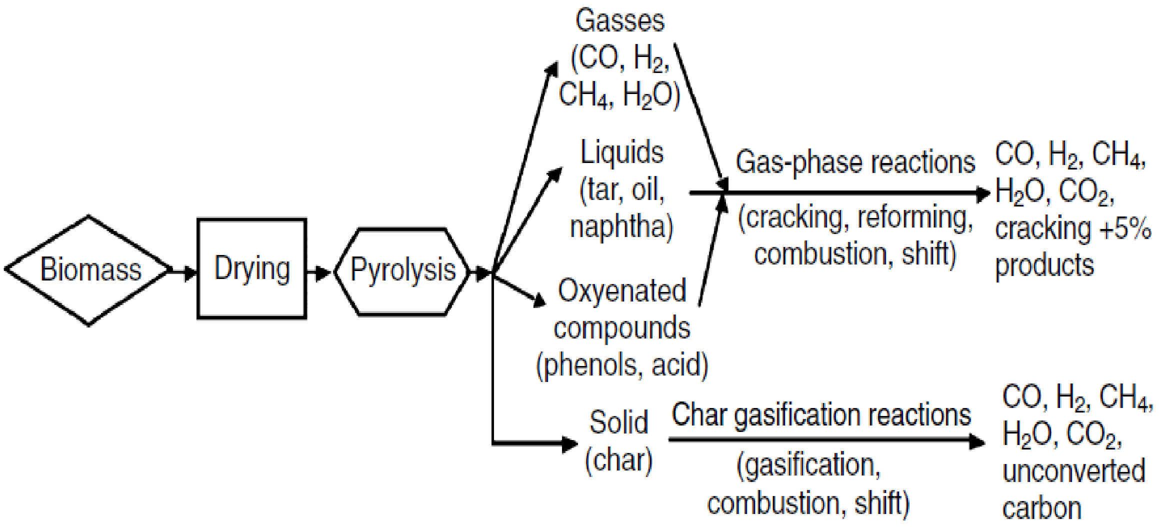

Fig.1.1 Potential paths of gasification.

In a typical process, biomass is first heated (dried) and then it undergoes thermal degradation or pyrolysis. The products of pyrolysis (i.e., gas, solid, and liquid) react among themselves as well as with the gasifying medium to form the final gasification product. In commercial gasifiers, the thermal energy necessary for the drying, pyrolysis, and endothermic reactions comes from a certain amount of exothermic combustion reactions allowed in the gasifier.

A variety of biomass gasifier types have been developed. They can be grouped into three major classifications: fixed-bed, fluidized-bed and entrained flow gasifier. Differentiation is based on the means of supporting the biomass in reactor vessel, direction of flow of both the biomass and oxidant, and way the heat is supplied to the reactor.

Table 1.4 Gasifier Classification **Ciferno et al. [3]**.

Gasifiers type	**Flow direction**		**Support**	**Heat source**
	Fuel	**Oxidant**		
Up-draft	Down	Up	Grate	Combustion of char
Down-draft	Down	Down	Grate	Partial combustion of volatiles
Bubbling fluidized bed	Up	Up	None	Partial combustion of volatiles and char
Circulating fluidized bed	Up	Up	None	Partial combustion of volatiles and char

1. <u>Fixed-bed gasifiers</u>:- Fixed beds are fed with biomass from the top of the reactor and form a bed, which gasifies as air moves through the bed . As the material releases volatile components, the char and ash exit through a grate at the bottom. Typical operating temperature range is 750°–900°C. The two main types of fixed-bed gasifiers are updraft and downdraft. Updraft gasifiers are also known as counterflow gasifiers. These are the oldest and simplest form of gasifiers. Biomass is introduced at the top of the reactor, and a grate at bottom of the reactor supports the reacting bed. Air or oxygen are introduced below the grate and diffuse up through the bed of biomass and char. Complete combustion of the char takes place at bottom of the bed, liberating carbon dioxide (CO_2) and water (H_2O). The hot gases (~1000^oC) pass through the bed above, where they are reduced to hydrogen (H_2) and carbon monoxide (CO) and cooled to 750^oC. Continuing up

the reactor, the reducing gases (H_2 and CO) pyrolyse the descending dry biomass and finally it dries the incoming wet biomass, which leaves reactor at a low temperature (~500^{o}C) **Ciferno et al. [3].** Fig1.2 shows the schematic diagram of updraft gasifiers.

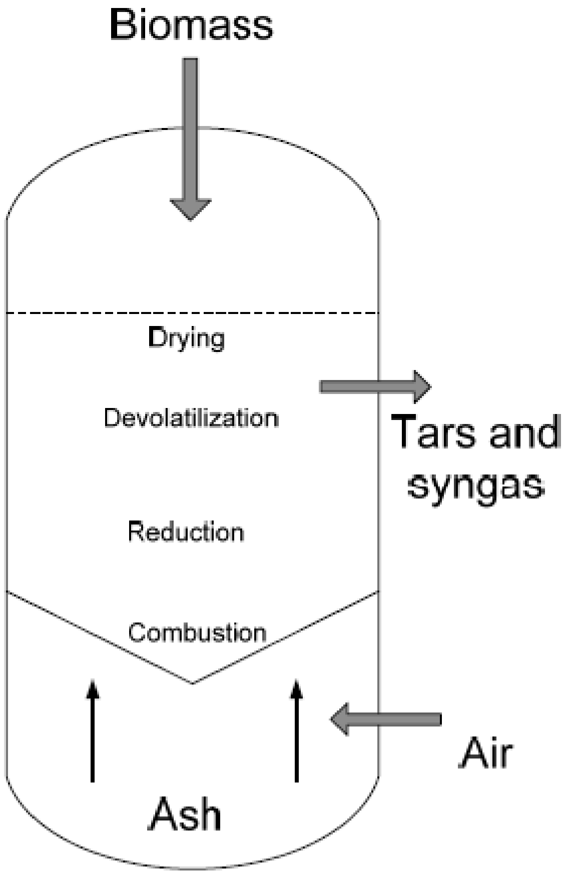

Fig1.2 Schematic diagram of fixed-bed updraft gasifier showing reaction zones **Swanson et al. [4].**

The major advantages of updraft gasification are:

- Simple, low cost process
- Capable of handling biomass with a high moisture and high inorganic content (e.g, Municipal solid waste)
- Proven technology

The major disadvantage of updraft gasification is:

- Syngas contains 10-20% tar by weight ratio, which requires extensive syngas cleanup before engine, turbine or synthesis applications

Downdraft is also known as cocurrent-flow gasifiers, the downdraft gasifier has the same mechanical configuration as the updraft gasifier except that the oxidant and product gases flow down the reactor, in same direction as the biomass. A major difference is that this process can combust up to 99.9% of the tars formed. Low moisture biomass (<20%) and air or oxygen are ignited in the reaction zone at the top of the reactor. The flame generates pyrolysis gas/vapor, which burns intensely leaving 5 to 15% char and hot combustion gas. These gases flow downward and react with char at the range between 800 to 1200^{o}C, generating more CO and H_2 while being cooled below 800^{o}C. Finally, unconverted char and ash pass through the bottom of the grate and are sent to disposal **Ciferno et al. [3].**

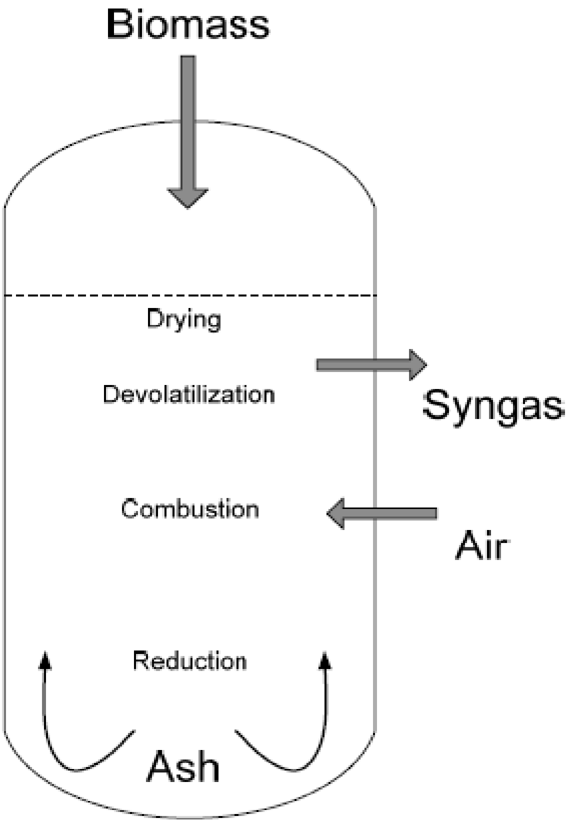

Fig. 1.3 Schematic diagram of fixed-bed downdraft gasifier showing reaction zones **Swanson et al. [4].**

The major advantages of downdraft gasification are:

- Up to 99.9% of tar formed is consumed, requiring minimum or no tar cleanup
- Minerals remain with the char/ash, which reduces the need for a cyclone
- Proven, simple and low cost process

The major disadvantages of downdraft gasification are:

- It requires feed drying to a low moisture content (<20%)
- Syngas exiting the reactor is at high temperature, which requires a secondary heat recovery system
- 4-7% of carbon remains unconverted

2. Fluidized bed gasifiers:- When the volumetric gas flow is increased through the grate, the fixed bed becomes a fluidized bed. Fluidized-bed gasifiers are so named because of the inert bed material that is fluidized by oxidizing gas creating turbulence through the bed material. Biomass enters just above the top of the bed and mixes with hot, inert material, creating very high heat and mass transfer. Operating temperature range is the same as for the fixed bed. Advantages of the fluidized bed include flexible feeds, uniform temperature distribution across the bed, and large volumetric flow capability. The main types of fluidized-bed gasifiers are circulating fluidized bed (CFB) and bubbling fluidized bed (BFB). A bubbling fluidized bed consists of fine, inert particles of sand or alumina, which have been selected for the size, density, and thermal characteristics. As the gas (oxygen, air or steam) is forced through the inert particles, a point is then reached when frictional force between the particles and the gas counterbalances the weight of the solids.

At this gas velocity (minimum fluidization), the bubbling and channeling of gas through the media occur, such that the particles remain in the reactor and appear to be in a "boiling state". The fluidized particles tend to break the biomass fed to the bed and ensure good heat transfer throughout the reactor **Ciferno et al. [3].** Fig 1.4 shows the schematic diagram of bubbling fluidizes bed.

The major advantages of bubbling fluidized-bed gasification are:

- Yields a uniform product gas
- It shows a nearly uniform temperature distribution throughout the reactor
- Able to accept a wide range of fuel particle sizes
- Provides high rate of heat transfer between fuel, gas and inert material
- High rate of conversion with low tar and unconverted carbon

The major disadvantages of bubbling fluidized-bed gasification are:

- Large size of bubble may result in gas bypass through the bed

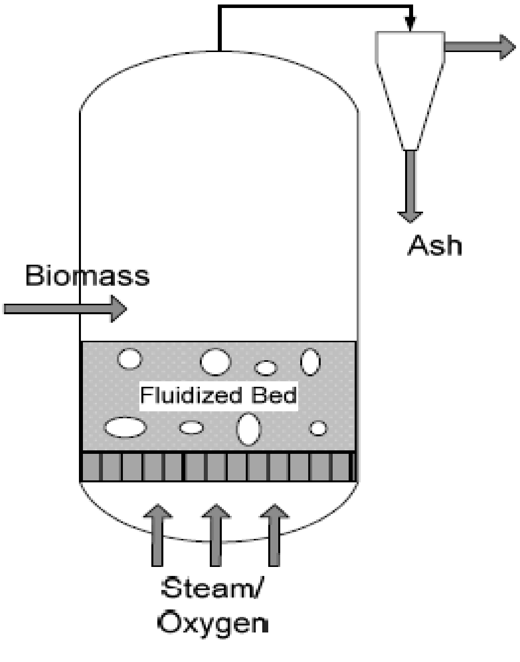

Fig 1.4 Schematic diagram of bubbling fluidized bed gasifier **Swanson et al. [4].**

Circulating fluidized bed gasifier operates at gas velocities higher than the minimum fluidization point, resulting in entrainment of the particles in gas stream. Entrained particles in the gas exit from the top of the reactor are separated in the cyclone and returned to the reactor **Ciferno et al. [3].** Fig 5 shows schematic diagram of circulating fluidized bed gasifier.

The major advantages of circulating fluidized-bed gasification are:

- Suitable for rapid reactions
- High heat transport rates are possible due to high heat capacity of bed material
- High conversion rates are possible with low tar and unconverted carbon

The major disadvantages of circulating fluidized-bed gasification are:

- Temperature gradients that occur in direction of solid flow
- Size of the fuel particles determine minimum transport velocity; high velocities

  can result in equipment erosion
- Heat exchange is less efficient than bubbling fluidized-bed

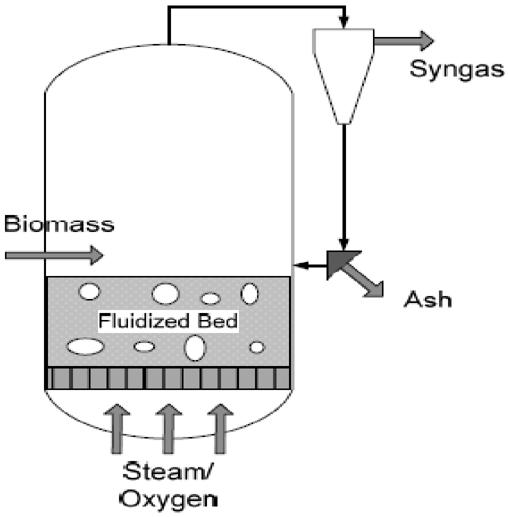

Fig 1.5 Schematic diagram of circulating fluidized bed gasifier **Swanson et al. [4].**

3. Entrained flow gasifier:- Another type of gasifier is the entrained-flow gasifiers. Normally operated at elevated pressures (up to 50 bar), it requires very fine fuel particles gasified at high temperatures to ensure complete gasification during the short residence times in the reactor. The energy research centre of the Netherlands has investigated this type of gasification and reported promise with biomass, as long as the biomass is pretreated to certain requirements. To keep the residence time at approximately the time for a particle to fall the length of the reaction zone, fuel particles smaller than 1 mm and high temperatures (1100°–1500°C) are necessary for successful operation. Entrained-flow gasification mixes the fuel with a steam/oxygen stream to form a turbulent flow within the gasifier. Ash-forming components melt in the gasifier and form a liquid slag on the inside wall of the gasifier, effectively protecting the wall itself. The liquid flows down and is collected at the bottom. To form the slag, limestone can be added as a fluxing material. For herbaceous biomass, such as switchgrass or corn stover, which is high in alkali content, there may be sufficient inherent fluxing material present. Advantages of entrained-flow gasification are that tar and methane content are negligible and high carbon conversion occurs due to more complete gasification of the char. Syngas cleanup is simplified because slag is removed at the bottom of the gasifier, negating the need for cyclones and tar removal. The disadvantages are that very high temperatures need to be maintained and the design and operation is more complex.

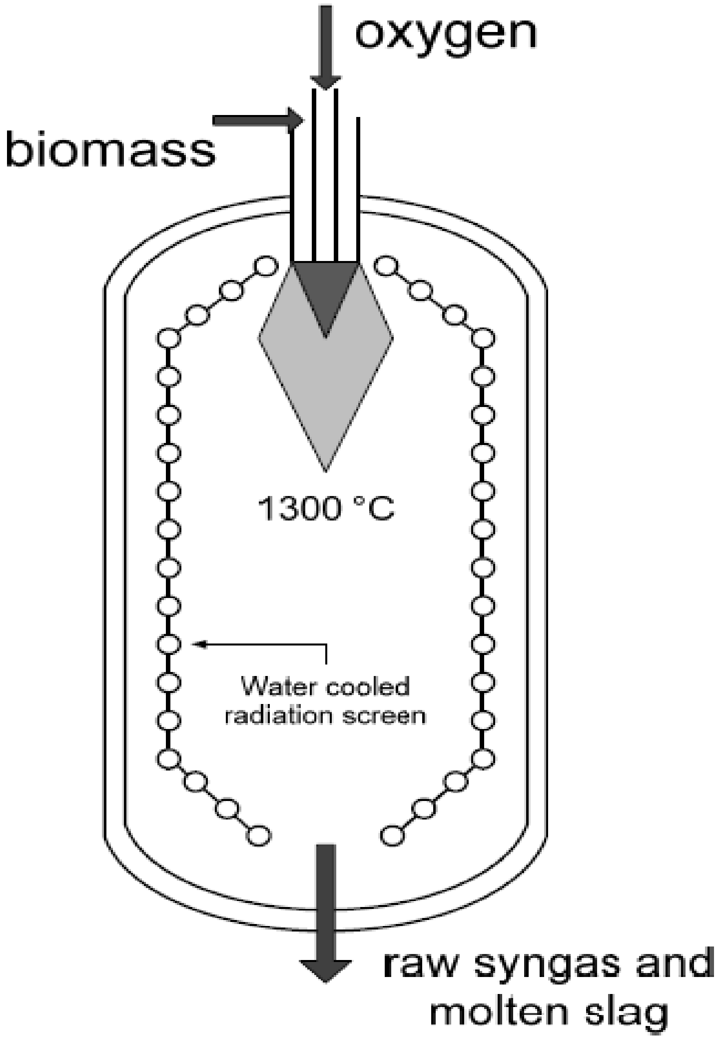

Fig 1.6 Schematic diagram of entrained flow gasifier **Swanson et al. [4]**

Recent trends of biomass gasification in india are:

- National biomass resource assignment program has been assigned the task of preparing a national resource atlas for the country
- Under the national biomass gasifier program in India, 1074 gasifier system aggregation of 34.36 MW been installed in different state

1.2 DUAL FUEL ENGINES:

Internal combustion engines operating on gaseous fuel have for long been known .Many large stationary engines use two fuels. Usually of these two fuels, one is gaseous and the other a liquid fuel. The two fuels can be taken as widely varying proportions to run an engine; such an engine is called a dual fuel engine. The first diesel engine patented by Dr. Diesel was essentially a dual fuel engine. The engine ran on gaseous fuel ignited by oil injection in the combustion chamber. It is only after the world war I attention was focused on the dual fuel engines due to shortage of liquid fuel and the realization that gaseous fuels are cheaper than liquid fuels. The development of very large tankers capable of transporting liquified gases economically has made natural gas available to most parts of the world at rates cheaper than the liquid fuels. The gaseous fuels require a high compression ratio to burn efficiently because they have high self ignition temperature. Natural gas is composed of mainly (about 95%) methane and other light paraffin that have self ignition temperature of about compared to $470^{o}C$ of octane. For this reason, mainly diesel engines have been used as dual fuel engines. Moreover, a diesel engine has an ability to run over a wide range of fuels ranging from light fuels like JP-4 and kerosene to heavier fuels and crude oils. Dual fuel operation combines in a simple manner the possibility of operating a diesel engine on liquid fuels such as diesel oil or gas oil and on gaseous fuels such as natural gas, sewage gas and coke oven gas etc. The engine can be switched from dual fuel to diesel operation almost instantaneously in case of emergency.

1.2.1 Working Principle: - The dual fuel engine works on diesel cycle. The gaseous fuel (primary fuel) is added to the air inducted by the engines or supplied by the supercharger at a pressure slightly above the atmospheric pressure. Mixture of air and gaseous fuel is compressed in the cylinder just like air in fuel normal diesel operation. Some point in the compression stroke, near top dead centre (TDC) a small charge of liquid fuel called pilot fuel (secondary fuel) is injected through a conventional diesel fuel system. This pilot fuel injection acts as a source of injection. The gas-air mixture in the vicinity of the injected spray ignites at number of places establishing a number of flame fronts. Thus combustion starts smoothly and rapidly.

In dual fuel engine the combustion starts in a fashion similar to the compression ignition engine but it propagates by flame fronts, in a manner similar to the spark ignition engines. The power output of the engine is normally controlled by changing the amount of primary gaseous fuel added to inlet manifold. The pilot oil quantity is usually kept constant for a given engine and is about 5 to 7 percent of the total heat of engine at full load. Dual fuel engine is capable of running on either gas or diesel oil or a combination of these two over a wide range of temperature ratios.

1.2.2 Combustion in Dual Fuel Engines:-The ignition of the gaseous fuel in a dual fuel engine is affected by introducing a small amount of fuel in the form of a spray near TDC. But it mainly depends on the amount of gaseous fuel supplied.

(a) Without gaseous fuel the pilot fuel burns like that in a diesel operation. It is not sufficient to maintain the speed of the engine at desired level. It requires about 15% of full load fuel to run the engine at no load while the pilot fuel is only about 5 to 7% of full load value. As the gaseous fuel is introduced the weak gas air mixture comes in contact with the injected spray of the pilot fuel. Only this part of the mixture which is within the combustion zone of sprays gets oxidised. The rest of gas remains unaffected and goes in exhaust. This results in a very low efficiency at part load operation of the engine.

(b) As the amount of the gaseous fuel is increased the gas-air mixture in the vicinity of the injected fuel spray also gets oxidised and starts burning at a number of places. Flame fronts start travelling from these ignition points and combustion takes place rapidly and almost completely. The combustion is then exactly similar to the combustion in spark ignition engine.

(c) Increased admission of the gaseous fuel results in very fast reaction rates. This is followed by ignition with very high rates of pressure rise and combustion becomes uncontrollable. This is the onset of knock. The high rates of pressure rise results in the combustion noise and a marked change in the shape of pressure crank angle diagram. The transition from normal to knocking condition is very sharp. A small increase in the gaseous fuel beyond a limit can result in very severe knocking which can damage the engine. The ignition quality and the amount of pilot fuel have little influence on the quality of the charge at knocking conditions as compared to the effect of primary gaseous fuel.

1.2.3 Weak and rich combustion limits:-With only pilot injection of fuel the rise in pressure after ignition is most noticeable. As the gaseous fuel is introduced this trend remains because at small quantities of pilot fuel the spray might be dispersed into the regions where the mixture strength is too low to auto ignite. As a little more gaseous fuel is introduced ignition takes place and is self sustaining to produce a noticeable change in the pressure of the combustion chamber .This condition of mixture is the weak combustion limit for the particular fuel. Similarly, when the mixture strength is increased very much, ignition delay also increases and there comes a limit at which again there is no rise in the combustion pressure. Under these conditions more heat is lost than released by the pre combustion reactions due to long delay periods. This limit is called rich combustion limit.

1.2.4 Factors affecting combustion in a dual fuel engine: A large number of factors affect the combustion in a dual fuel engine. Among them the important one's are:

(a) **<u>Pilot fuel quantity:-</u>** Ignition in dual fuel engine occurs in an envelope enclosing the pilot spray and then propagates to the rest of the charge. The pilot fuel undergoes pre combustion reactions and releases thermal energy which increases the temperature of the gaseous fuel and a flame front is developed. If the amount of pilot fuel is increased more energy will be available to the gaseous fuel and the combustion would be very rapid resulting in an increase in the maximum rate of pressure rise. Therefore a large quantity of pilot fuel will result in knocking because of very rapid rates of pressure rise.

(b) **<u>Injection timing:-</u>**Normal injection timing is within 20 to 16^{o} BDC. Advancing the injection timing results in higher maximum cylinder pressure and knocking occurs at a leaner mixture. Retarding the injection timing reduces the ignition delay but despite this reduced ignition delay the combustion starts only after TDC. This reduces the maximum rate of pressure rise and also the efficiency of the engine as part of the expansion stroke is lost without giving any useful power output. However the overall effect of the injection timing is not very high except that at a slightly retarded timing there is some improvement in the efficiency but the rate of pressure rise also increases making the engine more near to knocking condition.

(c) Effect of cetane number of pilot fuel :-With increase in the cetane number of pilot fuel the rate of pressure rise near the knock limit is slightly reduced. Thus a slight increase in the mixture strength is allowed near the knock limit. However, the power output is not improved. The use of low cetane number fuels results in poor performance of the engine and greatly affects the combustion. In general the ignition quality of the pilot fuel has little effect on the combustion in dual fuel engines as compared to the ignition quality of the primary fuel.

(d) Effect of type of gaseous fuels:-The knock limited output of the dual fuel engine is greatly dependent on the type of gaseous fuel used. As already stated the power output of a dual fuel engine varies logarithmically with the reciprocal of absolute inlet temperature of all hydrocarbon fuels but varies linearly with inlet temperature when hydrogen is the fuel. Methane which is a main constituent of natural gas does not undergo decomposition during the compressions in the engine and is more resistant to knock, pre ignition and backfiring from cylinder into gas/air inlet than other gases such as town gas etc. The main effect of the type of fuel is on the ignition and knocks limits. Due to wide variation in the composition of various types of gaseous fuels available all over the world it is not possible to give their effect on performance of dual fuel engine.

(e) Effect of throttling:-It is usual for conventional SI engine to resort to throttling for richer mixtures and improve the part load efficiency. However, when throttling is used on a dual fuel unit maximum cylinder pressure reduces greatly. This is because in a throttled dual fuel engine ignition occurs very late in the cycle because of ignition delay. Thus combustion occurs after TDC and a reduced maximum cylinder pressure is the result. The amount of throttling before the ignition failure limits are reached is very low. A diesel engine can run up to 50 percent throttling while decrease of 0.05bar in the inlet pressure might cause ignition failure due to increased ignition delay in a dual fuel engine.

(f) Effect of mixture strength:-The mixture strength is the charge of a dual fuel engine is strongly dependent on the amount of pilot fuel injected in the combustion chamber.

1.2.5 Main types of gaseous fuels:-Natural gas, sewage gas, LPG, town gas and hydrogen gas are the main gaseous fuels available in large quantities for utilization in a dual fuel engine. The gas must be clean, dry and must have a good part of its combustible constituents as methane for combustion in a dual fuel engine. For dual fuel operation the gas must have a minimum calorific value of about 4500 kcal/cm^3 and the light fuel oil must have a calorific value of at least 10,200 kcal/kg.

1.2.6 Supercharged dual fuel engines:-The admission of methane, the main constituent of natural gas, into the cylinder results in reduced overall average temperature at the end of compression because the specific heat ratio of methane is lower than the air. This temperature reduction is one of the most important factors which influences the whole of the combustion process and seriously limits the engine performance. It is seen that at 250 percent rich mixture the effective compression of the engine is only 9.3:1, rather than the geometric compression ratio of 14.2:1.The reduction in effective compression ratio seriously affects the combustion of the pilot fuel and limits the use of richer mixtures for producing more power. So in order to maintain regular ignition of the pilot fuel at richer mixtures the partial pressure of oxygen is increased by supercharging the engine. The amount of pilot fuel remains same as when naturally aspirated. The air is admitted at a higher pressure, usually with the help of a turbocharger. Almost all dual fuel supercharged engines use charge air coolers. The air is passed through the charge air coolers after leaving the turbocharger, thereby, increasing the weight of the air trapped in the cylinder for combustion purpose. This also reduces the possibility of knock because of high inlet temperature and allows richer mixtures to be used. Supercharged dual fuel engines are particularly sensitive to the excessive air temperature and usually the air temperature after the air cooler does not exceed 40^{o}C.The power output of a supercharged dual fuel engine reduces by about 6 percent for every 10^{o}C rise in the air intake temperature. Normally the use of supercharged engine is confined to natural gas and sewage gas. The lowest acceptable calorific value for dual fuel operation is about 4500kJ/m^3 and light oil with a calorific value of about 10,200kJ/kg. For town gas or gases from other centres the additional power output due to supercharging does not justify the extra cost needed. So these gases are uneconomical for use in supercharged dual fuel engines.

1.2.7 Knock control in dual fuel engines:-The engine output is limited by knock, thermal and mechanical loading. Of these knock is the most important. Knock in a dual fuel engine can be controlled by any of the following methods:

(a) Excess supply of air.

(b) Use of cold combustion air.

(c) Increased cooling of piston.

(d) Use of additives.

(e) Reducing the pressure of the gaseous.

All these methods tend to reduce the reaction rates and hence limit the maximum rate of pressure rise in the cylinder. Tetra methyl lead has been used to control knocking in the dual fuel engines. When a gaseous fuel contains a large proportion of gases liable to promote knocking it should be used on mixed-fuel principle.

1.2.8 Performance of dual fuel engines:-Dual fuel engines are capable of producing as much power when running with a gaseous fuel as primary fuel as when operating on liquid fuels only. Actually a dual fuel engine is slightly superior to the conventional diesel at full load. This is because of the fact that the gaseous fuel fills all parts of the combustion chamber and allows more air to be burned. However, the maximum output of the engine is about the same whether the engine is running on diesel or dual fuel. The efficiency of dual fuel engines at part loads is poor because of increased delay periods at low mixture strength. Efficiency can be increased by increasing the excess air or injecting more pilot fuel at part loads but still it will be less than for pure diesel operation at the same load. Typical dual fuel engine efficiency figures are 41 percent for diesel and 38.5 percent for dual fuel engines. The effective compression ratio of dual fuel engine is always less than that for diesel engine. Ignition pressure is higher on gas than those on diesel in spite of the fact that the compression ratios for operation of gas are low. Dual fuel pilot oil quantities remain constant throughout the load range and the actual amount is same for naturally aspirated and supercharged engines. Dual fuel engines can operate on a purely gaseous fuel or on a diesel fuel or on combination of the two. The engine can shift instantaneously from one type of fuel to other smoothly.

1.2.9 Advantages of dual fuel engines: - In addition to inherent advantage of using efficiently the cheap gas available from various sources the dual fuel engine has substantial advantage over a diesel engine which is as follows:

(a) The gas burns without leaving any residue and the exhaust is clean. It has a great importance in view of increasing emphasis on prevention of air pollution.

(b) The clean combustion results in reduced wear of the engine parts and reduced combustion of the lubricating oil. The lubricating oil changes periods are also increased as the maximum pressure in the cylinder are less than those for a diesel engine, thereby reducing the blow by past piston. This reduces the contamination of the lubricating oil.

(c) The utility of power plant is highly increased by its ability of instantaneous change over from gas to diesel and vice-versa. Continuity of service can be assured if due to some reason the gas supply breaks down

(d) Only a small amount of liquid fuel is needed to run the engine.

(e) Dual fuel engine is very suitable for total energy installation. For example, the exhaust heat of the engine can be used for digesting the sludge in a sewage disposal plant and the sewage gas produced can be used to run the engine itself.

(f) A typical use of the dual fuel engine has been to produce synthetic gas, which is a mixture of CO and H_2, by burning methane in it and also producing power at the same time.

(g) For LPG tankers, these engines are ideally suitable as they can utilize the gas which evaporates during transportation, by suitably arresting it.

CHAPTER 2

LITERATURE REVIEW

Fast depletion of fossil fuels and their detrimental effect on the environment is demanding an urgent need of alternative fuels for meeting sustainable energy demand with minimum environmental impact. A lot of research is being carried out throughout the world to evaluate the performance, combustion characteristics and exhaust emission of the existing engines using several alternative fuels such as hydrogen, compressed natural gas(CNG),alcohols(methanol and ethanol),liquefied petroleum gas(LPG), biogas, producer gas, syngas, sewage gas, biodiesels developed from vegetable oils and others. The three main concerns are contributions to global warming, air pollution and dependence on conventional fuels. Emissions from automobiles are currently a dominant source of air pollution representing 70% of carbon monoxide, 41% of oxides of nitrogen, 38% of hydrocarbon emissions globally. In addition 25% of the man-made CO_2 emissions globally add to the green house effect, which results in global warming. Several alternative fuels have been tried in order to reduce these emissions. Mixtures of H_2 and CO could serve as an alternative spark ignition (SI) fuel due to their high anti-knock behaviour. However addition of H_2 and CO tends to increase combustion temperatures and hence increases nitric oxide (NO) emissions under stoichiometric SI combustion.

According to **Boehman and corre [5],** the use of H_2 and CO mixtures is more appropriate in lean burn conditions where combustion temperatures are moderated by excess air like in a CI diesel engine. Also these mixtures could serve in dual fuel mode that operates under CI using a pilot injection of diesel fuel.

Again, in their published work, **Garnier et al [6]** have suggested the use of syngas in diesel engines with dual fuel mode for mechanical and electrical applications. They have defined dual fuel engine as an ideal multi fuel engine that operates effectively on a wide range of fuels including the flexibility of operating as a conventional diesel engine. During dual fuel operation a carburetted mixture of air and high octane index gaseous fuel is sucked and compressed like in a conventional diesel engine. The compressed mixture of air and fuel-gas does not auto ignite due to poor ignition quality of gaseous fuel. Hence, it is fired by a small liquid fuel injection known as pilot, which ignites spontaneously at the end of compression phase. The volumetric H_2/CO ratio of syngas fuels vary greatly depending on the source and the processing technique. The different compositions of H_2/CO ratios in syngas affect the efficiency, combustion and emissions of an IC engine when used in dual fuel mode.

Ahrenfeldt et al [7] have tested two different compositions H_2/CO producer gas as dual fuel in two different engines; SI engine and diesel converted SI engine. The compositions of dry and wet producer gas were 22% H_2 and 22.3% CO; and 23.7% H_2 and 15.75 CO respectively. For an IC engine, dry gas gave a slightly higher power output than wet gas. On the other hand, for a diesel converted SI engine, dry gas gave higher NOx and CO emissions than the wet gas.

Shudo et al. [8] have shown the influences of the volumetric composition CO/H_2 ratio from 1.0 to 0.6 of the waste-pyrolysis gases were analyzed in an SI engine. Minor influences of the CO/H_2 ratio on the maximum power output were observed. NOx emission tended to increase with the decrease in CO/H_2 ratio in the stoichiometric combustion. This was because of the faster combustion due to the increased H_2 fraction which increased maximum pressure and maximum temperature of in-cylinder gas. The higher adiabatic flame temperature of H_2 than that of CO might also be a reason for the larger NOx emission. But NOx emission in the lean combustion was very low. For all the tested fuels relatively high CO emissions were observed.

Tsolakis et al. [9] studied the effects of different H_2/CO ratios on a diesel engine combustion patterns, emissions and fuel consumption by introducing simulated reformed exhaust gas recirculation (REGR) into the engine suction. The combustion of REGR with maximum H_2 and minimum CO contents resulted in the highest reduction of NOx emissions. In all the examined cases, the use of REGR resulted in reduced NOx and smoke emissions. Improved fuel economy was achieved only at middle and at high load engine operation compared to the standard operation with diesel fuel only.

Similar types of test results were also observed by **Abu-Jrai et al. [10]** by varying H_2/CO ratios in the same engine.

According to the experiment carried out by **Bibhuti B Sahoo et al [11]**, to evaluate the performance of a base diesel engine using syngas under dual fuel mode without varying any of the existing engine design and operating parameters. In this study, the effects of simulated syngas with different compositions of H_2/CO ratios on the engine performance (brake thermal efficiency, diesel substitution, pressure-crank angle (P-θ) diagrams, maximum cylinder pressure, exhaust gas temperature) and emissions (CO, NOx, and HC) have been examined. The volumetric proportions of H_2 and CO in syngas considered for dual fuel study were 50:50, 75:25 and 100:0. The test results have been accessed from the operation of a four-stroke, constant speed, DI, diesel engine at varying engine loads of 20, 40, 60, 80 and 100%. In this way, the effects of syngas fuels produced from different source and processing technique conditions have been examined.

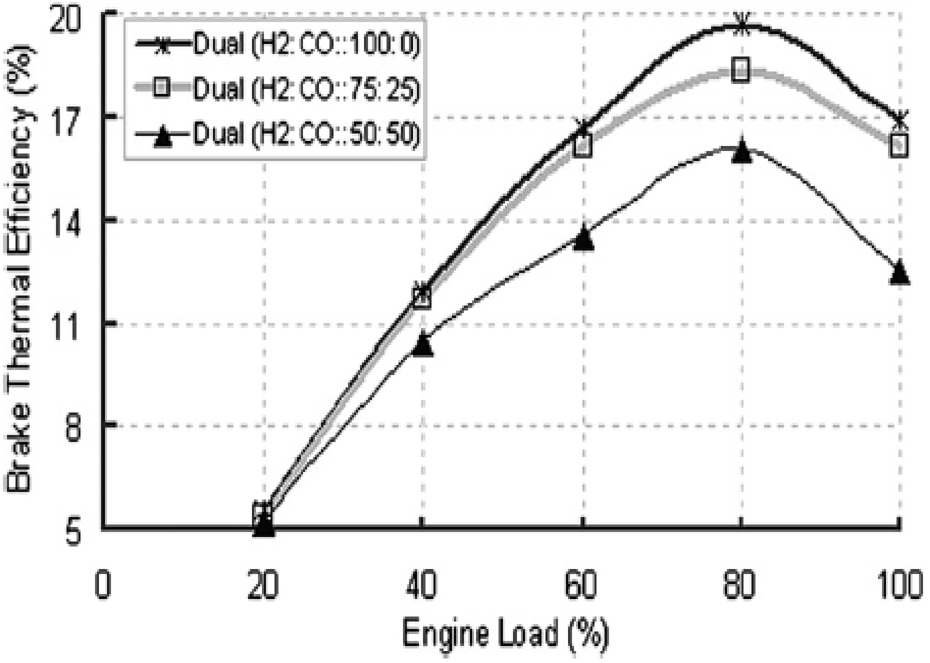

Fig. 2.1Variation of Brake thermal efficiency with engine load at various mixture values.

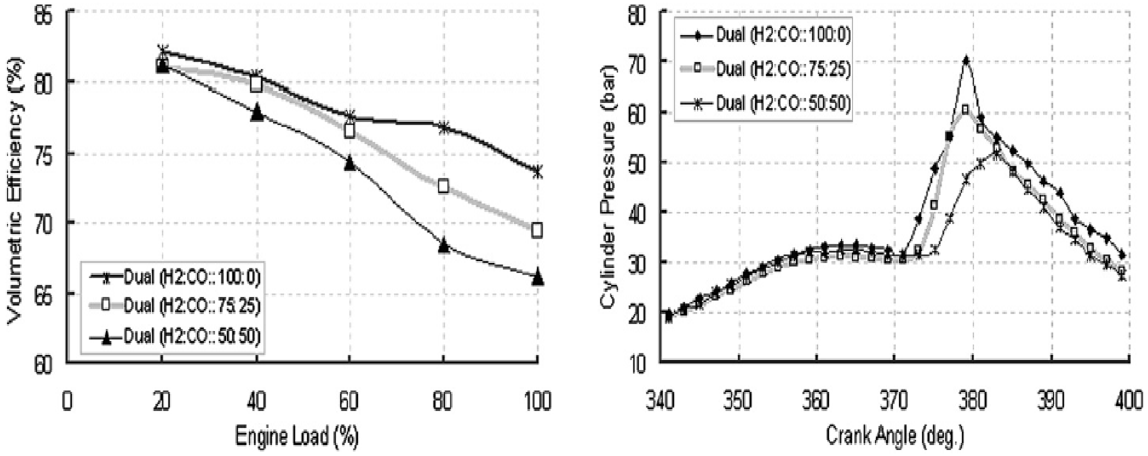

Fig.2.2 Effect of variation of engine load on volumetric efficiency and variation of cylinder pressure with crank angle.

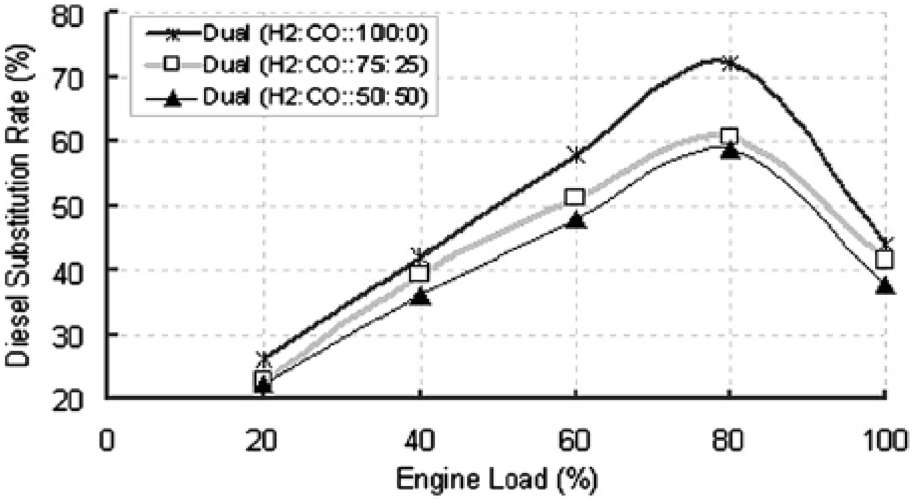

Fig. 2.3 Variation of diesel substitution with engine load

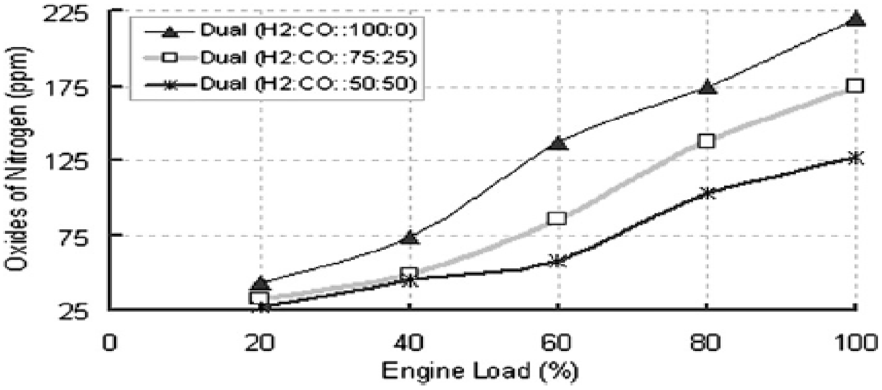

Fig.2.4 Amount of NO$_x$ with variation in engine load

In the past several decades a diesel engine has proved to be one of the most effective energy conversion systems. It is widely used as a power source for land vehicles, commercial marine vessels, and stationary power plants. But the exhaust of diesel engines is one of the major contributions to the air pollution problem, such as particulate matter, hydrocarbons, and nitrogen oxides emissions, and so on. Homogeneous charge compression ignition (HCCI) is an alternative operating mode for a diesel engine because it has the potential to reduce both particulate matter and nitrogen oxides emissions while maintaining high fuel efficiency.

According to **Machrafi et al. [12]** the emissions from an HCCI alternative combustion engine resulting from the auto-ignition of primary reference fuels. They showed that an increase in inlet temperature, the EGR temperature, equivalence ratio and the compression ratio produced a decrease of the emissions of CO and the hydrocarbons of up to 75%.

Komninos [13] investigated the importance of mass transfer on the formation of HCCI engine emissions using a multi-zone model. Furthermore, a comparison of the results was obtained from a modified HCCI multi-zone model to experimental measurements, at different loads and boost pressure conditions. His results indicated that the formation of HC and the CO emissions was located mainly at the crevice and the near the wall regions and was determined by the temperature field and mass transfer.

Hou et al. [14] modified a diesel engine for homogeneous charge compression ignition (HCCI) combustion with dimethyl ether. They showed that when combustion got into knock, in-cylinder pressure, temperature, and rate of heat release had a steep rise and a strong fluctuation; the rate of heat release peaks increased for both cool flame and hot flame, and heat release advanced, especially for hot flame.

Maurya and Agarwal [15] investigated the combustion and emission characteristics of a HCCI engine fueled with ethanol varying intake air temperature (120-150^{o} C) and at different air–fuel ratios. Their results indicated that the air–fuel ratio and intake air temperature significantly affected the maximum in-cylinder pressure and its position, thermal efficiency, maximum rate of pressure rise and the heat release rate. Moreover, for all stable operation points, NOx emissions were lower than 10 ppm, but HC and CO emissions were higher.

Kim et al. [16] therefore experimentally studied the combustion characteristics of partially premixed charge compression ignition engine; the experimental results were further compared with numerical results of thermodynamic analysis. They used gasoline and diesel fuels as the premixed fuel to investigate how premixed ratio influenced the combustion and emission characteristics in a diesel engine over various engine loads, speeds and intake temperatures. They found that the increase in premixed ratio of gasoline fuel generated the advance of ignition timing and the reduction of nitrogen oxides emission of the engine**.**

Ma et al. [17] conducted an experimental study of port injected n-heptane homogeneous charge compression ignition (HCCI) in combination with in-cylinder diesel fuel direct injection (DI) on a single- cylinder diesel engine. Their result displayed that NOx emissions decreased dramatically with partial premixing and it exhibited a descending trend as a function of premixed ratio when the premixed ratio was lower than 0.3, consequently it showed a great tendency to increase when the premixed ratio was higher.

Study of **Henham & Makkar [18]** shows that in dual-fuel compression ignition engine operation, biogas is also used mainly as a primary fuel with a ‘pilot’ amount of diesel fuel supplied from a normal diesel fuel injection system. The engine induces and compresses a mixture of gaseous fuel and intake air, which has been prepared in the external mixing device. The mixture does not auto ignite due to its high auto ignition temperature. It is ignited by energy from the combustion of the pilot diesel sprayed in. Normally, the diesel fuel needed for sufficient ignition contributes only to a small fraction of the engine power output.

Generally, biogas/ diesel dual-fuel engines performed well in short-term tests. Problems are anticipated after a long period of operation time. These problems may include corrosion of engine components due to acidic attack, carbon deposits on engine surfaces, inadequate engine lubrication, higher engine friction and excessive wear. Sulphur in biogas can be oxidised to form sulphur oxides in the engine cylinder. Sulphuric acid produced from a combination of sulphur trioxide and water vapour attacks engine parts, contributing to corrosion wear. Biogas, with a large proportion of methane, combusts at higher temperature than normal diesel fuel leading to higher in-cylinder temperatures. It may prevent effective formation of a lubricating oil film on the engine surfaces, resulting in metal-to-metal contact with subsequent damage.

Ghazi Karim [19] has underlined the importance of understanding combustion process in dual-fuel engines with regard to enhanced performance and reduced pollution. In his article, he has critically examined various gaseous fuels with regard to their availability, performance, cost aspects and environmental pollution.

Dong Jian et al. [20] have developed new type of dual-fuel supply system which could able to convert conventional diesel engines in to dual-fuel engines like LPG/Diesel engines and CNG/Diesel engines. These engines are capable of operating on the diesel baseline mode or dual-fuel mode depending upon the requirements. These diesel-LPG engines have been successfully applied to the diesel baseline buses of public transportation of Guangzhou city, one of the biggest cities of China.

Poonia et al. [21] have experimentally investigated the factors that affect performance of an LPG-Diesel dual-fuel engine. In this work, the effects of intake charge temperature, exhaust gas recirculation, pilot fuel quantity and throttling of the intake on the performance the LPG-Diesel dual-fuel engine have been studied. They have observed that under optimum operating conditions, the brake thermal efficiency of the engine on the dual-fuel mode has increased from 17.5% to 19.4% at 20% load and from 30.2% to 32% at 80% load. The emissions are also reduced significantly on the dual-fuel mode of operation.

Amarendar Rao et al [22] have performed experiments on a conventional diesel engine operating on dual-fuel mode using diesel and LPG. The experiments have been done at a constant speed of 1500 rpm and under varying load conditions; they have indicated that with the dual-fuel mode of operation, precious diesel could be conserved up to 80%. However, in their work, it could be done only up to 45% due to severe engine vibrations. The brake power of the engine was found to be about 15% more on the dual-fuel operation, while the brake specific fuel consumption was found to be about 30% lower than diesel fuel mode of operation. This could be due to better mixing of air and LPG and improved combustion efficiency.

Srinivasa Rao et al [23] have made experimental investigations on a single-cylinder water cooled compression ignition engine run on the dual-fuel mode with LPG as the main fuel and diesel as the pilot fuel. The engine was run under different operating conditions of load and speed. The optimum combination of fuels is evaluated at each of the conditions. The exhaust smoke level, exhaust gas temperature and other performance parameters were calculated and a cylinder pressure trace was obtained using a data acquisition system. The cylinder pressure so obtained was thermodynamically analyzed using a computer program and the heat release rate, cylinder gas temperature, equilibrium CO and NOx concentrations were calculated. In this work, LPG is being used for the partial replacement of diesel in the dual-fuel mode of operation. In this mode, LPG is used as the main fuel to generate the mechanical power and diesel is used as the pilot fuel to initiate the combustion process.

According to the **G.A Rao et al [24**], a 4-stroke, single-cylinder diesel engine has been considered for the purpose of experimentation. It is modified to run on the dual fuel mode. LPG carburettor is incorporated on the intake side of the engine. The fuel injection system is altered so that it injects only the pilot fuel. The engine is connected with a computer, to generate the data on-line and stored for the off-line analysis. Performance of the engine is evaluated at a constant speed of 1500 rpm under varying load conditions for different proportions of LPG energy. LPG energy substitution could be done up to 50% at lower loads and up to 20% at higher loads. The performance of engine is better on pure diesel up to engine loads of about 35%. At higher engine loads, the dual fuel mode is superior to the pure diesel mode of operation. It is true with regard to the emissions also. Smoke density is considerably reduced on dual-fuel operation, with that of pure diesel operation. At lower loads, to improve performance, engine could be operated on pure diesel operation. Subsequently for higher loads, the operation could be switched over to the dual fuel mode. Threshold load of transition from diesel fuel mode to the dual fuel mode is found to be about 35%. Dual fuel engines can be conveniently used in various applications, especially at higher loads.

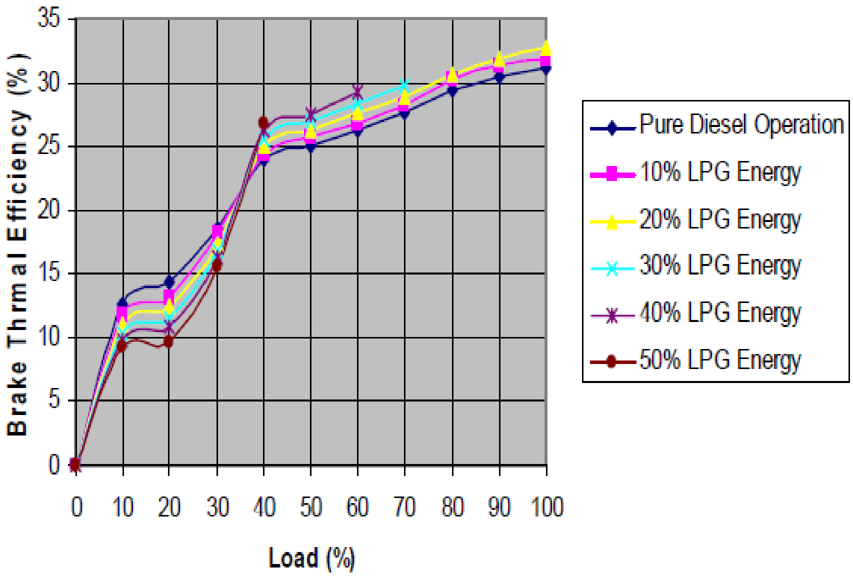

Fig. 2.5 Effect of load on break thermal efficiency

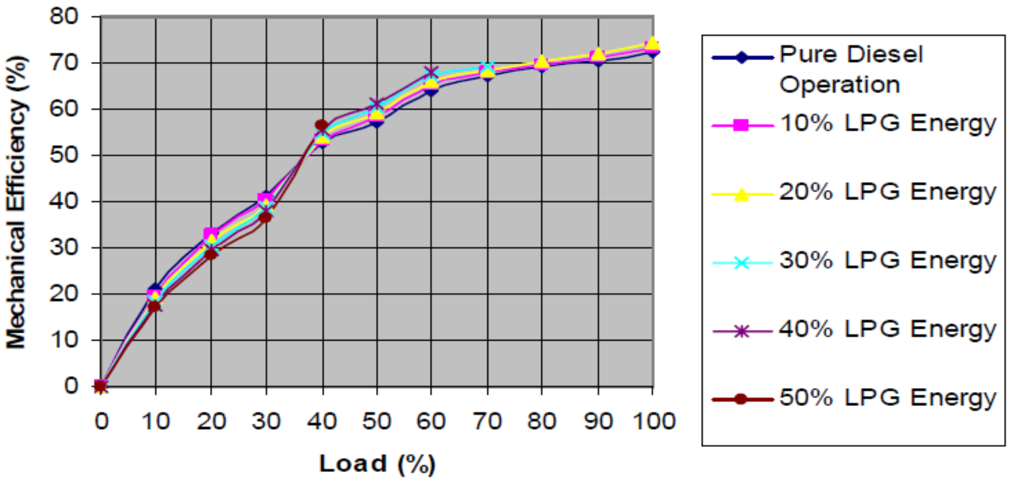

Fig.2.6 Effect of load on mechanical efficiency

N. Saravanan et al [25] had shown at full load the highest brake thermal efficiency was found to be 25.3% for hydrogen operation compared to diesel of 23.4%. The NOx emission was found to be high, 20.26 g/kWh at 75% load for hydrogen operation compared to diesel of 17.92 g/kWh. The literature shows that hydrogen diesel dual fuel technology is used widely and shows a significant improvement in performance and reduction in emissions. Hydrogen can be injected either by using mechanical or electronic injectors. Electronic injectors have a greater control over the injection timing and injection duration with quick response to operate under high speed conditions. In order to have a precise control of hydrogen flow and pre-ignition problems hydrogen injection into the intake manifold is preferred. The problems associated with inlet manifold injection, such as back fire and power daerating will not occur when using direct injection. The main problem associated with using hydrogen in engine is increase in NOx.

Gopal et al [26] investigated the performance in a conventional single cylinder four-stroke diesel engine with hydrogen as inducted fuel under wide range of the engine operation. The results showed that the thermal efficiency obtained were comparable with pure diesel operation and up to half the engine’s energy requirement could be derived from hydrogen. They pointed that the main problem area was the onset of knocking well before stoichiometric.

Mathur et al [27] found that hydrogen could be substituted for diesel oil up to 38% of full-load energy with no resulting loss in the efficiency and power output. However, hydrogen energy substitution of 85% was achieved with some penalty in engine performance. Furthermore, charge dilution by nitrogen and water achieved more than 90% hydrogen energy substitution. A significant efficiency advantage was found when using hydrogen as opposed to diesel fuel, with the hydrogen-fueled engine achieving a fuel efficiency of approximately 43% compared to 28% in the conventional, diesel-fueled mode. The reduction in nitrogen oxides emission formation of approximately 20% was further observed. In order to prevent knock, some diluents of nitrogen, helium or water were used. Nitrogen was the most effective to engine performance.

Aaron J Reiter et al [28] studied the combustion and emissions characteristics of a compression-ignition engine using a dual-fuel approach with ammonia and diesel fuel. Ammonia can be seen as a hydrogen carrier and used as a fuel, and its combustion do not produce carbon dioxide. In this study, ammonia vapour was introduced into the intake manifold and diesel fuel was injected into the cylinder to initiate combustion. The engine for testing was a four-cylinder, turbocharged diesel engine with modifications to the intake manifold for ammonia induction. An ammonia fuelling system was developed, and various mixtures of ammonia and diesel fuel were successfully tested. One scheme was to use different mixtures of ammonia and diesel fuel to achieve a constant engine power. Other was to use a small quantity of diesel fuel and vary the amount of ammonia to achieve variable engine power. With constant engine power operation, in order to achieve favourable fuel efficiency, preferred operation range was to use 40–60% energy provided by diesel fuel in conjunction with 60–40% energy supplied by ammonia. The exhaust carbon monoxide and hydrocarbon emissions using the dual-fuel approach were generally higher than those of using pure diesel fuel to achieve the same power output, while NO_x emissions varied with different fuelling combinations. NO_x emissions could be reduced if ammonia accounted for less than 40% of the total fuel energy due to the lower combustion temperature resulting in lower thermal NO_x. If ammonia is accounted for the majority of the fuel energy, NO_x emissions increased significantly due to fuel-bound nitrogen. On the other hand, soot emissions could be reduced significantly if a significant amount of ammonia was used due to the lack of carbon present in the combination of fuels. Inspite of the overall high ammonia conversion efficiency (nearly 100%), exhaust ammonia emissions ranged from 1000 to 3000 ppm and further after-treatment will be required due to health concerns. Whereas, the variable engine power operation resulted in relatively poor fuel efficiency and high exhaust ammonia emissions due to the lack of diesel energy to initiate effective combustion of the lean ammonia- air mixture. The in-cylinder pressure history was analyzed, results indicated that ignition delay increased with increasing amounts of ammonia due to its high resistance to auto ignition. The peak cylinder pressure also decreased because of the lower combustion temperature of ammonia. It is also recommended that further combustion optimization using direct ammonia/diesel injection strategies be performed to increase the combustion efficiency and reduce exhaust ammonia emissions.

The **heating value** (or energy value or calorific value) of a substance, usually a fuel or food (see food energy), is the amount of heat released during the combustion of a specified amount of it. Energy value is a characteristic for each substance. It is measured in the units of energy per unit of the substance, as mass, such as: kJ/kg, kJ/mol, kcal/kg, Btu/lb. Heating value is commonly determined by use of a bomb calorimeter. Heat of combustion for fuels is expressed as the HHV, LHV, or GHV.

The quantity known **as higher heating value** (HHV) (or gross energy or upper heating value or gross calorific value (GCV) or higher calorific value (HCV)) is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapour produced. Such measurements often use a standard temperature of 25°C. This is the same as the thermodynamic heat of combustion since the enthalpy change for the reaction assumes a common temperature of the compounds before and after combustion, in which the water produced by combustion is liquid. The higher heating value also takes into account the latent heat of vaporization of water in the combustion products, and is useful in calculating heating values for fuels where condensation of the reaction products is practical (e.g., in a gas-fired boiler used for space heat). In other words, HHV assumes the entire water component is in liquid state at the end of combustion (in product of combustion) and that heat above 150°C can be put to use. The quantity known as **lower heating value** (LHV) (net calorific value (NCV) or lower calorific value (LCV)) is determined by subtracting the heat of vaporization of the water vapour from the higher heating value. It treats any H_2O formed as a vapour. The energy required to vaporize the water therefore is not realized as heat.

Whereas LHV calculations assume that the water component of a combustion process is in vapour state at the end of combustion, as opposed to the higher heating value (HHV) (a.k.a. gross calorific value or gross CV) which assumes that all of the water in a combustion process is in a liquid state after a combustion process. The LHV assumes that the latent heat of vaporization of water in the fuel and the reaction products is not recovered. It is also useful in comparing fuels where condensation of the combustion products is impractical, or heat at a temperature below 150°C cannot be put to use. The most common methods currently being practiced to evaluate the heating of biomass are by using the equation derived by Dulong or by using the bomb calorimeter.

Changdong Sheng et al [29] had shown that the heating value is one of the most important properties of biomass fuels for design calculations or numerical simulations of thermal conversion systems for biomass. There are a number of formulas proposed in the literature to estimate the higher heating value (HHV) of biomass fuels from the basic analysis data, i.e. proximate, ultimate and chemical analysis composition. In this paper, these correlations were evaluated statistically based on a larger database of biomass samples collected from the open literature. It was found that the correlations based on ultimate analysis are the most accurate. It is found that the correlations based on the proximate data have low accuracy because the proximate analysis provides only an empirical composition of the biomass. Whereas the correlations based on the bio-chemical composition are not reliable because of the variation of the components properties.

Generally, the heating value of a fuel may be reported on two bases, the higher heating value and the lower heating value or net calorific value. The higher heating value (HHV) refers to the heat released from the fuel combustion with the original and generated water in a condensed state, while the lower heating value (LHV) is based on gaseous water as the product. The heating value of a biomass fuel can be determined experimentally by employing an adiabatic bomb calorimeter; it measures the enthalpy change between reactants and products. But, the measurement is a complicated and time-consuming process that requires the set-up, measurement and calculation procedures. In contrast, the conventional analysis, i.e. proximate and ultimate analyses, is a basic fuel characterization and can be carried out more easily, quickly, and cheaply by using common or modern laboratory equipments. Therefore, many attempts have been made to estimate the HHV based on correlating the heating value of biomass with the data of proximate analysis and ultimate analysis. So many correlations are available in the literature and each was reported with a high accuracy applied to the investigator's own database. An extrapolation to various biomass species, however, leads to considerable differences between the calculated results of the correlations. As a result, it would be very confusing for engineers to make their own selection. To achieve a higher accuracy, new correlations were proposed to estimate the HHV from the proximate and ultimate analyses based on the current database.

This new correlation between the HHV and dry ash content of biomass (in weight percent, wt %) (i.e. HHV (MJ/kg) = 19.914–0.2324 Ash) could be conveniently used to estimate the HHV from proximate analysis. This new formula, based on the composition of main elements (in wt %) C, H, and O (i.e. HHV (MJ/kg) = -1.3675 + 0.3137C + 0.7009H + 0.0318O), is the most accurate one, with more than 90% predictions in the range of ±5% error. Proximate analysis presents the weight percent of the moisture, volatile matter (VM), fixed carbon (FC), and the ash in the biomass material. It is the easiest and the most widely used method to characterize a biomass fuel. Therefore, correlating the heating value with the proximate analysis data is always attractive to fuel researchers and engineers.

CHAPTER 3

FUEL ANALYSIS

Fuel samples of biomass (mustard stalk, sugarcane bagasse and cotton stalk) were collected from Gujjarwal village in Ludhiana district, Punjab were subjected to proximate analysis in the laboratory.

3.1 Proximate Analysis of Fuel

The determination, by prescribed methods, moisture, volatile matter, fixed carbon and ash. It does not include determinations other than those named.

3.1.1 Determination of Moisture

The moisture can be defined as the difference in weight of sample when the same is heated at 110 °C for one hour under specified conditions.

3.1.1.1 Apparatus Required

1. Air Oven

Ventilated drying oven in which constant and uniform temperature of 110°C can be maintained.

2. Silica Crucible

One silica crucible is required.

3. Weighing Machine

It is required for weighing sample.

3.1.1.2 Procedure

Silica crucible was taken, cleaned and dried in an oven at 110°C for one hour. It was then cooled for 15 minutes and then weighed accurately. Then approximately one gram of sample was weighed and put into the silica crucible. After that, crucible was kept in an air-dried oven, which was maintained at 110°C for one hour. Then after one hour crucible was removed from the oven, cooled in a desicator and then weighed.

3.1.1.3 Calculations

Weight of dried and empty crucible with lid = x gm

Weight of sample and crucible = y gm

Weight of sample and crucible after heating = z gm

Therefore, weight of sample after heating = (y-x) gm.

Moisture = (y-z) gm.

Percentage of Moisture = {(y-z)/(y-x)}×100

3.1.2 Determination of Volatile Matter

Volatile matter can be defined as the loss of weight of sample when the same is heated under specified conditions in the absence of air at 900◦C for 9 minutes.

3.1.2.1 Apparatus Required

1. **Muffle Furnace**

Muffle furnace capable of giving uniform temperature of 900°C with the necessary thermocouples and pyrometers.

2. **Silica Crucible**

A translucent silica crucible with lid having external diameter of 25 mm should be used. The total height of the crucible should not exceed 38 mm and internal diameter should not be less than 22 mm.

3.1.2.2 Procedure

For the determination of volatile matter, a crucible with the lid was taken and then weighed. Now one gram of sample was weighed accurately into the crucible and spread evenly in the crucible by gentle tapping the crucible with the lid was transferred in the furnace at 900°C for nine minutes.

Then after nine minutes, the crucible was removed from furnace and placed on a cooled iron plate to ensure rapid cooling. Then the crucible was placed in a desicator for 15 minutes for further cooling and then weighed accurately.

3.1.2.3 Calculations

Weight of dried and empty crucible with lid = x gm

Weight of sample and crucible = y gm

Weight of sample and crucible after heating = z gm

Therefore, weight of sample after heating = (y-x) gm.

Loss of weight = (y-z) gm.

Percentage of Volatile Matter = $\{(y-z)/(y-x)\}\times 100$

3.1.3 Determination of Ash

Ash can be defined as the weight of residue left when a known weight of sample is burned at 800°C for one hour under specified conditions.

3.1.3.1 Apparatus Required

1. Muffle Furnace

Muffle furnace is capable of giving uniform temperature of 900°C with the necessary thermocouples and pyrometers.

2. Silica Crucible

A translucent silica crucible with lid having external diameter of 25 mm should be used. The total height of the crucible should not exceed 38 mm and internal diameter should not be less than 22 mm.

3.1.3.2 Procedure

For the determination of ash silica dish was taken, and heated at 800◦C for one hour. Then the dish was cooled for 20 minutes and then weight of empty dish was taken. One gram of sample was weighed in a balance and the sample was spread evenly in the crucible. Then silica dish containing sample as placed in the furnace at 450◦C for half an hour. Then temperature of the furnace was raised to 800◦C. The dish was kept at this temperature for another one hour. Then the dish was taken out, cooled and weighed accurately.

3.1.3.3 Calculations

Weight of dried and empty crucible with lid = x gm

Weight of sample and crucible = y gm

Weight of sample and crucible after heating = z gm

Therefore, weight of sample after heating = (y-x) gm.

Weight of Ash = (z-x) gm.

Percentage of Ash = $\{(z-x)/(y-x)\}\times 100$

Proximate analysis:

Table 3.1

S no.	**Type**	**Moisture (%)**	**VM (%)**	**Ash (%)**	**FC (%){100-(MC+VM+ASH)}**
1.	Mustard stalk	12.8	73.2	3.6	10.4
2.	Sugarcane bagasse	6.8	77.2	4.2	11.8
3.	Cotton stalk	9.9	72.1	5.16	12.84

3.2 Ultimate analysis: The procedure for determining the primary elements in a substance i.e carbon, hydrogen, oxygen, sulphur, nitrogen. The test for determining these elements were performed at CIL laboratory in Punjab University, Chandigarh. The values are shown as they were recorded without any modifications. The values of these elements are important to find out the heating values. These values are also important to find out the percentage of sulphur in the fuel.

Ultimate analysis:

Table 3.2.

Sample Name	Nitrogen%	Carbon%	Hydrogen%	Sulphur%
Mustard Stalk	0.6703092456	46.44974136	5.371822834	0
Cotton Stalk	1.196280003	46.72819519	5.133020401	0
Sugarcane bagasse	0.8670623302	43.06036758	5.09984684	0

CHAPTER 4

METHODOLOGY

4.1 Technical specifications:

Table 4.1

Model	AG-5
Gasifier type	Downdraft
Rated gas flow	15 Nm^3/hr
Gasification temperature	1050-1100^oC
Average gas calorific value	1000 $kcal/Nm^3$
Ash storage and removal	Storage below grate in reactor and manual removal in batch mode.
Start up	Through engine suction/blower.
Fuel type and size	Wood/Woody waste with max. dimension not exceeding 30 mm.
Biomass charging	Batch made, by topping up once every 4 hrs.
Permissible moisture content in the biomass	5-20 %
Rated hourly consumption	10-12 kg
Typical conservation efficiency	Over 75%
Typical gases in producer gas	CO, CH_4, H_2, N_2, NO_2
Average diesel replacement	65-70%

4.2 SYSTEM DESCRIPTION

4.2.1 General: - The biomass is fed through the feed door and stored in the hopper. Limited and controlled amount of air for partial combustion enters through two air Nozzles. The throat (or the hearth) ensures relatively clean and good quality gas production. The grate holds charcoal for reduction of partial combustion products while allowing the ash to drop off in the ash collection cone. The gas outlet is connected with the engine via Venturi scrubber, separator box cum fine filter and check filter with an air control valve to facilitate running of the engine in Dual- fuel mode.

Operating procedure: - Whenever it is required to be re-commissioned under maintenance schedule or otherwise, the procedure described must be followed.

- De-couple hopper and reactor.

- Fill good quality charcoal pieces above the grate up to the height marked by an arrow on the reactor inner wall and level it properly.

- Place the hopper carefully without damaging the seal rope on the reactor flange. After the hopper is properly located, tighten all flange bolts uniformly.

- Fill dry and prepared biomass in to the hopper on the top of this charcoal layer up to the top of the hopper such that the feed door can be conveniently closed.

- Lock the feed door and ensure locking of the ash discharge door of reactor as well fine filter and check filter doors.

- This must be strictly checked as even a minor leakage of air could lead to serious problems.

Fig.4.1 Grate with ash removing mechanism and de-coupled hopper with nozzles.

Fig. 4.2 Reactor filled with charcoal and gas cleaning filters and hopper reactor system coupled.

4.2.2 Start up procedure: -

- Every time before starting the gasifier, open ash discharge door of the reactor and yank the lever of ash control mechanism a few times to clean the charcoal bed. Then, close the ash discharge door.

- Push the ash control mechanism lever all the way towards the gasifier and let it stay in this upright position.

- Top up the gasifier hopper with biomass if its level is lower and lock the feed door.

- Shuffle and level the filter media check its level in the separator box cum fine filter and make it up as needed.

- Open the air control valve fully. Ensure that the engine governor controlling knob is in normal position.

- In normal, 100% diesel mode, the knob is far out for regular diesel injection. In dual fuel mode, the knob needs to be moved in to reduce diesel injection quantity.
- Start the engine.

- Measure diesel consumption per minute using burette.

- Start the pump.

- Remove the air nozzle plugs from both the air nozzles.

- Ignite the gasifier by holding lighted torch at both the air nozzles, one after the other, so the flame is sucked into the nozzles. After about a couple of minutes, remove the torch and observe the nozzle through the sight screen to check if there are glowing charcoal pieces inside or else repeat the procedure. This operation may take 2 to 4 minutes.

- Start closing the air control valve gradually to feed gas into the engine. Also slowly close the engine governor control knob to dual fuel position. Check diesel consumption using the burette. This is likely to require closing of the air control valve by 7 to 8 turns.
- The system is now ready for regular operation.

4.2.3 Shut down sequence

- Open the air control valve.
- Bring the engine governor control knob to its normal position.
- Plug both the air nozzles tightly.
- Stop the pump.
- Allow the engine to run on 100% diesel for a couple of minutes.
- Stop the engine.

4.2.4 Operating instructions: - Ensure that the drain hose of the separator box cum fine filter always remain sealed under the level of drain tub. This also confirms that sufficient quantity of water is being fed to the venture scrubber. The rate of flow of water coming through the drain must be maintained at a uniform rate.

4.2.5 Precautions: -

- Never close the air control valve beyond 7 to 8 turns.
- Clean the ash from the reactor during each shutdown.
- Strictly maintain the moisture content and size of the biomass samples.
- No parts of the gasifier and downstream sub systems other than the feed door are to be opened while the gasifier is in operation. Open them only when the gasifier is not in operation and cooled down.
- Care should be taken so that the foreign matter e.g stones, nails, sand etc. are not poured into the hopper along with the prepared biomass.

Fig.4.3 Flame appearing through the nozzle and gas cleaning by water.

4.2.6 Maintenance and Problems

4.2.6.1 Maintenance schedule

Table 4.2

Daily	Weekly	Every 300hrs
Check level of biomass in the hopper	Check hopper feed door rubber sealing cord and replace if required	Check charcoal bed for ash clinker up to arrow mark on reactor inner wall
Check tightening of hopper reactor main flange bolts	Check air nozzle plug	Check hopper reactor main flange sealing rope and replace if required
Check tightening of the ash control mechanism	Open drain plug at the bottom of filter and remove condensed moisture if any	Clean air inlet manifold of engine
Check diesel level in the tank of engine	Check gland sealing rope of ash control mechanism	Check entire gas pipeline for choking and clean if required
Check lube oil level in the engine	-	-

4.2.6.2 Filter media and check filter replacement

- Filter media replacement in separator box cum fine filter:

  Unlock door of separator box cum fine filter and open the flange of discharge port provided on the front side. Push the media out of discharge port by hand. Pour filter media through door and make approximately 100 mm thick layer of fresh media of perforated sheet. Close flange door.

- Filter bag replacement in check filter:

Unlock cover of check filter. As it is lifted out of its bottom casing, filter bag fixed with it by a rubber band can be seen. Remove the rubber band and pull out the bag by holding it at the bottom. Insert the cage with cover into a new/washed dry filter bag and secure it on top of cage by rubber band. The cover with the replaced bag can now be put back into casing. Tighten the bolts of the cover. Some quantity of filter media is likely to be carried over to the check filter over the time. When check filter is opened for change of filter bag or otherwise media should be returned either to the fine filter or storage of media.

4.2.7 Problems in development of gasifier: Some the major problems, technical and commercial are as follows:

(1) Fuel supply and cost: -The fuel requirement for gasifiers vary from 1.0-1.3 kg/kW depending upon the feed properties like moisture content, calorific value, ash content etc. and the conversion efficiencies of the system. Accordingly, a 100 kW and 300 kW systems can annually require approximately 850 MT and 2550 MT of feed respectively. Normally such quantities, especially 1000 MT and above are not easily available at a particular location from a single source except in case of large agricultural or forestry processing center. In view of this, the large systems need to be designed to have flexibility in terms of feed materials. The biomass materials, especially agricultural residues are not available throughout the year and hence, need to be transported and stored for continuous availability. In practice, this can cause problems due to high cost of transportation, and inventory costs ensure continuous and ready availability of biomass feed materials. The cost of fuel supply is also important; biomass resources may become costlier in future.

(2) Capital costs and economics: -Depending on the cost of present source of energy supply, various alternatives can become economically favorable or unfavorable. Besides this, the economics of other competing technologies also needs to be considered before an appropriate decision can be taken in favour of gasification.

(3) Technology development: -Following areas needs further technical development in gasifiers:

- Bridging and jamming associated with handling of feed and / or ash either inside or outside gasifiers.
- Lack of proven gas clean up systems which results in tar build up on the valves and fast wearing of engine cylinder and pistons. This in turn results in frequent overhaul of the system.
- Lack of data to carry out proper modifications in air-fuel mixing systems as well as the engines.

(4) Safety: - Producer gas is a low heating value gas, which is poisonous and explosive. Hence, proper carbon monoxide metering arrangements as well as safety devices needs to be provided with the systems, especially when gasifiers are installed in buildings.

(5) Market barriers: -The known technologies and conventional fuels can pose problems for gasifier marketing. The potential user recognizes the risk in new technology that has been fully demonstrated to be significantly less expensive or more reliable. Hence the gasification system suppliers must convince the potential users that the cost is worthy and there is no risk of operating a new technology.

(6) Gas reservoir: - There is no gas reservoir to store and control the gas when gasifier is running in a single mode (diesel) mode. Also in a dual mode, a part of the gas that is producing in the hopper is allowed to go inside the cylinder. The remainder part has no space to store so it exerts pressure inside the equipment and tries to flow through the air nozzles and water tank. Gas at higher pressure also carries some impurities (i.e ash, moisture etc.), which causes carbon deposition inside the engine cylinder. So to make the proper supply of clean gas inside engine cylinder at a required pressure, it should be controlled, stored and maintained at proper place.

CHAPTER 5

OBSERVATIONS

5.1 Observations: - The observations made for the samples of cotton stalk, mustard stalk and sugarcane bagasse collected from the village Gujjarwal distt Ludhiana are given in following tables:

(1) Diesel only:

Table 5.1

S.No	Load(kW)	Time(min)	Fuel Consumption(ml)
1	2	1	13
2	4	1	21
3	6	1	30

(2) Primary fuel: Diesel
Secondary fuel: Mustard stalk

(a) Three Revolutions of Gasifier valve

Table 5.2

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	7
2	4	1	10
3	6	1	24

(b) Six Revolutions of Gasifier Valve:

Table 5.3

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	4
2	4	1	9
3	6	1	17

(c) Max. Possible Revolutions of Gasifier Valve:

Table 5.4

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	8
2	4	1	6
3	6	1	11

(3) Primary fuel: Diesel
Secondary fuel: Cotton stalk

(a) Three Revolutions of Gasifier Valve:

Table 5.5

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	6
2	4	1	11
3	6	1	21

(b) Six Revolutions of Gasifier Valve:

Table 5.6

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	4
2	4	1	8
3	6	1	13

(c) Max. Possible Revolutions of Gasifier Valve:

Table 5.7

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	4
2	4	1	7
3	6	1	17

(4) Primary fuel: Diesel
Secondary fuel: Sugarcane bagasse

(a) Three Revolutions of Gasifier Valve:

Table 5.8

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	12
2	4	1	17
3	6	1	30

(b) Six Revolutions of Gasifier Valve:

Table 5.9

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	8
2	4	1	16
3	6	1	28

(c) Max. Possible Revolutions of Gasifier Valve:

Table 5.10

S.No	Load(kW)	Time(min)	Fuel consumption(ml)
1	2	1	6
2	4	1	9
3	6	1	31

5.2 Graphical representation of the data: The graphs shown below are the representation of the data collected while operating the engine on dual fuel mode with diesel being the primary fuel and the producer gas produced in the gasifier is the secondary fuel. The data is collected for various load conditions the load being 2 kW, 4 kW and 6 kW. For the different openings of the gasifier valve, for three revolutions, six revolutions and for the maximum possible revolutions.

(1) Primary fuel: Diesel

Secondary fuel: Mustard stalk

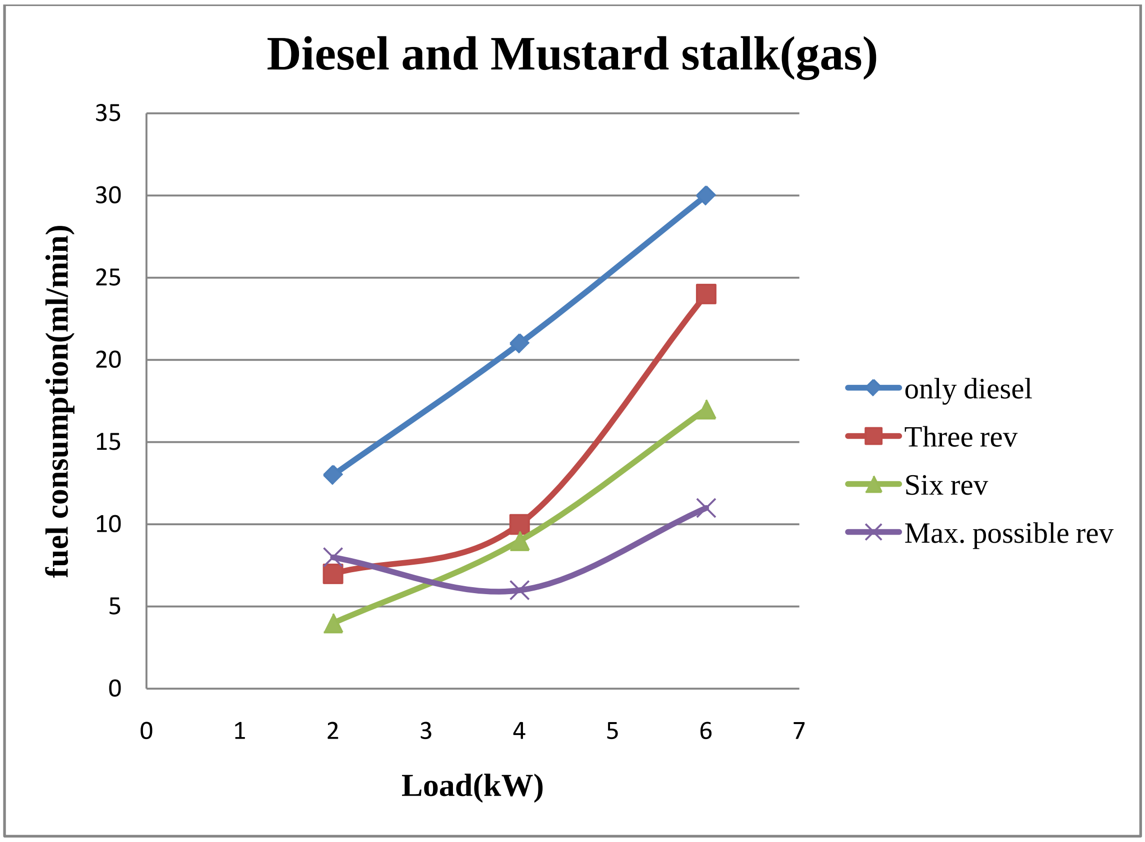

Fig. 5.1 Fuel consumption at varying loads for different openings of valve.

(2) Primary fuel: Diesel

Secondary fuel: Cotton stalk

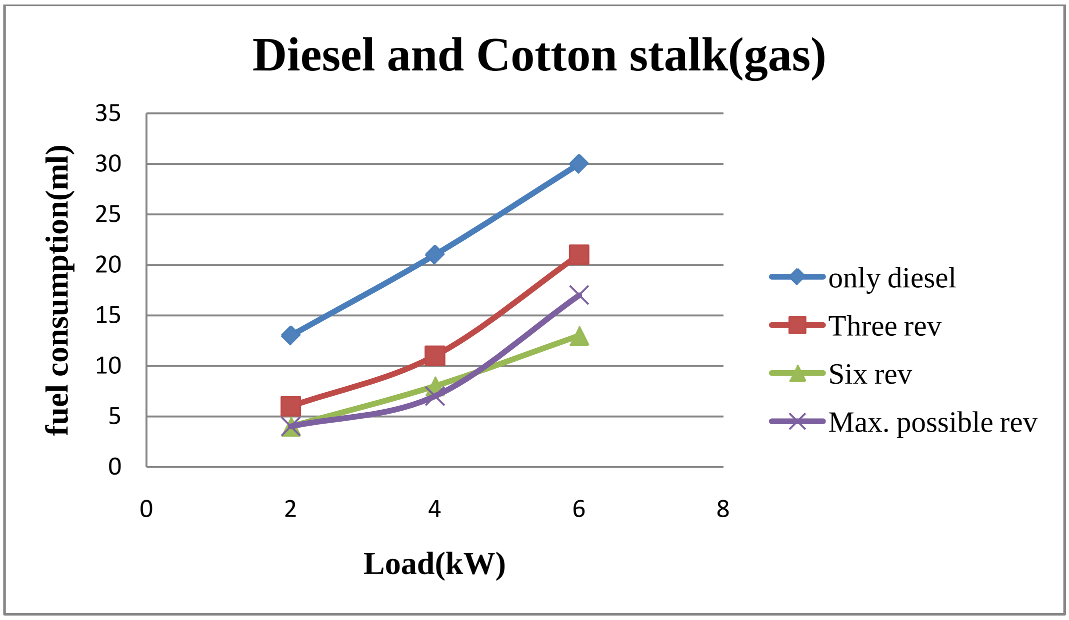

Fig. 5.2 Fuel consumption at varying loads for different openings of valve.

(3) Primary fuel: Diesel

Secondary fuel: Sugarcane bagasse

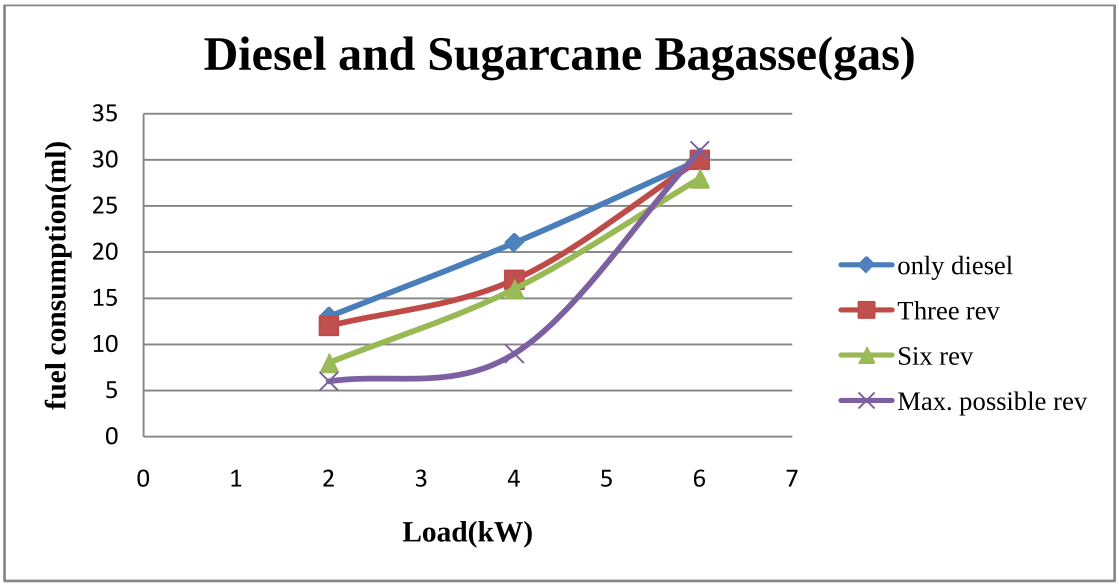

Fig. 5.3 Fuel consumption at varying loads for different openings of valve.

5.3 Cost Analysis

For the economic analysis of the biomass gasifier attached with a C.I engine we have to take in to consideration the cost of the fuel i.e diesel and the biomass fuel we are using for the experiment i.e cotton stalk, mustard stalk and sugarcane bagasse, as these form of biomass are not used commercially so they are considered as a agricultural waste and having no such price, apart from being used in the form of fuel for burning in domestic purposes (cooking etc.). In the economic study the price of biomass is neglected and only the price of diesel is considered (approx. Rs 50).

Only Diesel:

Table 5.11 Cost of operation for only diesel.

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	780	39
2	4	1260	63
3	6	1800	90

Dual fuel mode:

(1) Primary fuel: Diesel

Secondary fuel: Mustard stalk

(a) Three revolutions of gasifier valve:

Table 5.12

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	420	21
2	4	600	30
3	6	1440	72

(b) Six revolutions of gasifier valve

Table 5.13

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	240	12
2	4	540	27
3	6	1020	51

(c) Max.Possible revolutions of gasifier valve

Table 5.14

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	480	24
2	4	360	18
3	6	660	33

(2) Primary fuel: Diesel
Secondary fuel: Cotton stalk

(a) Three revolutions of gasifier valve

Table 5.15

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	360	18
2	4	660	33
3	6	1260	63

(b) Six revolution of gasifier valve

Table 5.16

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	240	12
2	4	480	24
3	6	780	39

(c) Max. Possible revolutions of gasifier valve

Table 5.17

S.No	Load(kw)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	240	12
2	4	420	21
3	6	1020	51

(3) Primary fuel: Diesel

Secondary fuel: Sugarcane bagasse

(a) Three revolutions of gasifier valve

Table 5.18

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	720	36
2	4	1020	51
3	6	1800	90

(b) Six revolutions of gasifier valve

Table 5.19

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	480	24
2	4	960	48
3	6	1680	84

(c) Max. possible revolutions of gasifier valve

Table 5.20

S.No	Load(kW)	Fuel consumption/hr(ml)	Cost of operation/hr(Rs)
1	2	360	18
2	4	540	27
3	6	1860	93

Graphical representation of cost analysis:

(1) Primary fuel: Diesel

Secondary fuel: Cotton stalk

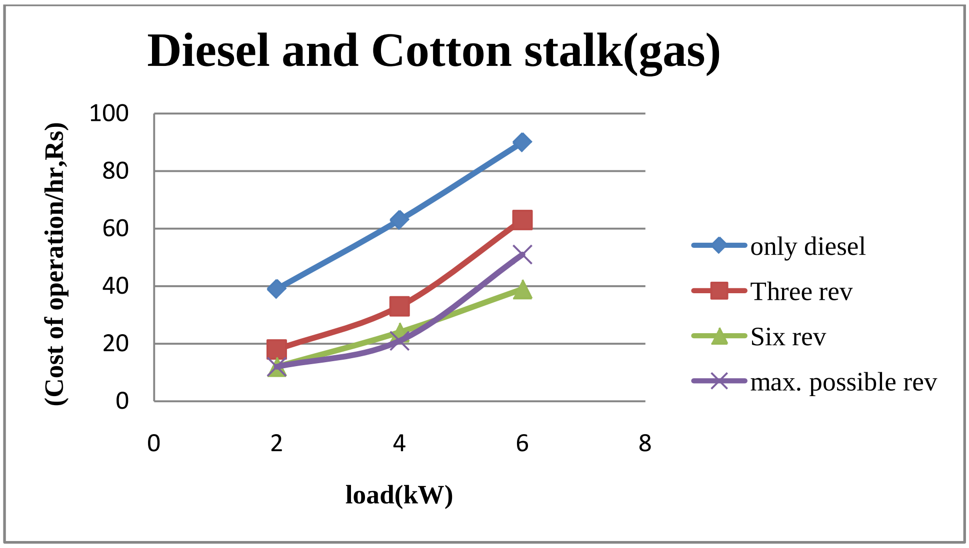

Fig. 5.4 Cost of operation for various loads and openings of valve (Cotton stalk)

(2) Primary fuel: Diesel

Secondary fuel: Mustard stalk

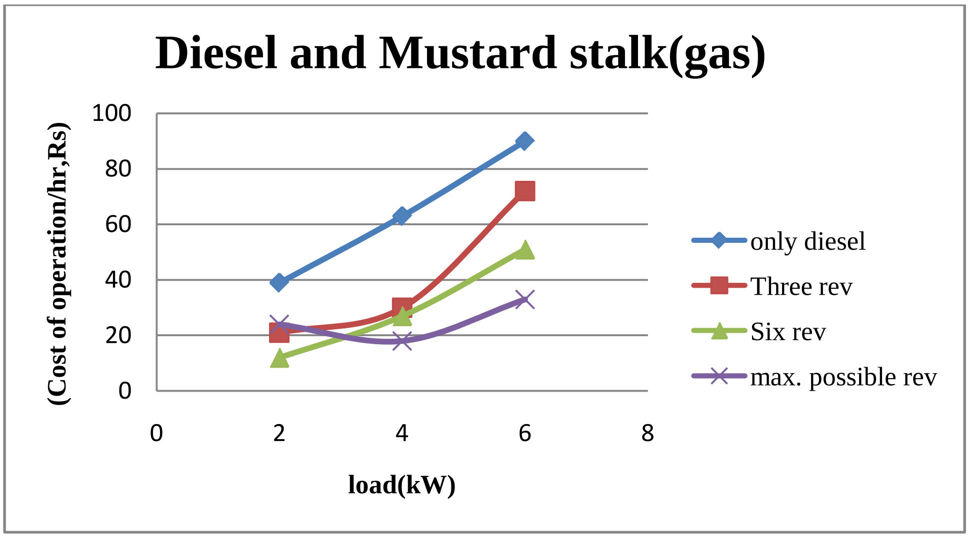

Fig. 5.5 Cost of operation for various loads and openings of valve (mustard stalk)

(3) Primary fuel: Diesel

Secondary fuel: Sugarcane bagasse

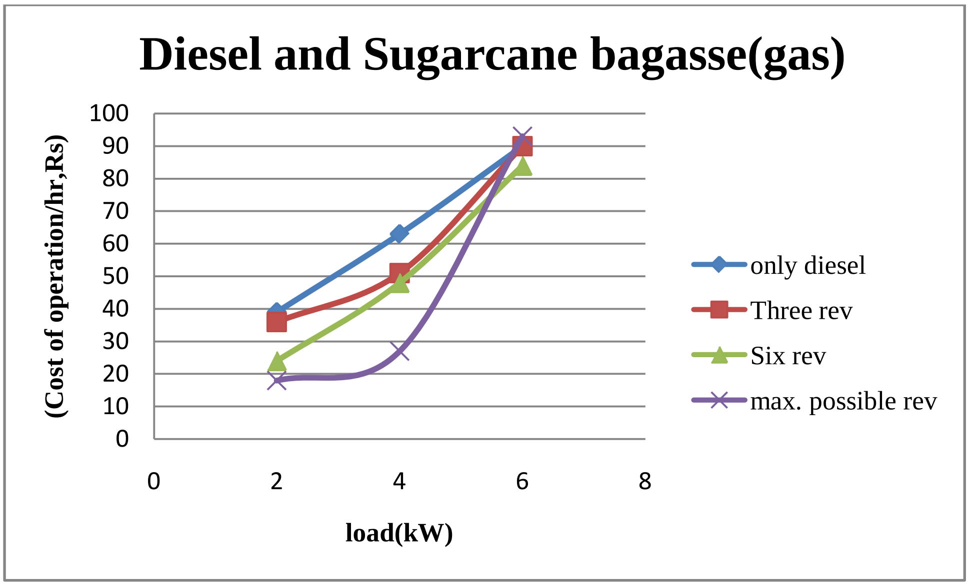

Fig. 5.6 Cost of operation for various loads and openings of valve (sugarcane bagasse)

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Diesel consumption: Comparison is shown between the samples of biomass taken i.e cotton stalk, mustard stalk and sugarcane bagasse on the basis of diesel consumption. The values are shown at different openings of the gasifier valve and at loads of 2 kW, 4 kW and 6 kW respectively.

(a) For three revolutions of the gasifier valve:

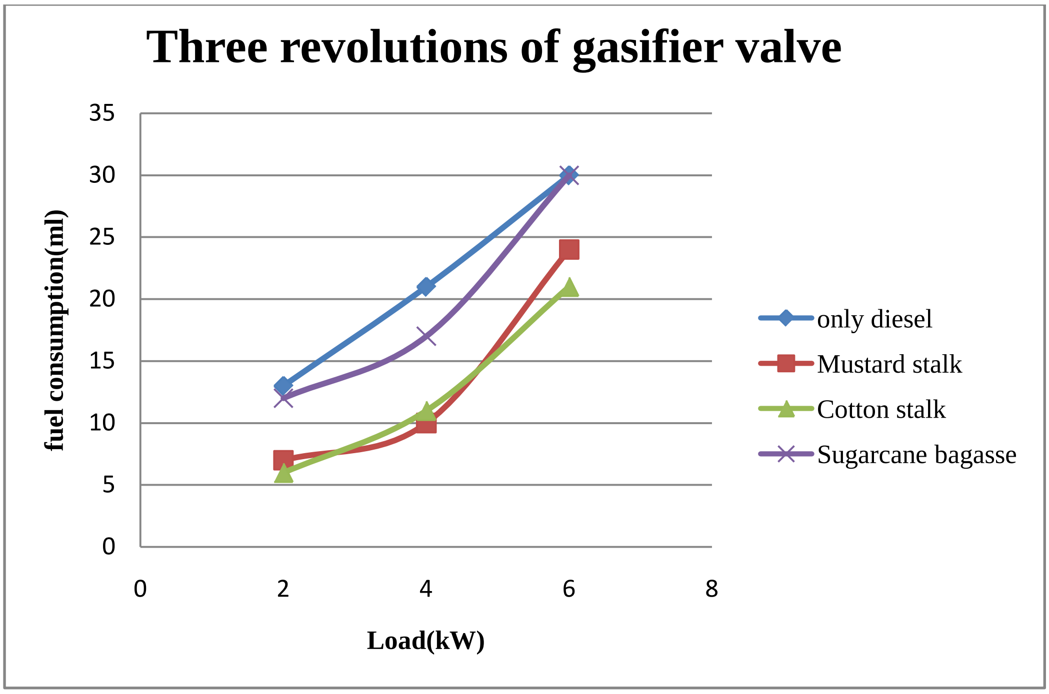

Fig. 5.7 Comparison of biomass fuels for three revolutions of valve (fuel consumption).

(b) For six revolutions of the gasifier valve:

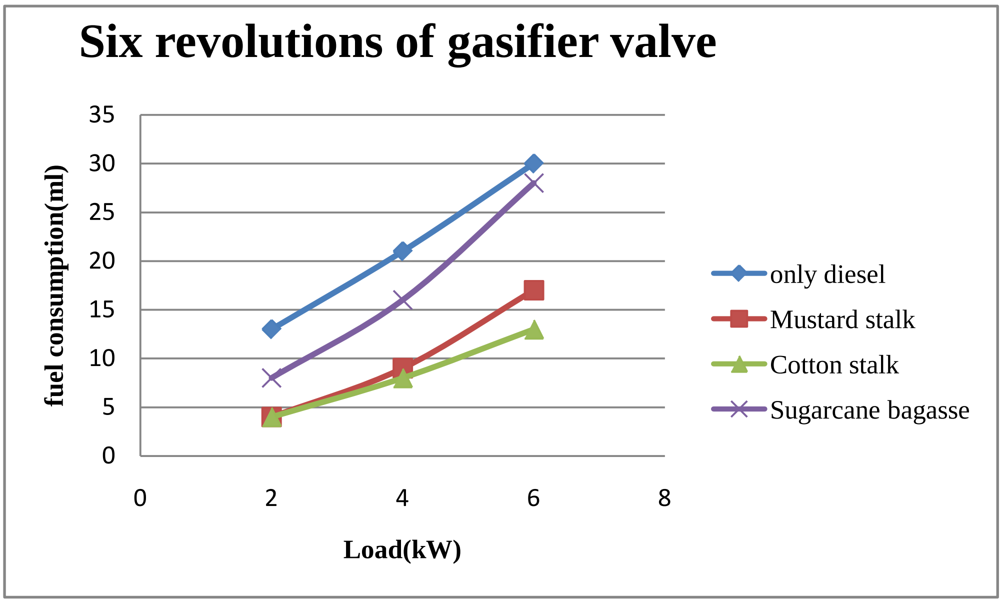

Fig.5.8 Comparison of biomass fuels for six revolutions of valve (fuel consumption)

(c) For max. Possible revolutions of the gasifier valve:

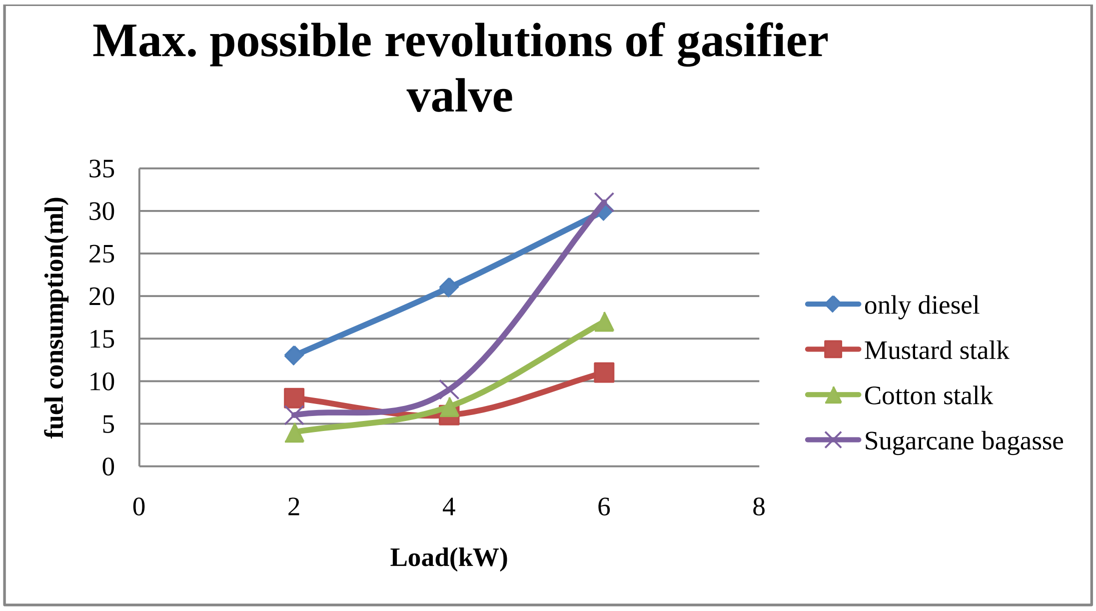

Fig. 5.9 Comparison of biomass fuels for max. revolutions of valve(fuel consumption)

6.2 Cost of operation: Comparison is shown between the samples of biomass taken i.e cotton stalk, mustard stalk and sugarcane bagasse on the basis of cost of operation. The values are shown at different openings of the gasifier valve and at loads of 2 kW, 4 kW and 6 kW respectively.

(a) For three revolutions of gasifier valve:

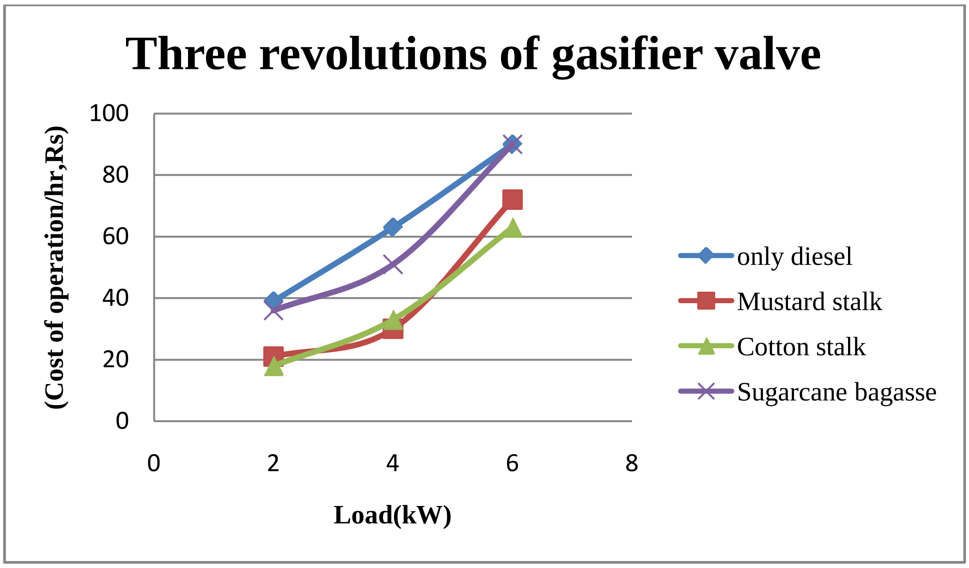

Fig.5.10 Comparison of biomass fuels for three revolutions of valve (cost of operation)

(b) For six revolutions of gasifier valve:

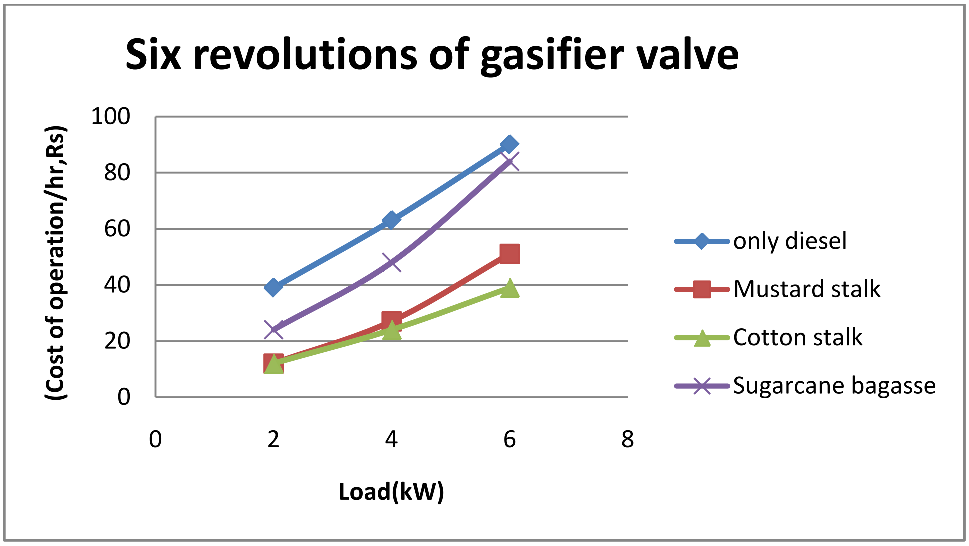

Fig. 5.11 Comparison of biomass fuels for six revolutions of valve (cost of operation)

(c) For max. possible revolutions of gasifier valve:

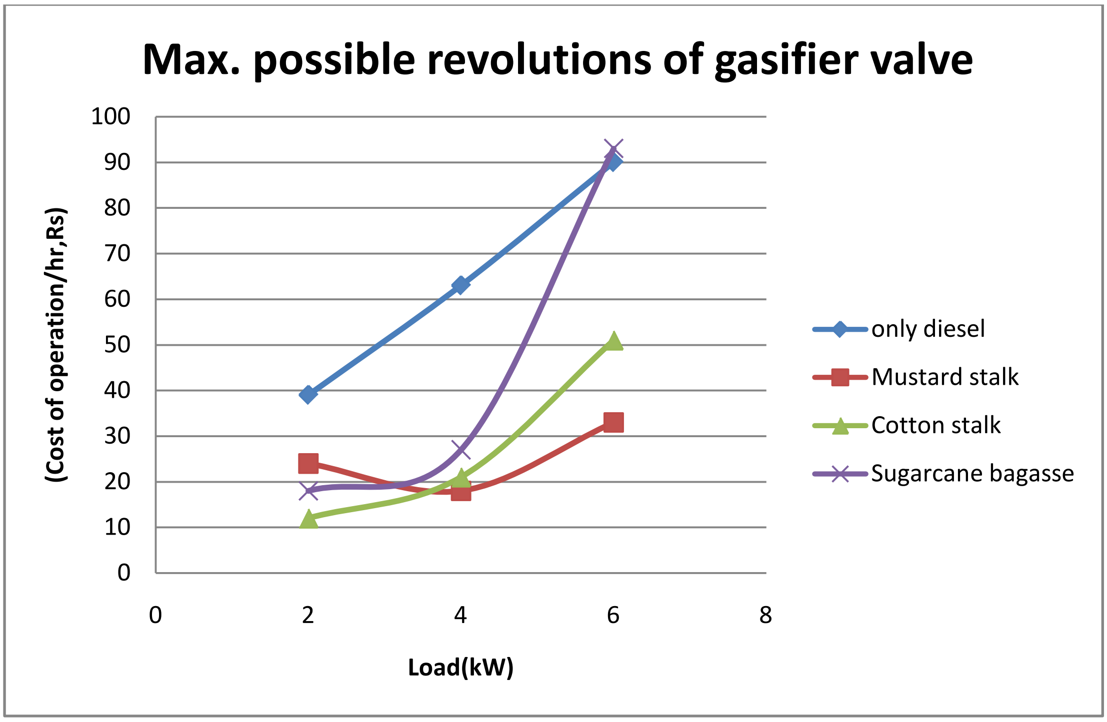

Fig. 5.12 Comparison of biomass fuels for max. revolutions of valve (cost of operation)

Now, from the comparison of the various biomass (i.e cotton stalk, mustard stalk and sugarcane bagasse) fuels used in the experiment on the basis of fuel i.e diesel consumption and on the basis of cost of operation. The analysis is done on the basis of load and the revolutions of the gasifier valve open to induct the producer gas in to combustion chamber as a replacement to the incoming air. It is done by taking the three, six and max. Possible revolutions of the gasifier valve opened without any disturbance to normal operation and the capacity of the engine to bear the given load. And the load taken is same as 2 kW, 4 kW and 6 kW respectively.

As we are using biomass to replace diesel, so in the following tables it shown that what percentage of diesel is being saved by the use of gasifier with various biomass fuels at various load conditions and at different openings. For this comparison the values of the engine while operating on diesel only are taken as the benchmark.

(1) Primary fuel: Diesel
Secondary fuel: Mustard stalk

(a) Three revolutions of gasifier valve

Table 5.21

S.No	Load (kW)	Diesel replacement (%)
1	2	46.2
2	4	52.39
3	6	20

(b) Six revolutions of gasifier valve

Table 5.22

S.No	Load (kW)	Diesel replacement (%)
1	2	69.24
2	4	57.15
3	6	43.34

(c) Max. possible revolutions of gasifier valve

Table 5.23

S.No	Load (kW)	Diesel replacement (%)
1	2	38.47
2	4	71.43
3	6	63.34

(2) Primary fuel: Diesel

Secondary fuel: Cotton stalk

(a) Three revolutions of gasifier valve

Table 5.24

S.No	Load (kW)	Diesel replacement (%)
1	2	53.8
2	4	47.62
3	6	30

(b) Six revolutions of gasifier valve

Table 5.25

S.No	Load (kW)	Diesel replacement (%)
1	2	69.24
2	4	61.91
3	6	56.67

(c) Max. possible revolutions of gasifier valve

Table 5.26

S.No	Load (kW)	Diesel replacement (%)
1	2	69.23
2	4	66.66
3	6	43.33

(3) Primary fuel: Diesel

Secondary fuel: Sugarcane bagasse

(a) Three revolutions of gasifier valve

Table 5.27

S.No	Load (kW)	Diesel replacement (%)
1	2	7.69
2	4	19.04
3	6	-

(b) Six revolutions of gasifier valve

Table 5.28

S.No	Load (kW)	Diesel replacement (%)
1	2	38.46
2	4	23.80
3	6	6.66

(c) Max. possible revolutions of gasifier valve

Table 5.29

S.No	Load (kW)	Diesel replacement (%)
1	2	53.84
2	4	57.14
3	6	-

DISCUSSION: In case of diesel consumption, for the condition when only diesel is used i.e the engine is running normally without the gasifier the fuel consumption curve is linear, diesel consumption increases with increase in the loading condition. It is minimum for 2 kW load and is maximum for the 6 kW load. For three revolutions of the gasifier valve, for mustard stalk initially the value is lower than diesel and it increases gradually with load but is lesser than diesel eventually. For cotton stalk it starts with the least of all and then increases at medium load, a bit higher than the mustard stalk but it decreases to be minimum of all at the full load. For sugarcane bagasse it starts just below the diesel line and dips at the medium load but is more than the cotton and mustard, in the end means at higher load it turns up to be same as that of diesel.

For the three revolutions of the gasifier valve the best biomass fuel among the three taken is the cotton stalk as it replaces the diesel maximum at all the three loading conditions and is more uniform in results than the others.

The same trend follows for the six revolutions of the gasifier valve slight changes in the values, the results remains the same as cotton stalk emerges to be the best among the fuels in replacing diesel.

For the maximum possible revolutions of the gasifier valve, mustard stalk starts with a high consumption but then at medium loads it consumes lesser fuel than the other two. Cotton remains steady with the lowest consumption in starting and increases with load and in the end it finishes just above the mustard. Sugarcane starts in the middle of others and then is higher at the medium load and it shoots up to the level of diesel point at higher loads.

Cotton stalk again stands out to be the better biomass fuel among the taken samples with maximum diesel replacement and stable working under various loads and it remains uniform as it has the maximum amount of fixed carbon.

Sugarcane bagasse shows some indifferent behavior than the other biomass samples taken, though it has the highest calorific value among the taken samples but it does not perform as expected. It lags behind the other two in terms of diesel replacement and cost of operation. The reason found behind this behavior is that it goes under complete combustion and is not able to form the producer gas and instead of decreasing the diesel consumption, at a time it increases the consumption at higher load for full opening of the gasifier valve.

CONCLUSION:

(1) Dual fuel engine is going to be more attractive in coming years to utilize biomass waste.

(2) Cotton stalk gives the best performance out of the three biomass samples taken.

(3) Cotton stalk have lowest cost of operation and the highest diesel replacement.

FUTURE SCOPE:

- Effect of particle size distribution on the performance of gasifier of biomass fuel can be studied.
- Emission parameters of the agricultural wastes can be analyzed to know their effect on global climate.
- Effect of long term operation on the various components of the engine can be studied.

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