Biogas Production from Kitchen Wastes: its Purification and Application in C.I Engine in dual Fuel Mode

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ABSTRCT:

Biodegradable wastes such as kitchen wastes, agricultural wastes & animal wastes are used to produce Biogas, a powerful greenhouse gas. Biogas derived from kitchen wastes is a potential alternative to the partial substitution of petroleum derived fuels because it is from renewable resources that are widely available. Producing renewable energy from our biodegradable wastes helps to tackle the energy crisis. Anaerobic digestion (AD) is a treatment that composts these wastes in the absence of oxygen, producing a biogas that can be used to generate Heat & Power. AD produces biogas of around 60 per cent methane, 30 percent carbon dioxide (CO_2), 2 percent hydrogen sulphide (H_2S) and other constituents. For application as a fuel in I.C Engines it is required to remove carbon dioxide (CO_2) and hydrogen sulphide (H_2S), because H_2S corrodes vital mechanical components of engine and CO_2 reduces heating effect if it is not removed. Therefore Biogas is required to be upgraded through purification by removing H_2S and CO_2. In this paper, the important parameters of performance characteristics (such as: power output, thermal efficiency & fuel consumption) of biogas-fuelled C.I engine are studied and estimated with change of engine speed and load. The obtained results when operating with biogas are used to compare with that of diesel fuel under the same operating conditions. The experimental results show that the tested engine operated with richer biogas-air mixture than that of diesel-air mixture under the same test conditions.

Keywords: Anaerobic digestion, kitchen wastes, Biogas, dual fuel, performance test, BSFC, C.I engine, BTE

I.INTRODUCTION

The continuous generation of municipal wastes and kitchen wastes has become an environmental and social concern due to the large impacts of its improper treatment and management. Rapid biodegradation of the organic wastes is of key importance to identify environment in more responsible way to process it rather than land filling or composting it. Anaerobic digestion has the advantage of biogas production and can lead to efficient resource recovery and contribution to the conservation of non-renewable energy sources. Biogas is developed from the biodegradation of kitchen wastes in absence of oxygen and consists of mainly methane, hydrogen sulphide and carbon dioxide. Biogas can be upgraded through purification and can be used as an alternative to the partial or total substitution of diesel fuels in C.I engines without requiring extensive engine adjustments or modifications. In this study we have reviewed the anaerobic digestion reactions of kitchen wastes, biogas production, purification and application in C.I engines in dual fuel mode.

To operate with biogas, diesel engines can be conveniently converted to a fumigated dual fuel engine, which is the most practical and efficient method. Since biogas has a high octane number, it can be employed in a high compression ratio engine to maximize its conversion efficiency. In dual fuel operation mode, biogas is mixed with air prior to entering the combustion chamber. At the end of compression stroke, a pilot amount of diesel fuel is injected to ignite the mixture, as long as proper spray penetration and evaporation are achieved. One advantage of this method is that the engine can be switched back to conventional diesel operation mode when the biogas supply is not available. In this investigation testing of compression ignition engine is operated with biogas and diesel dual fuel mode. The main objective is to evaluate performance characteristics of a small, naturally aspirated, direct C.I engine using diesel and biogas in a dual fuel mode.

II. ANAEROBIC DIGESTION AND BIOGAS PRODUCTION

Anaerobic digestion (AD) is a microbial decomposition of organic matter into methane, carbon dioxide, inorganic nutrients and compost in oxygen depleted environment and presence of the hydrogen gas. This process is also known as bio-methanogenesis which helps rapid and controlled decomposition of kitchen wastes feedstock to methane, carbon dioxide and stabilized residue. In the generalized scheme of the anaerobic digestion, the feedstock is collected, coarsely shredded and placed into a reactor with active inoculums of methanogenic microorganisms. Since the methane is a significant greenhouse gas, anaerobic digestion has higher control over the methane production and contributes to lower the carbon foot print of the kitchen waste management in the way that the fugitive emissions are lower than then the emissions in the cases of the land filling and aerobic composting (Levis et al. 2010). Generally three main reactions occur during the entire process of the anaerobic digestion to methane: hydrolysis, acid forming and methanogenesis.

Fig.1 Anaerobic digestion of kitchen wastes

2.1 Hydrolysis.

Hydrolysis is a reaction that breaks down the complex organic molecules into soluble monomers (constituents).This reaction is catalyzed by enzymes excreted from the hydrolytic and fermentative bacteria. End products of this reaction are soluble sugars, amino acids; glycerol and long-chain carboxylic acids (Ralph & Dong 2010). The approximate chemical formula for organic waste is $C_6H_{10}O_4$ (Shefali & Themelis 2002)

Hydrolysis reaction of organic fraction is represented by following reaction:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$$

(Ostrem & Themelis 2004)

2.2 Acid-forming stage.

This stage is facilitated by microorganisms known as acid formers that transform the products of the hydrolysis into simple organic acids such as acetic, propionic and butyricacid as well as ethanol, carbon dioxide and hydrogen. Acid forming stage comprises two reactions, fermentation and the acetogenesis reactions. During the fermentation the soluble organic products of the hydrolysis are transformed into simple organic compounds. The acetogenesis is completed through carbohydrate fermentation and results in acetate, CO_2 and H_2, compounds that can be utilized by the methanogens. The presence of hydrogen is critical importance in acetogenesis of compounds such as propionic & butyric acid. These reactions can only proceed if the concentration of H_2 is very low (Ralph & Dong 2010).

2.3 Methanogenesis.

Methanogenesis is a reaction facilitated by the methanogenic microorganisms that convert soluble mater into methane. Two thirds of the total methane produced is derived converting the acetic acid or by fermentation of alcohol formed in the second stage such as methanol. The other one third of the produced methane is a result of the reduction of the carbon dioxide by hydrogen. Considering that the methane has high climate change potential the goal is to find an alternative in order to lower the environmental foot print of the organic waste treatment. Therefore this stage is avoided and instead of methane the production of volatile fatty acids is targeted.

The reactions that occur during this stage are as follows (Ostrem & Themelis 2004).

- Acetate conversion:

$2CH_3CH_2OH + CO_2 \leftrightarrow 2CH_3COOH + CH_4$

Followed by: $CH_3COOH \leftrightarrow CH_4 + CO_2$

- Methanol conversion:

$CH_3OH + H_2 \leftrightarrow CH_4 + H_2O$

- Carbon dioxide reduction by hydrogen

$CO_2 + 4H_2 \leftrightarrow CH_4 + H_2O$

III. COMPOSITION OF BIOGAS

The composition of biogas depends on a number of factors such as the process design and the nature of the substrate that is digested. The main components are methane and carbon dioxide, but several other components also exist in the biogas. The table-1 below lists the composition of Biogas in Anaerobic digestion.

Table-1-Approximate Biogas Composition in Anaerobic Digestion

Gas	Concentration %
CH_4	50-70
CO_2	25-30
N_2	0-10
H_2O	0-5
H_2S	0-3
O_2	0-3
C_xH_y	0-1
NH_3	0-0.5
R_2SiO	0-50 mg/m3

IV. PURIFICATION OF BIOGAS FOR C.I ENGINES

Biogas is comprised of methane, carbon dioxide and other compounds including hydrogen sulphide, water, and other trace gas compounds. Methane is a powerful greenhouse gas if emitted into the atmosphere, but can also represent a valuable renewable energy source, with the potential to reduce GHG emissions when it is collected and substituted for fossil fuels. Biogas can be used directly in C.I.Engines, but the large volume of CO_2 reduces the heating value of the gas. For use as a fuel, purification to remove carbon dioxide (CO_2) and hydrogen sulphide (H_2S) is required, because H_2S corrodes vital mechanical components within engine generator sets and vehicle engines if it is not removed.

Biogas emits less nitrogen oxide, hydrocarbon and carbon monoxide than gasoline or diesel, and engines fuelled by purified biogas are quieter than diesel engines. Refuelling with biogas presents fewer environmental risks than refuelling with gasoline or diesel, because it can be done at small units, minimizing the potential impacts if leaks or spills occur. Potential negatives include the high cost to upgrade the biogas, reduced driving range for engines, dependent on specialty fuel and less space due to biogas storage. Feasible biogas purification technologies exist for large-scale kitchen waste digesters and the technologies for upgrading biogas, compressing, storing and dispensing bio-methane are well developed.

4.1 Purification by Water Scrubbing

Water scrubbing is used to remove CO_2 and H_2S from biogas since these gases are more soluble in water than methane. The absorption process is purely physical. Usually the biogas is pressurized and fed to the bottom of a packed column while water is fed on the top and so the absorption process is operated counter-currently (Figure-2). Water scrubbing can also be used for selective removal of H_2S since H_2S is more soluble than carbon dioxide in water. The water which exits the column with absorbed CO_2 and/or H_2S can be regenerated and re-circulated back to the absorption column. Regeneration is accomplished by de-pressuring or by stripping with air in a similar column. Stripping with air is not recommended when high levels of H_2S are handled since the water quickly becomes contaminated with elementary sulphur which causes operational problems. When cheap water can be used, for example, outlet water from a sewage treatment plant, the most cost efficient method is not to re-circulate the water.

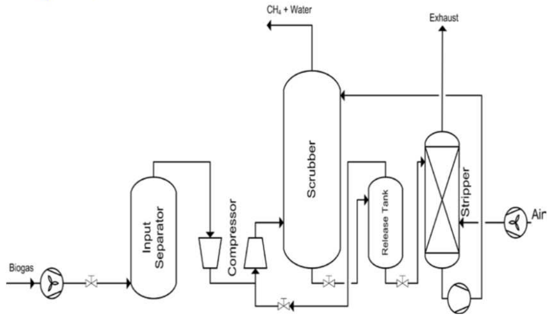

Fig.2 Flow chart of water scrubbing technology

V. BIOGAS IN C.I ENGINE APPLICATIONS

Biogas can be used in both heavy duty and light duty vehicles. Light duty vehicles can normally run on biogas without any modifications whereas, heavy duty vehicles without closed loop control may have to be adjusted, if they run on biogas. Petrol engines can use biogas directly and Diesel engines require combination of biogas and diesel oil for combustion. For use of biogas as a fuel, it is first upgraded by removing impurities like CO_2,H_2 S and water vapour. After removal of impurities it is compressed in a three or four stage compressor up to a pressure of 20 MPa and stored in a gas cascade, which helps to facilitate quick refuelling of cylinders. If the biogas is not compressed than the volume of gas contained in the cylinder will be less hence the engine will run for a short duration of time.

5.1 Biogas in Dual Fuel Engine Application

In this case, the normal diesel fuel injection system still supplies a certain amount of diesel fuel. The engine however sucks and compresses a mixture of air and biogas fuel which has been prepared in external mixing device. The mixture is then ignited by and together with the diesel fuel sprayed in. The amount of diesel fuel needed for sufficient ignition is between 10% and 20% of the amount needed for operation on diesel fuel alone. Operation of the engine at partial load requires reduction of the biogas supply by means of a gas control valve. A simultaneous reduction of airflow would reduce power and efficiency because of reduction of compression pressure and main effective pressure. So, the air/fuel ratio is changed by different amounts of injected biogas. All other parameters and elements of diesel engine remain unchanged.

VI. EXPERIMENTAL PROGRAMME

The tests and estimation of engine performance characteristics (like brake power, thermal efficiency and specific fuel consumption) of biogas internal combustion engines are limited by the lack of specially testing devices and measuring equipments. It is expected that the performance characteristics of biogas-fuelled engine must be studied for a wide change of engine speed and load. Then the obtaining results should be used to compare with operation the conventional fuels like diesel. Thus, the main objectives of this study are to evaluate the performance characteristics of biogas fuelled C.I engine.

6.1 Experimental procedure

The experiment was carried out with the conventional diesel fuel and the engine was kept running till it reached the operating temperature. The load was kept constant for various RPM throughout the experiment. For diesel and biogas consumption by the engine, all the parameters were observed at different speed and load on the engine. Moreover, time for fuel consumption by the engine was also noted to calculate the specific fuel consumption under various conditions. To reduce the effect of dispersion in the data each set of experiment was repeated two times. The Brake Power, Brake Specific Fuel Consumption, Brake Thermal Efficiency and exhaust emission were calculated.

In order to draw conclusion, the experiments were conducted by varying RPM and volume of Biogas and Diesel over wide ranges. To evaluate comparatively of performance characteristics of C.I engine using diesel and biogas, engine speed is changed from 1400 rpm to 1600 rpm with a step of 50 rpm. a total of five measurement points (1400, 1450, 1500, 1550, 1600 rpm).

6.2 Experimental Set Up

The particular type of engine used in this investigation is a single cylinder 3.7 KW diesel engine. Setup of the investigation engine is illustrated in Fig.3 and its specifications are noted in the table 2.The engine is cooled by water cooling system fitted in the engine itself. There is only one change in the engine was biogas and air are mixed in the one chamber like T joint near intake manifold.

The engine was run at the idling condition for certain period of time. The engine was properly fitted with the mechanical loading arrangement for better results. After running the engine with this condition for certain time, readings were taken for different load conditions. The performance test was carried out with same test set up and then the engine run with dual fuel of diesel and biogas

Fig.3 Experimental setup of biogas-fuelled C.I engine

Table 2. Engine Specifications

. Engine	Kirloskar
Type	Water cooled
B P	3.7 KW
Number of Cylinders	1
Bore	80 mm
Stroke	110 mm
Rated speed	1500 RPM
Combustion	Compression Ignition

Biogas used in the tests was supplied from a biogas plant. It was stored and compressed in a collapsible rubber balloon from where it was fed to the engine intake manifold. Before storing in the balloon it was upgraded through purification to reduce CO_2 and some amount of H_2S. Its compositions were 60% CH_4, 30% CO_2, 5% N_2, and 2% O_2 with some traces of H_2S. The biogas was also compared along with diesel for the properties obtained from the literature shown in Table 3.

Table 3. Property of diesel and biogas

Property	**Biogas**	**Diesel**
Cetane number	-	50
Heating Value (MJ/Kg)	24.50	45.91
Viscosity @ 40ºc (cSt)	-	3.34
Specific gravity @15 ºc	0.001	0.830
Sulphur content (%wt.)	0.12	0.037

VII. RESULTS AND DISCUSSION

7.1 Brake power

Brake power of engine is measured by a rope brake dynamometer. The experiment is conducted at the same conditions with biogas and diesel. When the engine speed increases, the brake torques for both cases increases. However, the difference in brake power at each operating point is less than 5%. Engine speed is set at 1400 rpm (idle speed), 1450, 1500, 1550, 1600 rpm. Theoretically, brake power of same engine fuelled with diesel is higher than that using biogas, because diesel has higher LHV than biogas. In this study, however, brake power (determined by dynamometer) is constantly kept in order to estimate the power output, fuel consumption and thermal efficiency for two study cases. The trend shows (fig.4) that brake engine power increases with the increase of engine speed. This is due to a reduction in ignition delay at high temperature in engine cylinder at high speeds. The brake engine power decreases as the percentage of biogas increases, as a result of lower energy contents in fuel mixture. It is also found that conventional diesel fuel always has higher brake engine power as compared to diesel and biogas.

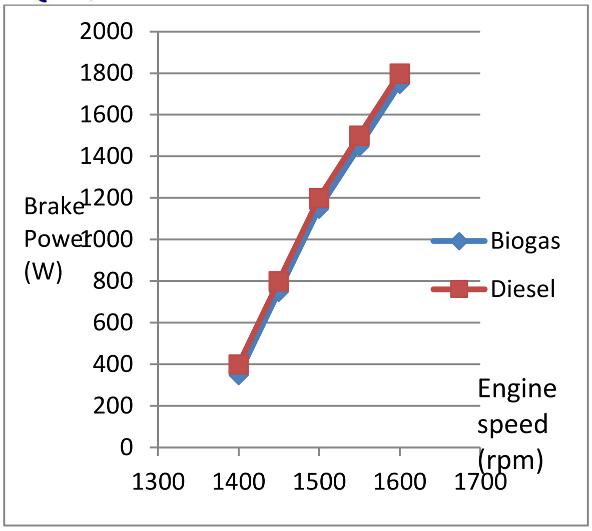

Fig.4 Variation of Brake Power vs. Engine Speed

7.2 Intake air and biogas mass flow rate

Fig.3 shows the change of air mass flow with engine speed. Both intake air flow and biogas flow increase and the variation of A/F rate of air-biogas mixture has a similar tendency. At 1400 rpm, air-fuel mixture is quite dense because biogas has high impurities (CO_2 more than 30%), engine is difficult to start and keep stability in low load. In that case, engine need to close air throttle to reduce air mass flow. When engine speed increases up to 1450 rpm, engine operation has conducted smoothly and air mass flow increase relatively linear. Varying trends and causes of intake air and diesel supply in Fig. 5

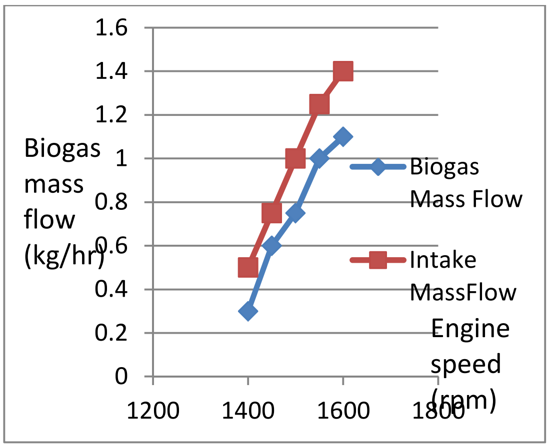

Fig.5 Variation of intake air mass flow and biogas mass flow with respect to engine speed

It shows that the supplied amount of biogas is higher than diesel at the same experimental conditions (with the same brake power at each engine speed). This demonstrates that the diesel engine operated with biogas needs higher fuel consumption than diesel operation. To produce the same brake power, in other words, the engine using biogas-air mixture is burned denser than diesel-air mixture. The main reason, as explained above, is due to lower calorific value of biogas in comparison with diesel.

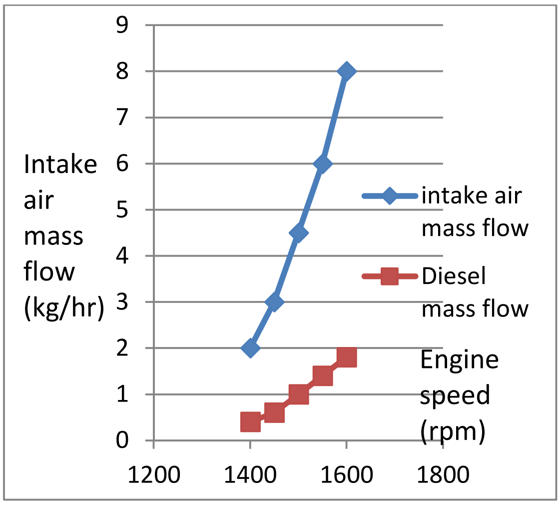

Fig.6 Variation of intake air mass flow and diesel mass flow with respect to engine speed

7.3 Brake specific fuel consumption (BSFC)

The variation in Brake Specific Fuel Consumption at different engine speeds is shown in Fig.7. The Brake Specific Fuel Consumption is proportional to mass of fuel consumed as well as brake engine power. The Brake Specific Fuel Consumption increases as the percentage of diesel increases in the diesel and biogas combustion as compared to pure conventional diesel fuel. This is due to the lower energy contents in diesel fuel with biogas. The BSFC is increased with the increase or decrease in engine speed because of the decrease in volumetric efficiency of the engine.

As shown in Fig.7, for each engine speed, the BSFC of engine operated with diesel is lower than that operated with biogas. At idle speed of 1400 rpm, BSFC for two cases is almost similar without load conditions. When engine speed increases from 1500 to 1600 rpm, the difference of BSFC is about 30%. This is caused by the increase of consumption fuel for the operation of same power.

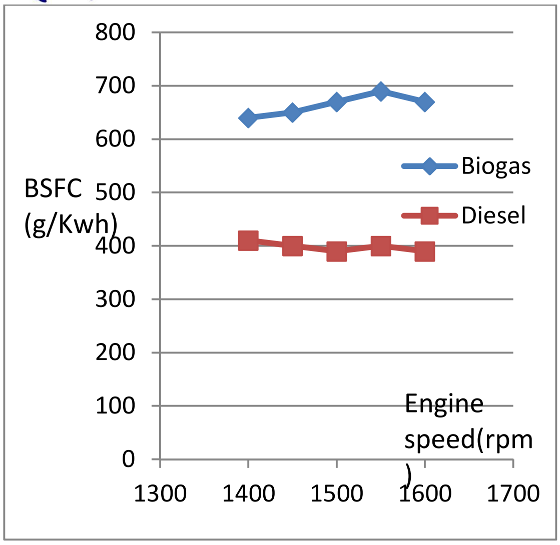

Fig.7 Comparison BSFC of two cases with respect to engine speed

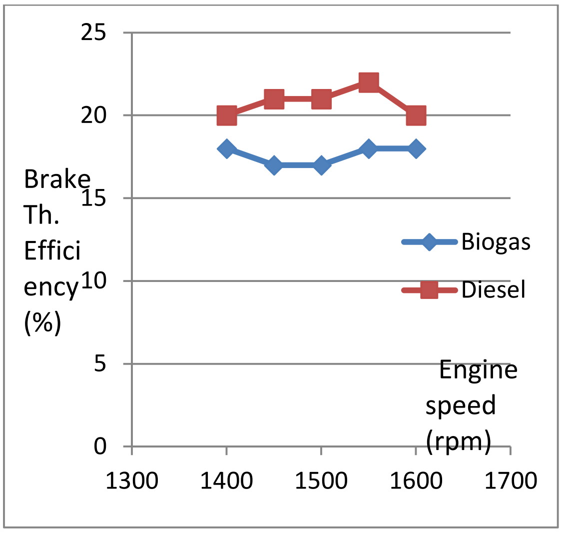

Fig. 8 Variation of brake thermal efficiency versus engine speed

7.4 Brake Thermal efficiency

The variation in Brake Thermal Efficiency at different engine speeds is shown in Fig.8. Due to low BSFC of pure conventional diesel fuel, its Brake Thermal Efficiency is higher than diesel fuel with biogas. It is evident from the figure that the Brake Thermal Efficiency is decreased as the percentage of biogas increased. It may be attributed to lower energy contents in fuel mixture. Thermal efficiency of engine is inversely proportion to BSFC tendency and LHV of tested fuel. In Fig. 8, the BSFC of engine using biogas is higher than that of using diesel. Thus, for whole range of engine speed, brake thermal efficiency of biogas-fuelled diesel engine is lower as shown in Fig. 8. This is because, biogas has many impurities like CO_2, O_2, H_2S and other components limiting the combustion and mechanical durability of the engine. Reduction in brake power of engine leads to reduce thermal efficiency. In addition, thermal efficiency of biogas operation is lower by lower heating value

7.5 Mechanical efficiency

Initially engine runs with the diesel fuel and after some time engine runs with dual fuel operation. Readings are taken at different load conditions.Fig.9 shows, at dual fuel mode the comparison of mechanical efficiency is more with diesel as fuel and less with dual fuel operation. It means fuel consumption is more at more load with higher efficiency. The brake thermal efficiency with respect to fuel consumption difference is also higher.

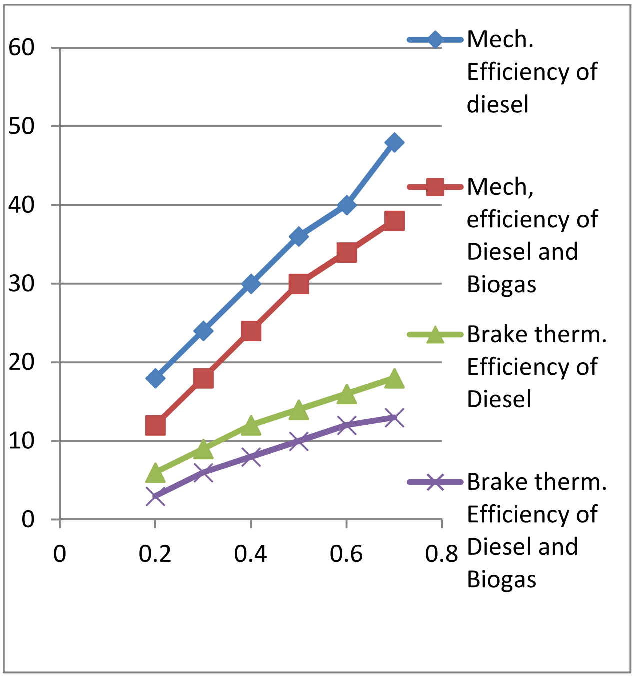

Fig.9 Comparison of Mech. Efficiency and Brake Th. Efficiency

7.6 Effect of load conditions

7.6.1 Comparison of fuel consumption with different loading

Fuel consumption of the engine with different loading arrangements is shown in fig.10. The difference in diesel consumption is up to 20% at the engine loading condition and up to 50 % diesel consumption for further loading.

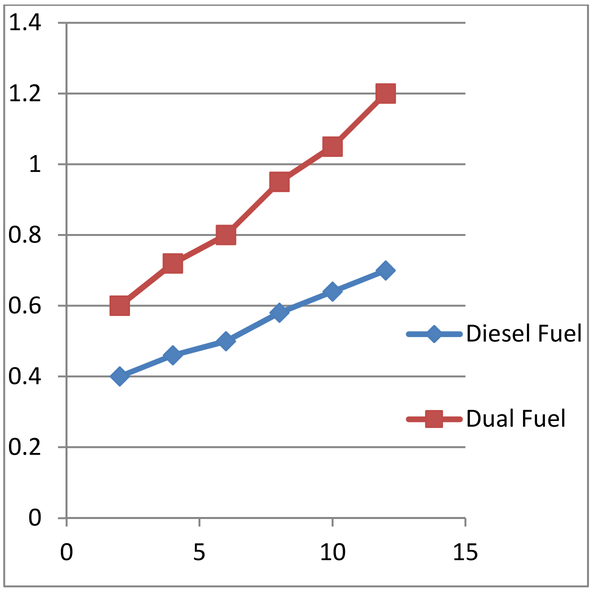

Fig.10 Comparison of fuel consumption with different loading

7.6.2 Biogas mass flow

Effect of load (brake power) on the variation of biogas mass flow is shown in Fig.11. When load increases, the amount of biogas increases linearly. At each point of load, higher engine speed, higher biogas mass flow due to higher volumetric efficiency.

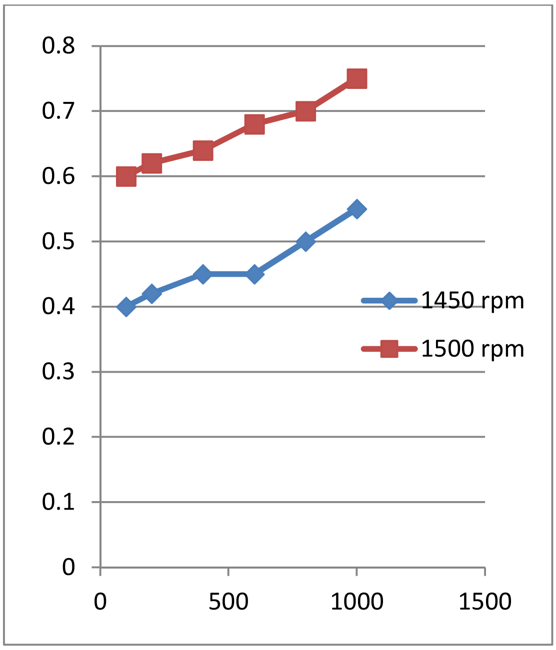

Fig. 11 Change of intake biogas mass flow with respect to brake power for two cases

7.6.3 Brake specific fuel consumption (BSFC)

Fig. 12 shows the change of BSFC with respect to load for two different speeds. As shown in figure, the amount of biogas supply at speed of 1500 rpm is higher than that of 1450 rpm. This may be caused by the increase of volumetric efficiency at high speed. Also, when engine load increases, BSFC decreases.

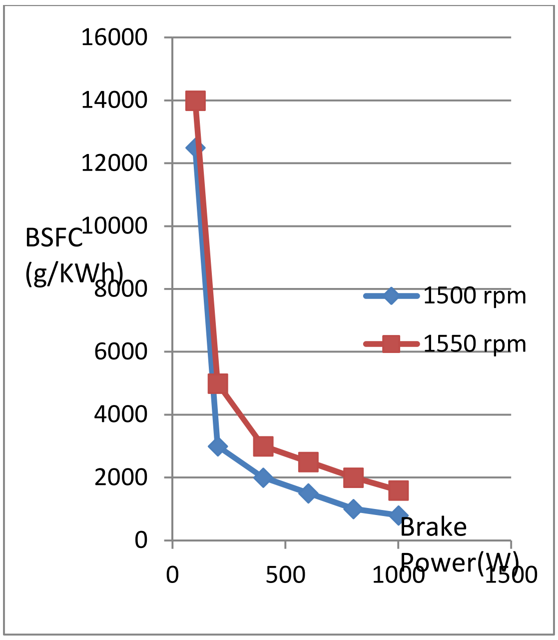

Fig. 12 Change of BSFC with respect to load

VIII. CONCLUSION

The study concludes the biogas production from organic wastes, its' composition and properties for use in C.I Engines. Different techniques for CO_2, H_2S scrubbing are discussed, among which water scrubbing is a simple continuous and cost effective method for purification. The study carried out in this review has shown that the anaerobic digestion of kitchen waste is a feasible alternative to biogas generation. This finding is of special importance because this lowers the operating costs, decreases the capital and operating costs of the anaerobic digestion of source-separated kitchen waste, and reduces the greenhouse gas emissions of both processes. Attention is also focused for making biogas as alternate fuel in C.I Engines and dual fuelling is recommended to be the best one for biogas engine operation. Drop of CO_2 in biogas for dual fuelling increases the thermal efficiency. Therefore it is recommended to use biogas as alternate fuel in I.C engines.

In this study, investigation of engine performance test operating on biogas-diesel dual fuel in a small diesel injection engine at different speed and load conditions has been carried out. Diesel engine performance has been experimentally investigated and the following conclusions may be drawn.

1) Diesel consumption by this small diesel engine at different loading arrangement is around 50% diesel we can save by using biogas-diesel as a fuel in that engine.

2) Efficiency of the engine 20% is increased by using dual fuel arrangement.

3) The Brake Specific Fuel Consumption increased as the percentage of biogas increased in the diesel fuel as compared to pure conventional diesel fuel. This is due to lower energy contents in diesel fuel with biogas.

4) The Brake Thermal Efficiency is decreased as the percentage of biogas increased as compared to pure conventional diesel fuel. This is due to lower energy contents in diesel fuel with biogas. .

5) The brake engine power decreases as the percentage of biogas increases. This is due to lower energy contents in biogas. It is also found that conventional diesel fuel has higher brake engine power as compared to diesel and biogas.

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