Performance characteristics of compression ignition engine using alternative fuels

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ABSTRACT

Numerous vegetable oils suitability has been investigated for use in internal combustion engines. The effects of different fuels on the performance characteristics of engines have been extensively reported. The high viscosity and low volatility of these vegetables oils are the major problem for their use in the diesel engines. However use of different biodiesels in an engine results in variability in the engine performance and emission due to physical and chemical characteristics of fuel. The effect of these physio-chemical properties on fuel supply system such as fuel pump and fuel filter have already been reported.

In this work an attempt is made to improve the combustion characteristics of the engine fueled with biodiesel. Hence a detailed investigation is carried out on the underlying combustion and heat release characteristics. The experimental work is conducted on 4S, single cylinder, water cooled and DI stationary diesel engine. In this work bsfc and thermal efficiency are computed, for different incylinder pressure and peak heat release rate.

1. TYPES OF ALTERNATIVE FUELS

Alternative fuels are fuels that aren't made from petroleum. There is much different kind of fuels that vehicles can use that aren't made from petroleum. Here are the different types of alternative fuels:

- Solar Energy
- Alcohols - ethanol and methanol
- Compressed Natural Gas (CNG) - natural gas under high pressure
- Electricity stored in batteries
- Hydrogen (considered a special gas)
- Liquefied Natural Gas (LNG) – natural gas that is very cold
- Liquefied Petroleum Gas (LPG) – called propane, it is hydrocarbon gas under low pressure
- Liquids made from coal – gasoline and diesel fuel that isn't made from petroleum
- Bio-diesel – diesel fuel made from plant oil or animal fat.

2. PALM STEARIN METHYL ESTER (PSME)

Palm oil can be further refined into palm olein and palm stearin. Palm stearin is the solid fraction of palm oil that is produced by partial crystallization at controlled temperature. It is more variable in composition than palm olein, the liquid fraction of palm oil, especially in terms of its solid fat content, and therefore has more variable physical characteristics. Like crude palm fruit oil, palm stearin contains carotenoids, but physically refined palm oils do not, as they are removed or destroyed in the refining process. Palm oil can be used to produce biodiesel, which is also known as palm oil ester. Palm oil methyl ester is created through a process called transesterification. Palm oil biodiesel is often blended with other fuels to create palm oil biodiesel blends. The organic waste matter produced when processing oil palm, including oil palm shells and oil palm fruit bunches, can also be used to produce energy. This waste material, also known as biomass, can be converted into pellets that can be used as a biofuel. Additionally, palm oil that has been

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used to fry foods can be converted into methyl esters for biodiesel. The used cooking oil is chemically treated to create a biodiesel similar to petroleum diesel. According to a 2108 report published in the Renewable and sustainable energy reviews, palm oil was determined to be a sustainable source of both food and biofuel. The production of palm oil biodiesel does not pose a threat to edible palm oil supplies. According to a 2109 study published in the Environmental science and policy journal, palm oil biodiesel might increase the demand for palm oil in the future, resulting in the expansion of palm oil production, and therefore an increased supply of food.The iodine value of palm oil is lower (44-58) when compared to other vegetable oils because of high proportion of saturated fatty acids. Palm oil is solid at ambient temperature and fluid in tropical and subtropical climates with certain fractions held in crystalline form. It is used in manufacturing plastics, fibers and soaps. It is available in Asia, Africa, Indonesia, Nigeria and Malaysia.

Palm oil with an estimated global (annual) production of 25-27 million tons is the second most produced oil in the world. By country, the leading producers of palm are Malaysia (13 million tons) and Indonesia (10 million tons), and together they have provided about 80% to 90% of the world's palm oil. Also among the various vegetable oils palm oil is the most available one.

In our present study palm oil is transesterified and the obtained biodiesel, palm oil methyl ester is used as alternate fuel for diesel engine. The properties of diesel and palm stearin methyl ester are given in following table1.

Property	**Palm Stearin Methyl Ester (PSME)**	**Diesel**	**Animal Tallow Methyl Ester (ATME)**
Density (gm/cc) at 30ºC	0.877	0.830	0.873
Viscosity (cst)	5.495	5.0	4.9
Flash Point (ºC)	230	57	175
Fire Point (ºC)	280	65	230
Calorific Value (kj/kg)	39097	42100	40930
Cetane Number	42	50	58

Table1. Comparison of properties of Palm Stearin Methyl Ester, diesel and Animal Tallow Methyl Ester.

3. VARIATION OF INJECTION PRESSURE

The fuel injection system in a direct injection diesel engine is to achieve a high degree of atomization in order to enable sufficient evaporation in a very short time and to achieve sufficient spray penetration in order to utilize the full air charge. The fuel injection system must be able to meter the desired amount of fuel, depending on engine speed and load and to inject that fuel at the correct time and with the desired rate. Further on, depending on the particular combustion chamber, the appropriate spray shape and structure must be produced. A supply pump draws the fuel from the fuel tank and carries it through a filter to the high-pressure injector. During this phase of the project, injection pressure is varied. The injection pressure of this high speed diesel engine is approximately 190 bars. The injection pressure of the injector can be varied by tightening or loosening the screw of the injector as shown in the figure 1. The injector pressure can be determined by a fuel injector pressure tester as shown in the figure 2 given below.

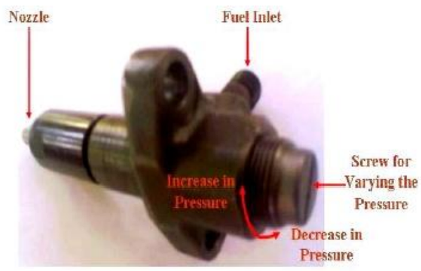

Fig.2.1. Fuel Injector

Fig.2. pressure Tester gauge

4. EXPERIMENTAL SET-UP

The Kirloskar engine is one of the widely used engines in agriculture pump sets, farm machinery and medium scale commercial purposes. The setup consists of a single cylinder, four strokes, naturally aspirated, water cooled Diesel engine connected to eddy current dynamometer. This eddy current dynamometer is used for loading the engine. The engine is interfaced with Engine Soft Software for the measurement of combustion parameters. It is provided with necessary instruments for combustion chamber pressure and crank-angle measurements. For the measurement of cylinder pressure, a pressure transducer is fitted on the engine cylinder head and a crank angle encoder is used for the measurement of crank angle and TDC position. The pressure and crank angle signals are fed to a data acquisition card fitted with Pentium 4 personal computer. The engine speed is sensed and indicated by an inductive pick up sensor in conjunction with a digital rpm indicator, which is a part of eddy current dynamometer. The liquid fuel flow rate is measured on the volumetric basis using a burette and a stopwatch. Provision is also made for interfacing airflow, temperatures and load measurement. The airflow is measured using an orifice meter and the exhaust gas temperatures are recorded with chromel- alumel thermocouples. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rota meters are provided for cooling water and calorimeter water flow measurement. A computerized Diesel injection pressure measurement can be conducted through sensor transmitters. The Instruments of the Experimental Setup are

- The engine
- Dynamometer
- Exhaust Gas Analyzer

The Engine:

The Engine chosen to carry out experimentation is a single cylinder, four stroke, vertical, water cooled, direct injection computerized Kirloskar make CI Engine. This engine can withstand higher pressures encountered and also is used extensively in agriculture and industrial sectors. Therefore this Engine is selected for carrying experiments.

Fig.3. Experimental setup of computerized CI Engine

5. ENGINE SPECIFICATIONS

Number of cylinders	01
Number of Strokes	04
Fuel	Diesel
Rated Power & Speed	5.4 KW/7.5 hp @ 1600 RPM
Cylinder bore & Stroke	89.3 & 115 mm
Compression Ratio	19.5:1
Dynamometer arm length	190 mm
Dynamometer Type	Eddy current
Type of cooling	Water cooled

Table2. Engine specifications

6.1 RESULTS AND DISCUSSIONS ON ENGINE PERFORMANCE

Graphs at Injection Pressure of 190, 210, 230 bar

Piston1-Hemispherical

Piston2-Flat

PSME- Palm Stearin Methyl Ester

ATME-Animal Tallow Methyl Ester

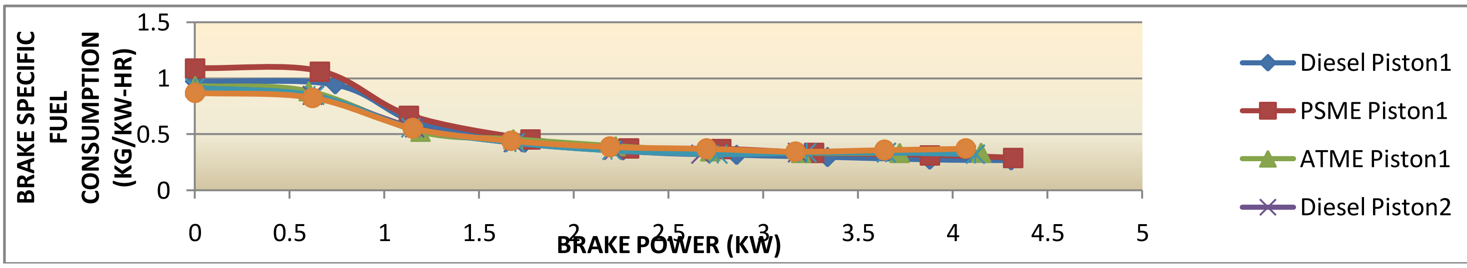

Fig 6.1 Comparison Graph for BP vs BSFC at Injection pressure of 190 bar

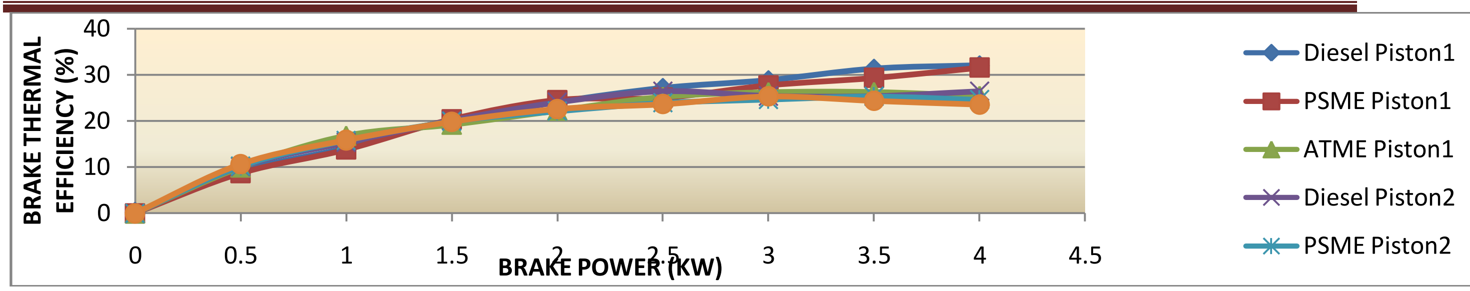

Fig 6.2 Comparison Graph for BP vs BTHE at Injection Pressure of 190 bars

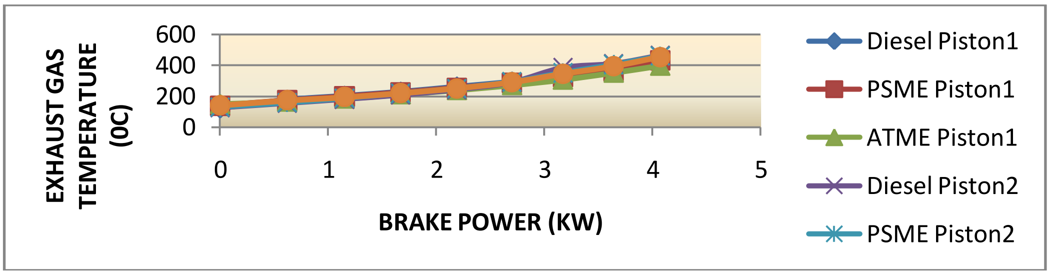

Fig 6.3 Comparison Graph for BP vs EGT at Injection Pressure of 190 Bar

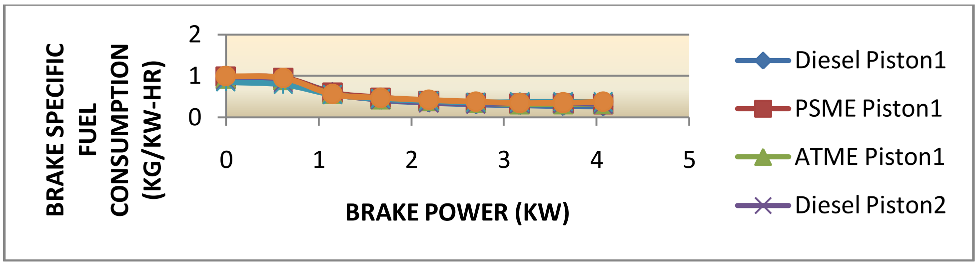

Fig 6.4 Comparison Graph for BP vs BSFC at Injection pressure of 210 bar

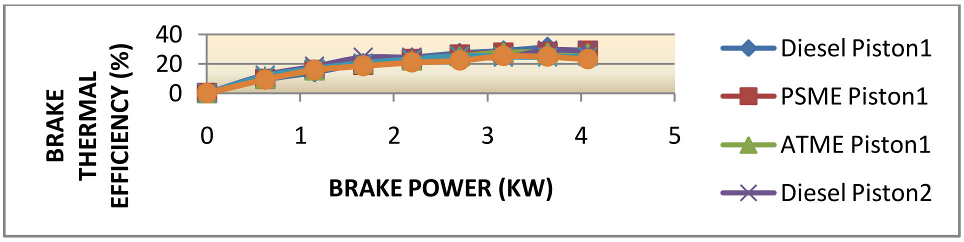

Fig 6.5 Comparison Graph for BP vs BTHE at Injection Pressure of 210 bar

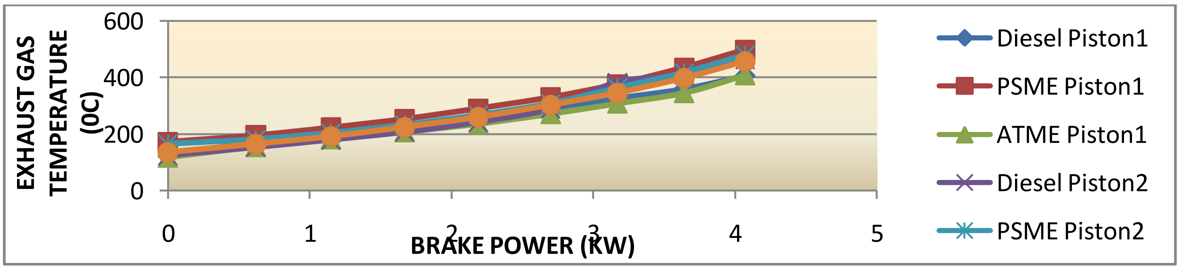

Fig 6.6 Comparison Graph for BP vs EGT at Injection Pressure of 210 bar

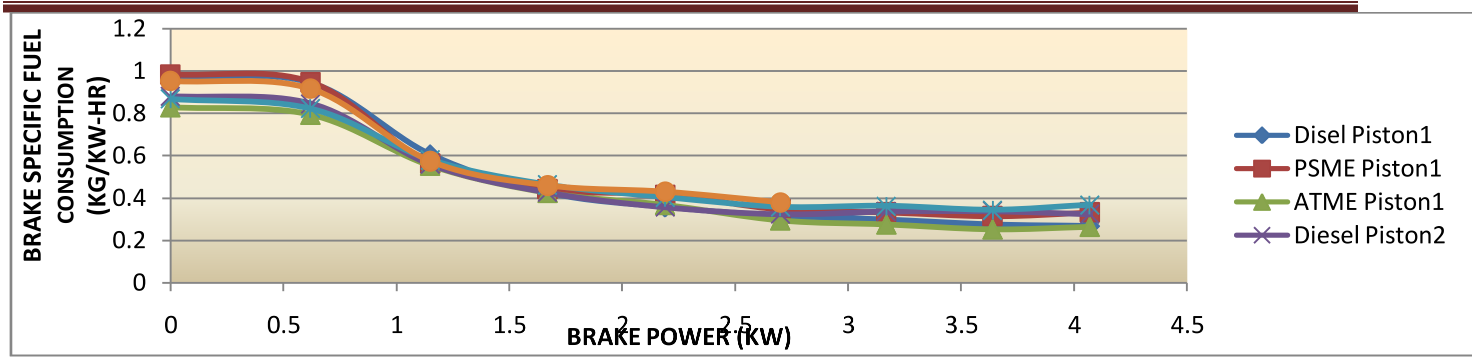

Fig 6.7 Comparison Graph for BP vs BSFC at Injection pressure of 230 Bar

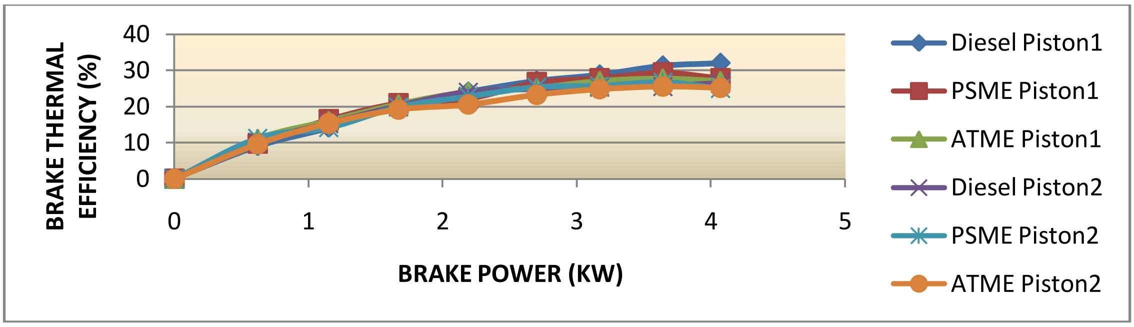

Fig 6.8 Comparison Graph for BP vs BTHE at Injection Pressure of 230 bar

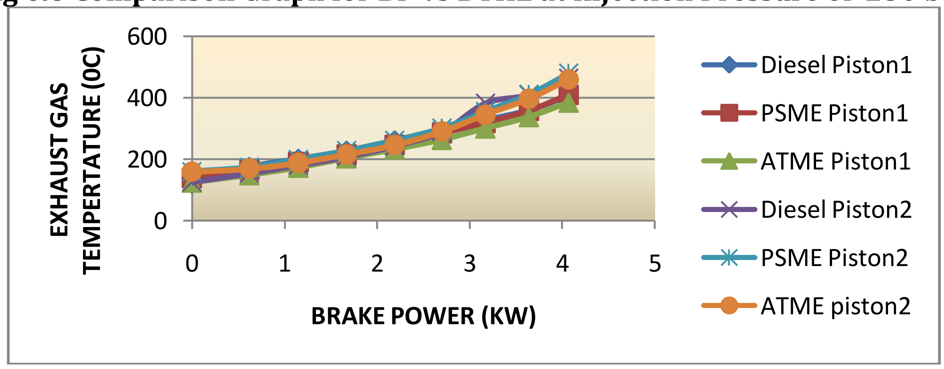

Fig 6.9 Comparison Graph for BP vs EGT at Injection Pressure of 230 Bar

The Experimental Discussions from the above graphs for Engine Performance at different injection pressures of 190, 210, 230 bars for Palm Stearin Methyl Ester (PSME), Animal Tallow Methyl Ester (ATME) and Diesel for both Hemispherical (Piston1) and Flat (Piston2) pistons are given below.

6.1.1 Brake Specific Fuel Consumption:

Figures 6.1, 6.4, 6.7 show comparison of Brake power with Brake Specific Fuel Consumption in case of Diesel with PSME and ATME for hemi spherical and flat piston at injection pressures of 190, 210, 230, . bars. From the graph it has been found that bsfc is decreasing for all pressures. For ATME Piston1 at a pressure of . bar the bsfc has lower value of 0.245 kg/kw-hr. At a pressure of . bar we have observed that the bsfc value for PSME Piston2 is slightly higher which is 0.4 kg/kw-hr comparing with diesel which is 0.267 kg/kw-hr. At rated load, bsfc for PSME Piston2 at a pressure of . bar is higher by 49.81% compared to Diesel. This observed phenomenon is due to higher viscosity of the fuel.

6.1.2 Brake Thermal Efficiency:

Figures 6.2, 6.5, 6.8 show comparison of Brake power with Brake Thermal Efficiency in case of Diesel with PSME and ATME for hemi spherical and flat pistons at injection pressures of 190, 210, 230, . bars. From the graph it has been found that Brake Thermal Efficiency is increasing for all pressures. For PSME Piston2 at a pressure of . bar the Brake Thermal Efficiency has lower value of 23%. At a pressure of . bar we have observed that the Brake Thermal Efficiency value for ATME Piston1 is slightly higher which is 35.67%

comparing with diesel which is 32.05%.This is attributed to lower calorific value, lower viscosity coupled with density of the fuel.

6.1.3 Exhaust Gas Temperature:

Figures 6.3, 6.6, 6.9 show comparison of Brake power with Exhaust Gas Temperature in case of Diesel with PSME and ATME for both hemispherical and flat pistons at injection pressures of 190, 210, 230, . bars. From the graph it has been found that Exhaust Gas Temperature is increasing for all pressures. Exhaust Gas Temperature for ATME Piston1 at a pressure of . bar has lower value. However Exhaust Gas Temperature for PSME Piston1at a pressure of 210 bar has higher value compared to diesel. So ATME Piston1at . bar pressure has higher performance compared to other fuels due to reduction in exhaust heat loss.

6.2 RESULTS AND DISCUSSIONS ON ENGINE EMISSIONS

Graphs at Injection Pressure of 190, 210, 230 bar
Piston1-Hemispherical
Piston2-Flat
PSME- Palm Stearin Methyl Ester
ATME-Animal Tallow Methyl Ester

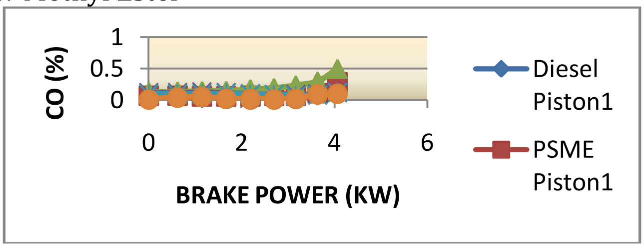

Fig 6.13 Comparison Graph for BP vs CO at Injection Pressure of 190 bar

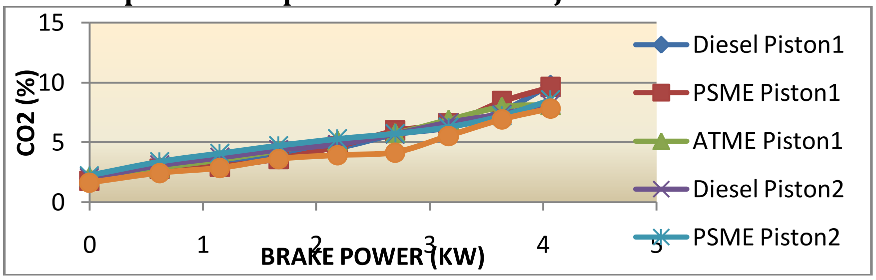

Fig 6.14 Comparison Graph for BP vs CO2 at Injection Pressure of 190 bar

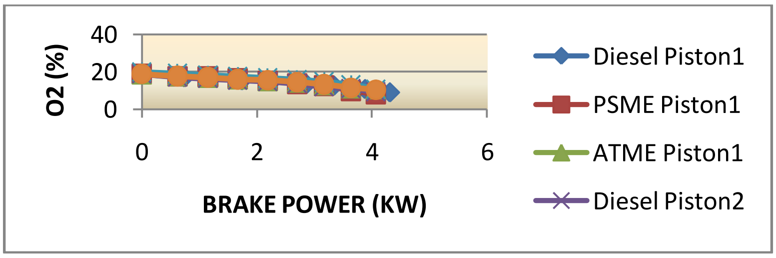

Fig 6.15 Comparison Graph for BP vs O2 at Injection Pressure of 190 bar

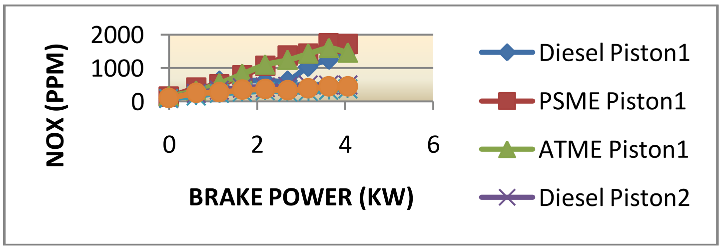

Fig 6.16 Comparison Graph for BP vs NOX at Injection Pressure of 190 bar

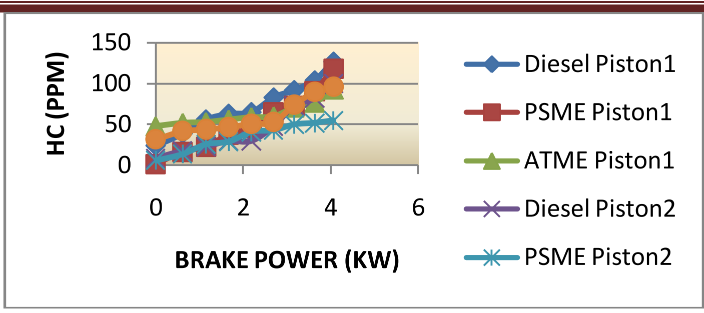

Fig 6.17 Comparison Graph for BP vs HC at Injection Pressure of 190 bar

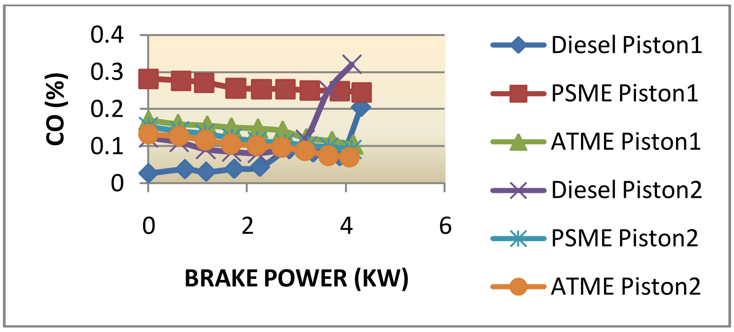

Fig 6.18 Comparison Graph for BP vs CO at Injection Pressure of 210 bar

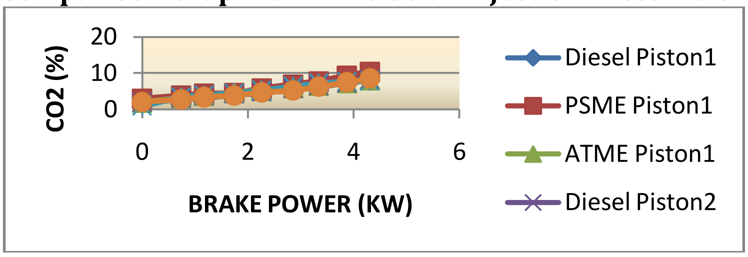

Fig 6.19 Comparison Graph for BP vs CO2 at Injection Pressure of 210 bar

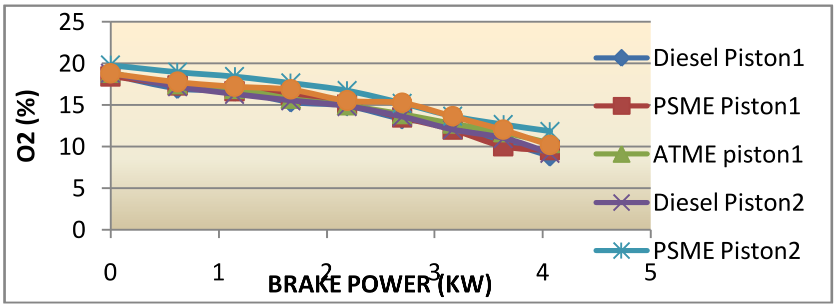

Fig 6.20 Comparison Graph for BP vs O2 at Injection Pressure of 210 bar

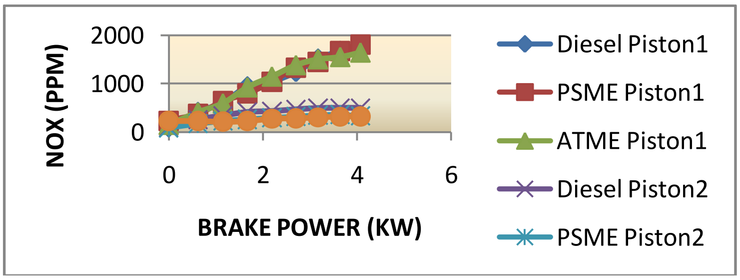

Fig 6.21 Comparison Graph for BP vs NOX at Injection Pressure of 210 bar

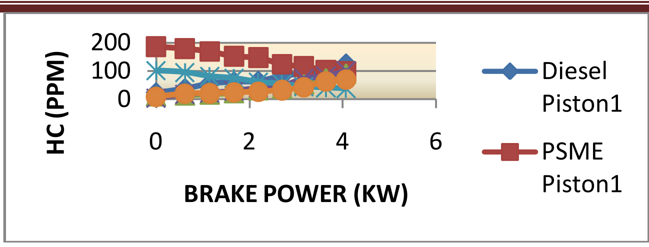

Fig 6.22 Comparison Graph for BP vs HC at Injection Pressure of 210 bar

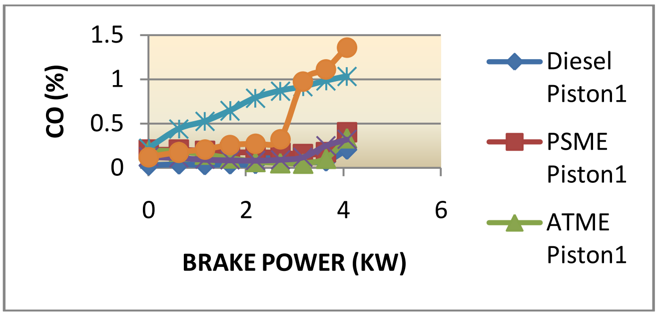

Fig 6.23 Comparison Graph for BP vs CO at Injection Pressure of 230 bar

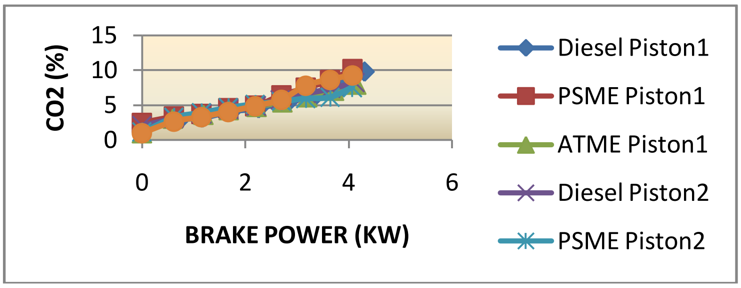

Fig 6.24 Comparison Graph for BP vs CO2 at Injection Pressure of 230 bar

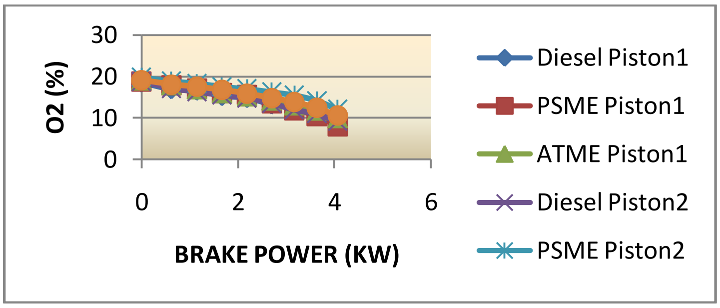

Fig 6.25 Comparison Graph for BP vs O2 at Injection Pressure of 230 Bar

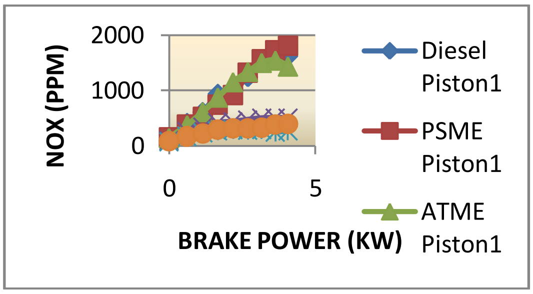

Fig 6.26 Comparison Graph for BP vs NOX at Injection Pressure of 230 bar

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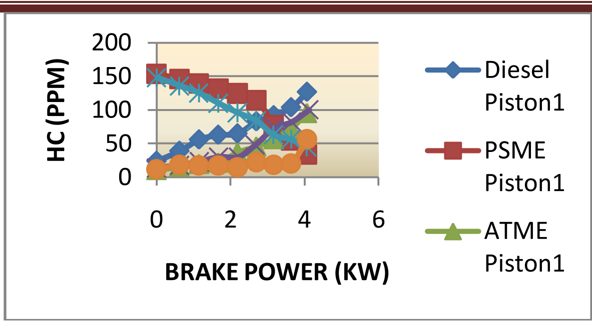

Fig 6.27 Comparison Graph for BP vs HC at Injection Pressure of 230 bar

The Experimental Discussions from the above graphs for Engine Emissions at different injection pressures of 190, 210, 230 bars for Palm Stearin Methyl Ester (PSME), Animal Tallow Methyl Ester (ATME) and Diesel for both Hemispherical (Piston1) and Flat (Piston2) pistons are given below.

6.2.1 Carbon Monoxide:

Figures 6.13, 6.18, 6.23 show comparison of Brake power with CO in case of Diesel with PSME and ATME for both hemispherical and flat pistons at injection pressures of 190, 210, 230 bars. ATME Piston2 at a pressure of 210 bar has lower CO emissions for all loads compared to other fuels at different pressures for both the pistons.CO emissions for ATME Piston2 at a pressure of 230 bar at a rated load is higher by 85.99% compared to diesel. This is due to incomplete combustion of fuel.

6.2.2 Carbon Dioxide:

Figures 6.14, 6.19, 6.24 show comparison of Brake power with CO2 in case of Diesel with PSME and ATME for both hemispherical and flat pistons at injection pressures of 190, 210, 230 bars. PSME Piston2 for 210 bar has lower CO2 emissions for all loads compared to other fuels at different pressures for both the pistons. CO2 emissions for PSME Piston1at a pressure of 230 bar at a rated load is higher by 38.21% compared to diesel. This is because of excess supply of oxygen is the influencing criterion.

6.2.3 Oxygen:

Figures 6.15, 6.20, 6.25 show comparison of Brake power with O2 in case of Diesel with PSME and ATME for both hemispherical and flat pistons at injection pressures of 190, 210, 230 bars. . From the graph it has been found that oxygen % is decreasing for all pressures. PSME Piston1 for 190 bar has lower O2 emissions for all loads compared to other fuels at different pressures for both the pistons. PSME Piston2 for . bar at a rated load is higher by 5.95% compared to diesel. The oxygen % is more in the combustion chamber for biodiesel compared to diesel, so there will be better combustion in the combustion chamber.

6.2.4 Nitrogen Oxides:

Figures 4.16, 4.21, 4.26, 4.31 show comparison of Brake power with NOX in case of Diesel with PSME and ATME for both hemispherical and flat pistons at injection pressures of 190, 210, 230, . bars. From the graph it has been found that NOX (PPM) is increasing for all pressures. From the graph it was observed that the emissions for Piston2 for all the fuels is higher compared to Piston1.PSME Piston2 for 230 bar has lower emissions which is 276 ppm compared to other fuels at different pressures for both the pistons. PSME Piston1 for 210 bar at a rated load is higher by 11.59% compared to diesel. This is attributable to higher peak combustion temperature in the combustion chamber influences this factor. Nox increases for biodiesel compared to diesel due to more oxygen in the combustion chamber.

6.2.5 Hydro Carbons:

Figures 4.17, 4.22, 4.27, 4.32 show comparison of Brake power with NOX in case of Diesel with PSME and ATME for both hemispherical and flat piston at injection pressures of 190, 210, 230, bars. At 190 bar the HC increases for Diesel, PSME, ATME for Piston1 and Piston2. Whereas HC decreases for PSME Piston1 and

PSME Piston2 at 210 and 230 pressures. At 230 bar PSME Piston1 has less emissions. PSME Piston1at 190 bar is lower by 7.67% compared to diesel. This is due to better vaporization and proper atomization.

6.3 RESULTS AND DISCUSSIONS ON COMBUSTION CHARACTERISTICS

Graphs at Injection Pressure of 190, 210, 230, bar
Piston1-Hemispherical
Piston2-Flat
PSME- Palm Stearin Methyl Ester
ATME-Animal Tallow Methyl Ester

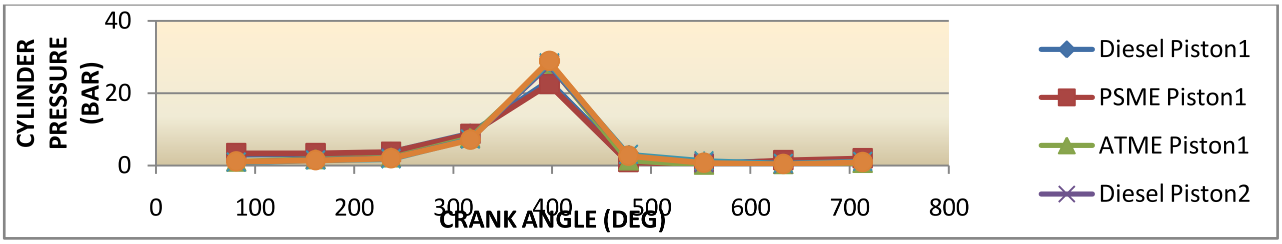

Fig 6.33 Comparison Graph for CA vs CYLINDER PRESSURE at Injection Pressure of 190 bar

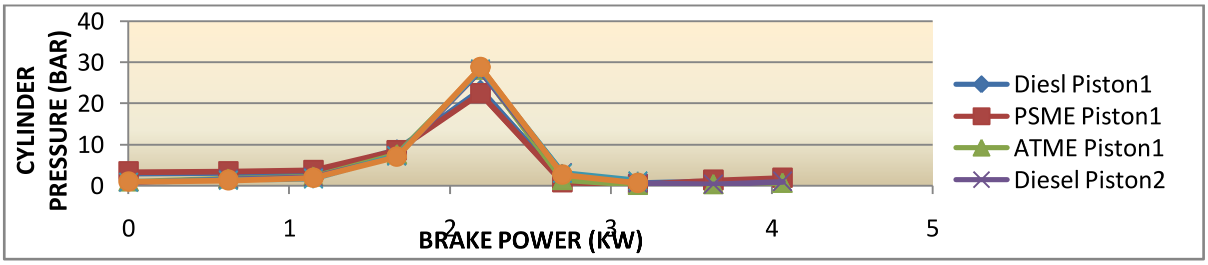

Fig 6.34 Comparison Graph for BP vs CYLINDER PRESSURE at Injection Pressure of 190 bar

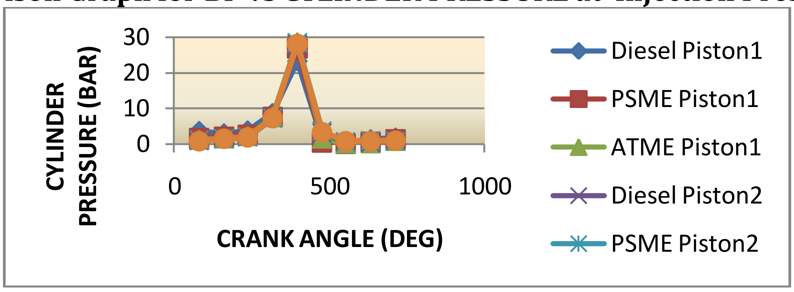

Fig 6.35 Comparison Graph for CA vs CYLINDER PRESSURE at Injection Pressure of 210 bar

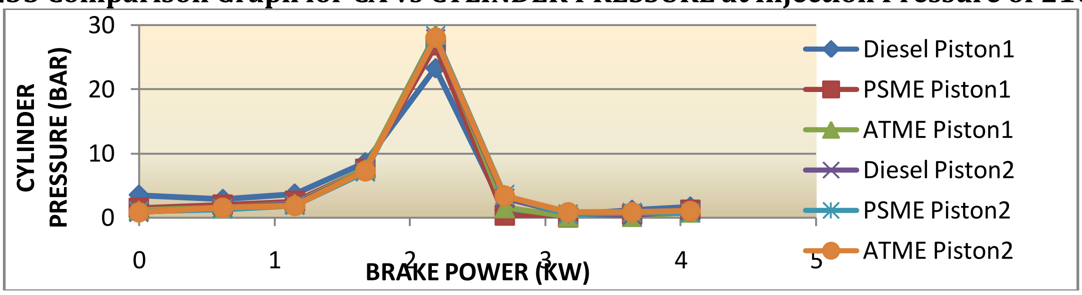

Fig 6.36 Comparison Graph for BP vs CYLINDER PRESSURE at Injection Pressure of 210 bar

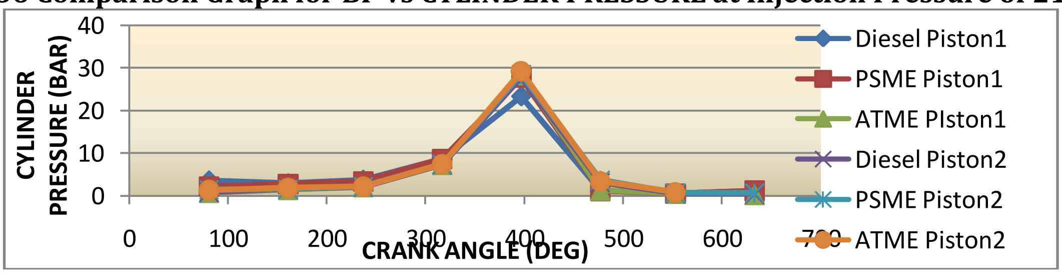

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Fig 6.37 Comparison Graph for CA vs CYLINDER PRESSURE at Injection Pressure of 230 bar

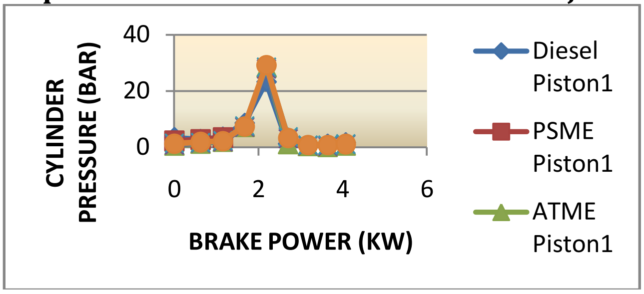

Fig 6.38 Comparison Graph for BP vs CYLINDER PRESSURE at Injection Pressure of 230 bar

The Experimental Discussions from the above graphs for Combustion Characteristics at different injection pressures of 190, 210, 230 bars for Palm Stearin Methyl Ester (PSME), Animal Tallow Methyl Ester (ATME) and Diesel for both Hemispherical (Piston1) and Flat (Piston2) pistons are given below.

6.3.1 Effect of Injection Pressure on Combustion Characteristics:

Figures 6.33, 6.35, 6.37show comparison of Crank Angle with Cylinder Pressure in case of Diesel with PSME and ATME for both hemispherical and flat pistons at injection pressures of 190, 210, 230, . bars. The maximum rise of cylinder pressure during combustion near to TDC i.e. 325º-450º crank angle. ATME Piston1 at 230 bar is having higher in-cylinder pressure compared to all other fuels at different pressures. The result shows that peak cylinder pressure of engine running with biodiesel is slightly higher than engine running with diesel. The main cause for higher peak in-cylinder pressure in the CI engine running with biodiesel is because of the advanced combustion process initiated by easy flow-ability of bio-diesel due to the physical properties of biodiesel. In addition, owing to the presence of oxygen molecule in biodiesel, the hydrocarbons achieve complete combustion resulting in higher in-cylinder pressure.

6.3.2 Variation of Cylinder Pressure with Brake Power:

Figures 6.34,6.36, 6.38 show comparison of Brake Power with Cylinder Pressure in case of Diesel with PSME and ATME for both hemispherical and flat pistons at injection pressures of 190, 210, 230, bars. Figure shows the maximum rise of cylinder pressure is at 2.26 kw for brake power. The peak pressure of ATME Piston2 at 230 bar is slightly greater than Diesel and PSME for piston1 and piston2 at different pressures and peak pressures is decreased with preheating.

CONCLUSIONS

In this work the experiments are conducted at varied injection pressures using two types of piston geometry. These experiments are conducted using Diesel, Palm Stearin Methyl Ester and Animal Tallow Methyl Ester to evaluate engine performance, emissions and combustion characteristics of CI diesel engine.

The conclusions drawn from this work are as follows:

- The Brake Specific Fuel Consumption for Palm Stearin Methyl Ester (PSME) for Hemispherical and Flat bowl Pistons at Injection pressures of 190, 210, 230 bar is higher than that of diesel. The PSME for Flat bowl piston at injection pressure of 230 bar is 49.81% higher than that of normal diesel, this is due to higher viscosity.
- The CO2 emissions for Palm Stearin Methyl Ester (PSME) for Flat bowl piston at injection pressure of 230 bar at a rated load is higher by 5.95% compared to diesel. The oxygen % is more in the combustion chamber for biodiesel compared to diesel, so there will be better combustion in the combustion chamber.
- The NOX emissions for Palm Stearin Methyl Ester (PSME) for Hemispherical bowl Piston for 210 bar at a rated load is higher by 11.59% compared to diesel. This is owing to higher peak combustion temperature in the combustion chamber influences this factor.
- The HC emissions for Palm Stearin Methyl Ester (PSME) for Hemispherical bowl Piston at 190 bar is lower by 7.67% compared to diesel.

- The in-cylinder pressure for Animal Tallow Methyl Ester (ATME) for Hemispherical bowl piston at injection pressure of 230 bar is having higher incylinder pressure compared to diesel near to TDC i.e., 325º-450º crank angle. The main cause for higher peak incylinder pressure in the CI engine running with biodiesel is attributable to the advanced combustion process initiated by easy flow-ability of bio-diesel due to the physical properties of biodiesel.

From the above results, it has been found that performance, Emissions of Palm Stearin Methyl Ester (PSME) and Animal Tallow Methyl Ester (ATME) for both Hemispherical and Flat piston at injection pressure of . bar is superior when compared with normal standard diesel. The HC and NOX emissions for PSME and ATME at injection pressure of 190 and 230 bar are superior when compared with diesel. The in-cylinder pressure for ATME for Hemispherical piston at injection pressure of 230 bar is higher compared to diesel.

The experimental results also prove that Palm Stearin Methyl Ester (PSME) and Animal Tallow Methyl Ester (ATME) at injection pressure of . bar are best alternative fuels for diesel engine.

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