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Evaluation of Performance and Emissions of A VCR DI Diesel Engine Fuelled with Preheated CsME

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Keywords : CsME, compression ratio, preheating, room temperature, variable compression ratio.

I. Introduction

The population of fossil fuel run vehicles is increasing in multifold each year leading to peak pollution levels. Mismatch between demand and supply of fossil fuels and fluctuating fuel prices and associated pollution problems making it difficult for the existence of fossil fuels in the long run. Vegetable oils are found to have its physical, thermal and chemical characteristics close to that of diesel oil. However, vegetable oils cannot be used directly because of its high viscosity. The raw vegetable oils used in engines without any modification results in poor performance and leads to wear of engine parts [Bari et al., 2002]. Vegetable oils cause formation of gummy substances at high temperatures and pressures. It is reported that these problems may cause engine failures such as piston ring sticking, injector chocking, formation of carbon deposits and deterioration of lubricating oil after the use of vegetable oil for long period of time [Avinash Kumar Agarwal, 2007]. Hence direct utilization of vegetable oils is not advisable on the diesel engine.

Methyl/Ethyl esters of vegetable oils may be obtained by pyrolosyis, transesterification, etc. Biodiesel, transesterificated vegetable oils, is promising alternate fuels for compression ignition engines. Bio-diesels are oxygenated fuels and their calorific values (8-10 kJ/kg) are comparable with petro diesels and they are localized fuels. Bio-diesels are renewable and bio-degradable. Several attempts are made to analyze the characteristics of a compression ignition engine fuelled with biodiesel derived from different vegetable oils which are grouped in edible and non-edible oils [Da Silva et al., 2003; Nwafor, 2004; Nabiet et al., 2006]. The calorific value, cetane number, heat of evaporation and stoichiometric air fuel ratio all these properties are very nearer to petroleum diesel and encourage to be adopted in diesel engines.

Hossain et al.(2010) reported that the cetane number of bio-diesels is higher than the diesel. If the vegetable oils are converted as esters of Methyl or Ethyl, they can be used in diesel engines. Nurun Nabi et al. (2010) reports the inbuilt oxygen of bio-diesel lower the adiabatic flame temperature, as a result NOx emission decrease linearly. Smoke opacity is a direct measure of smoke and soot. Agarwal et al. 2001 concluded that smoke opacity for bio-diesel is less than diesel. Qi et al. (2009) reported that the fuel properties of biodiesel are slightly different from those of diesel. The viscosity of biodiesel is evidently higher than that of diesel, especially at low temperatures. The specific gravity of the biodiesel is approximately 6.1% higher than that of diesel.

Arul Mozhi Selvan et al.(2009) reported that at higher compression ratios, the diesel-biodiesel ethanol blends have faster premixed combustion which leads to higher peak cylinder gas pressure. It is observed that the peak pressure increases with the increase in the brake mean effective pressure and compression ratio. It is observed that the peak heat release rate increases

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decreases with increase in the compression ratio and higher load conditions. The total combustion duration decreases with increase in the compression ratio.

In the present work, biodiesel (cotton seed methyl ester) is preheated to 52^{0}C temperature where the viscosity is equal to viscosity of diesel at room temperature. Along with this preheating, compression ratio is also varied. The collective effect of preheating of fuel and different compression ratios for the engine is studied and analyzed. On increasing of C.R, the intake air is compressed to higher pressure and all the air particles are much close to each other. When the fuel is injected into that air, the rate of reaction in between air and fuel particles will improve. Increase in the temperature of fuel, will lead to better atomization and reduction in particulate size. Combination of increasing of C.R of engine and temperature of the fuel will cause reduction of droplet size, quick evaporation and homogenization and as a result, efficient combustion will be there.

II. Experimental Set Up and Experimentation

The experimental setup consists of a single cylinder, four stroke, and naturally aspirated DI diesel engine with an arrangement to change the compression ratio. Optical pressure sensor is attached nearby the fuel injector in cylinder head to read the pressure signature. An auxiliary camshaft is provided to the engine to operate the valve mechanism. When the C.R is changed, cylinder head is displaced along with the valve operating mechanism. Crank angle encoder is connected to the auxiliary camshaft. A graph is plotted between the pressure signature and crank angle (P-θ diagrams) using "VCMRFE 5.73 combustion" software. The specifications of the test engine are given in Table 1. The test bed contains instruments for measuring various parameters such as engine torque, fuel consumption, air flow rate, fuel inlet temperature, combustion parameters (combustion pressure, heat release rate and exhaust emissions).

Experiments are performed with diesel at room temperature and CsME at 52^{0}C preheated temperature. Preheating of CsME is done by using three electric heaters which are directly fixed over the fuel flow line. The fuel temperature sensor has direct contact with the fuel which is being injected, which helps in the recording of exact temperature of the fuel entering into the combustion chamber. An electrical eddy current dynamometer is employed for measuring the engine torque. The fuel consumption is measured using a burette and stop watch. A damping tank and an orifice plate along with manometer are used to measure the air flow rate. To get P-θ and HRR graphs, a pressure sensor is fixed over the cylinder head and crank angle encoder is fixed at the camshaft. The exhaust gas temperature is measured with thermo couple and each reading is taken after the stabilization of exhaust gas temperature which indicates the stable running of the engine at a particular load. To measure the exhaust gas emissions crypton-290 five gas analyzer is used which is approved by ARAI. The engine runs at 1500rpm and readings are taken from no load to full load at different compression ratios such as 16.5:1, 17.5:1, 18.5:1, and 19:1 at preheated CsME. Experimental setup is shown in figure 1. The experiments are carried at no load to full load to evaluate the performance and combustion parameters of the engine.

Table 1 : Specifications of the VCR DI- Diesel Engine

Rated Horse power:	5 hp (3.73 kW)
Rated Speed:	1500rpm
No of Strokes:	4
Mode of Injection and injection pressure	Direct Injection, 200 kg/cm^2
No of Cylinders:	1
Stroke	110 mm
Bore	80 mm
Compression ratio	15:1 to 20:1
Method Of Loading	Eddy Current Dynamometer

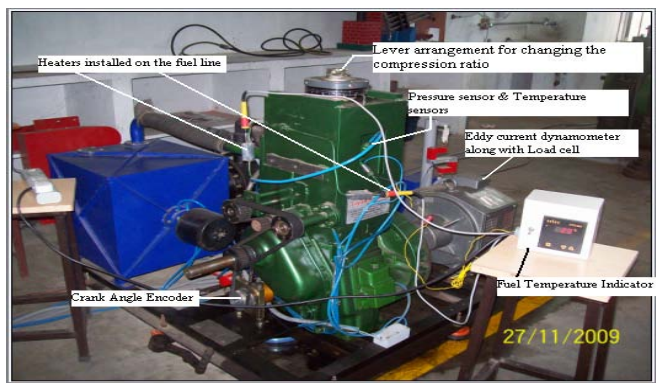

Fig. 1 : Engine setup for the experimentation

III. Results & Discussions

Experimental investigations are carried out on a Single-cylinder water cooled DI diesel engine adopting Cotton Seed Methyl Ester (CsME), with preheating at different compression ratios such as 16.5:1, 17.5:1, 18.5:1 and 19:1; to evaluate the performance of the engine. The preheating temperature is 52^{0}C. The graphs are plotted for each case to finally optimize the parameters with better performance, combustion and emissions of the engine. Tests conducted with diesel at room temperature and with standard compression ratio 16.5:1 are chosen as baseline characteristic. The results are analyzed at room temperature with diesel and preheated CsME at different compression ratios. The comparison of physical properties of CsME and Diesel oil are shown in Table 2.

Table 2 : Properties of CsME and Diesel oil.

Property	Diesel	CsME	ASTM
Chemical Formula	$C_{14.09}H_{24.78}$	$C_{54}H_{101}O_6$	
Density at 33°C Kg/m^3	830	866	D1298
Gross Calorific Value, KJ/Kg	43000	38,100	D240
Viscosity at 33 °C, cSt	3.28	6.16	D445
Cetane Number	45	53-55	D613
Flash Point, °C	50	200	D93
Acid Number, mg KOH/gm	0.2 Max	< 0.2	D664

a) Performance Analysis

Even though the Compression Ratio is one of the parameters to influence the performance as well as combustion and emissions, the viscosity of fuel is another parameter which governs the atomization, homogenization and vaporization and spray characteristics of the fuel. Further set of the experiments are conducted without changing the injection pressure of fuel. The viscosity of presently chosen vegetable oil even after converting into methyl ester i.e. the viscosity of CsME is more than that of petro-diesel, which is shown in Table 2. Generally for liquids, the viscosity decreases with increase in temperature. It is found that even after converting the cotton seed oil into their corresponding methyl esters, the viscosity could not be brought down to the level of petro-diesel fuel. Moreover, in order to utilize vegetable oils effectively, it is felt to preheat the CsME before it is supplied to the engine for combustion. Thus, with preheating, the viscosity of CsME will decrease and improves atomization and vaporization during the combustion.

The variation in viscosity of CsME with temperature and viscosity of petro diesel at room temperature are compared which is found to be equal (Fig. 2). At this temperature different compression ratio such as 16.5:1, 17.5:1, 18.5:1 and19:1 is considered and performance, combustion and exhaust gas analysis are carried out.

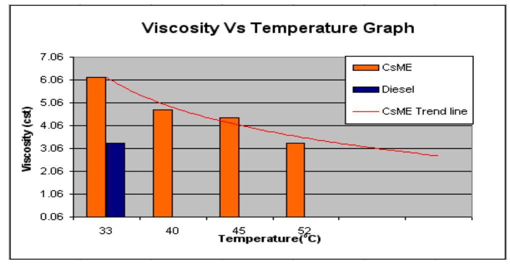

Fig. 2 : Comparison viscosities of Diesel and CsME at different temperatures

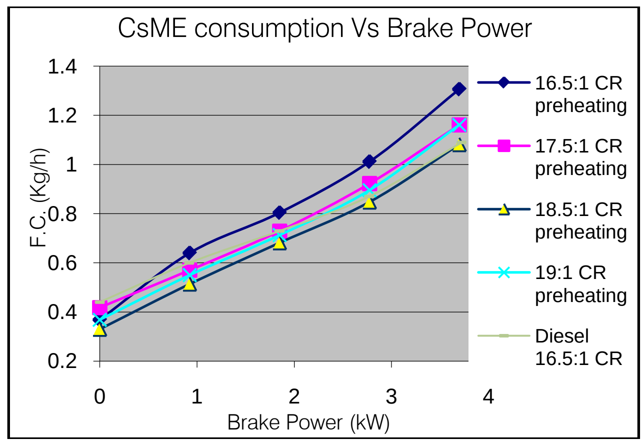

Fig. 3 : Fuel consumption Vs Brake Power at different compression ratios

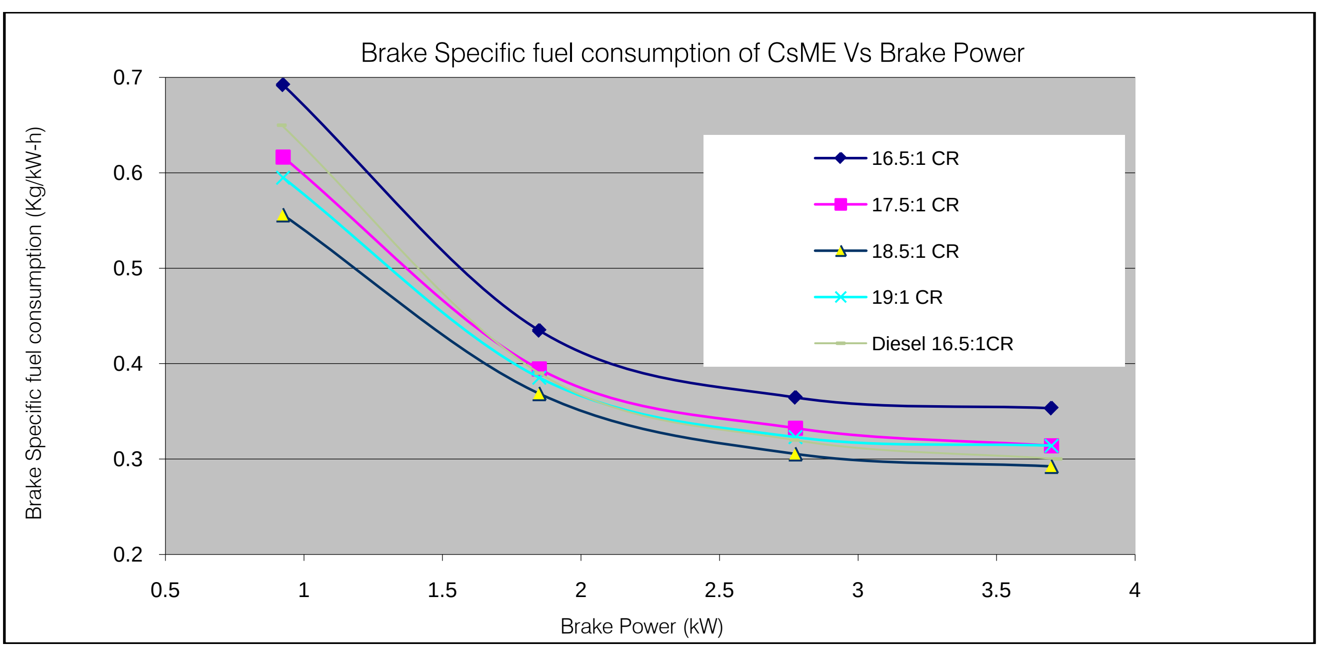

Fig. 4 : Brake Specific Fuel consumption Vs Brake Power at different compression ratios

From Fig.3 & Fig. 4, it is observed that on preheating, the gradual decrement of fuel consumption is obtained from 16.5:1 C.R to 18.5:1 C.R. The following table shows the fuel consumption per hour at Room Temperature (RT) and 52°C with CsME application.

Table 3 : CsME Consumption at Full load operation

	16.5:1 CR (CsME) at 52°C	16.5:1 CR (Diesel) at RT	17.5:1 CR (CsME) at 52°C	18.5:1 CR (CsME) at 52°C	19:1CR (CsME) at 52°C
With prehe-ating	1.31 kg/hr	1.093 kg/hr	1.16 kg/hr	1.08 kg/hr	1.16 kg/hr

The consumption of diesel at room temperature with 16.5:1 C.R is 1.09285 kg/hr (Table 3), and the consumption of CsME at 18.5:1 C.R with 52°C preheated temperature is 1.08 kg/hr (Table 3). This value is almost equal to the consumption of petro diesel even though calorific value of CsME is less than diesel. Preheating and increasing of compression ratio are the reasons for better combustion, resulting in lower consumption of CsME. On increasing of C.R, the intake air is compressed to higher pressure and all the air particles are much closer to each other. When the fuel is injected into the air, the rate of reaction in between air and fuel particles have improved. Combination of increasing in C.R of engine and inlet temperature of the fuel will further enhance evaporation and homogenization, and as a result efficient combustion is obtained. On preheating of CsME, the inbuilt oxygen release rate will improve; but on increasing of compression ratio the availability oxygen from air will decrease. These two parameters are balanced at 18.5:1 C.R and gives better results. On further increasing of compression ratio to 19:1 with preheating, it creates fluctuations in the flow of air and leads to unavailability of sufficient oxygen for combustion. This has resulted in increased fuel consumption at 19:1 C.R and reaches value of 1.16 kg/hr. Similar reflections are observed from the brake thermal efficiency versus brake power (Fig.5). Since the specific fuel consumption is inversely proportional to the thermal efficiency, the behaviour is proved in the present set of experiments. It indicates on preheating most of the thermal energy is converted into mechanical work. In this set of experiments C.R. of 18.5:1 yielded superior performance compared to other C.Rs. At full load, with preheating the brake thermal efficiency is 32.32 % at 18.5:1 C.R. On preheating of CsME at 16.5:1 C.R, the brake thermal efficiency is 26.74% which is 5.58% less than 18.5:1 C.R. At room temperature with 16.5:1 C.R for diesel operation, the brake thermal efficiency is 28.33% which is 4% less than CsME operation at 18.5:1CR. Comparison of brake thermal efficiencies is shown in Table 4.

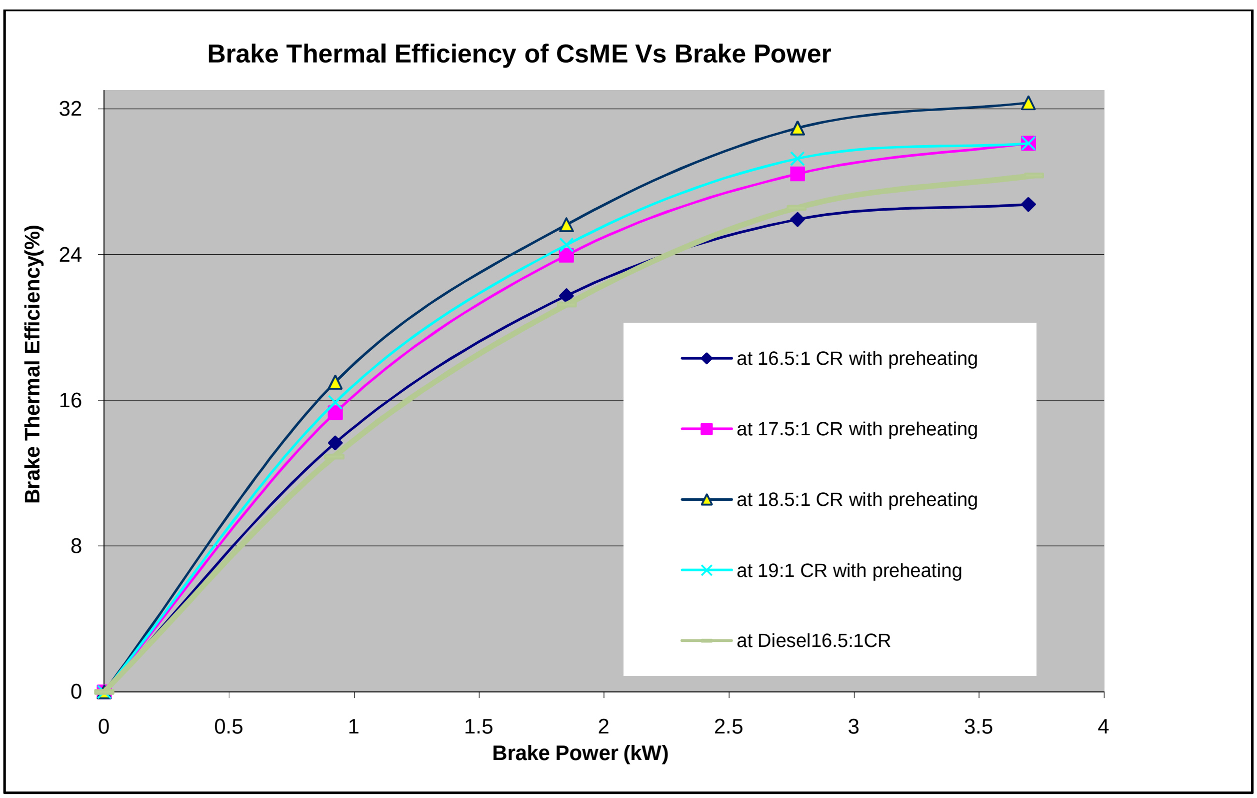

Fig. 5 : Brake Thermal Efficiency Vs Brake Power at different compression ratios

Table 4 : Comparison of brake thermal efficiencies at full load

Brake thermal efficiency (Diesel operation 16.5:1C.R) at RT	Brake thermal efficiency of CsME operation at 52^{0}C	
	16.5:1 C.R	18.5:1 C.R
28.33%	26.74%	32.32%

b) Emission analyses

As discussed above on the effect of preheating which improved the combustion leading to lower specific fuel consumption and better performance. This is further with the reduction in gaseous pollutants. On preheating, the levels of CO and HC in the exhaust gas are decreased significantly with the improved combustion.

From Fig. 6 at higher compression ratios after preheating, CO emission is minimum at 18.5:1 C.R. The amount of reduction in CO emission with CsME at 18.5:1 CR is 0.47% compared with CsME at 16.5:1 CR. The amount of CO emitted with CsME at 18.5:1 CR is marginally higher than diesel at standard compression ratio.

The variation of CO_2 on preheating at different compression ratios is not significant. The average variation at different compression ratios with respect to the load is 0.734%. It indicates that the formation of CO_2 during combustion at different compression ratios is almost equal; it is low at 18.5:1 CR shown in Fig.7.

The presence of HC in the exhaust gas is another parameter which reflects the incomplete combustion. The unburnt HC (Fig.8) in the exhaust gas is lower at higher compression ratios. It is lower at 17.5:1 & 18.5:1 C.R. At 19:1 C.R due to rich fuel combustion the presence of HC is slightly increased.

The increment of compression ratio will lead to the decrease of availability of oxygen from the free air; but due to preheating the release of molecular oxygen will improve. Compensation of decrement of oxygen availability from the free air with molecular oxygen causes the decrease of CO & HC. As a result, there is no much variation in free oxygen in the exhaust at preheating condition. The percentage of free oxygen is slightly higher at 18.5:1 C.R which supports the above statement (Fig.9).

On preheating at 16.5:1 C.R the exhaust gas temperature is higher (Fig.10). The delay period of CsME at 16.5:1 C.R is higher. The accumulation of fuel in the delay period is caused for higher temperatures. On increasing of compression ratio along with preheating, the delay period decreases and the peak temperature obtained are less. On preheating the exhaust gas temperature is lower at 18.5:1 C.R. At 19:1 C.R, the temperature is 609^{0}C which may be due to rich fuel combustion or after combustion.

From Fig.11 the NOx at 16.5:1 C.R of preheated CsME is 1465ppm. On preheating, release of molecular oxygen will be improved. At 18.5:1 C.R with preheating the value of NO_x is 1405 ppm. On preheating, the rate of combustion has increased. As a result, the oxygen will rapidly react with HC and later on will react with nitrogen. Even though the value of NO_x with preheating is higher, it is less than the diesel operation at room temperature. Comparison of NO_x is shown in Table 5.

Table 5 : Comparison of NO_x at full load

NO_x(Diesel operation 16.5:1CR)at RT	NO_x CsME operation at 52^{0}C	
	16.5:1 CR	18.5:1 CR
1570 ppm	1465ppm	1405 ppm

On preheating at 18.5:1 compression ratio, the smoke values are less at all other compression ratios including diesel at 16.5:1 CR is shown in figure 12. From the exhaust gas analysis of preheated CsME, 18.5:1 CR gives better results in the environmental aspect.

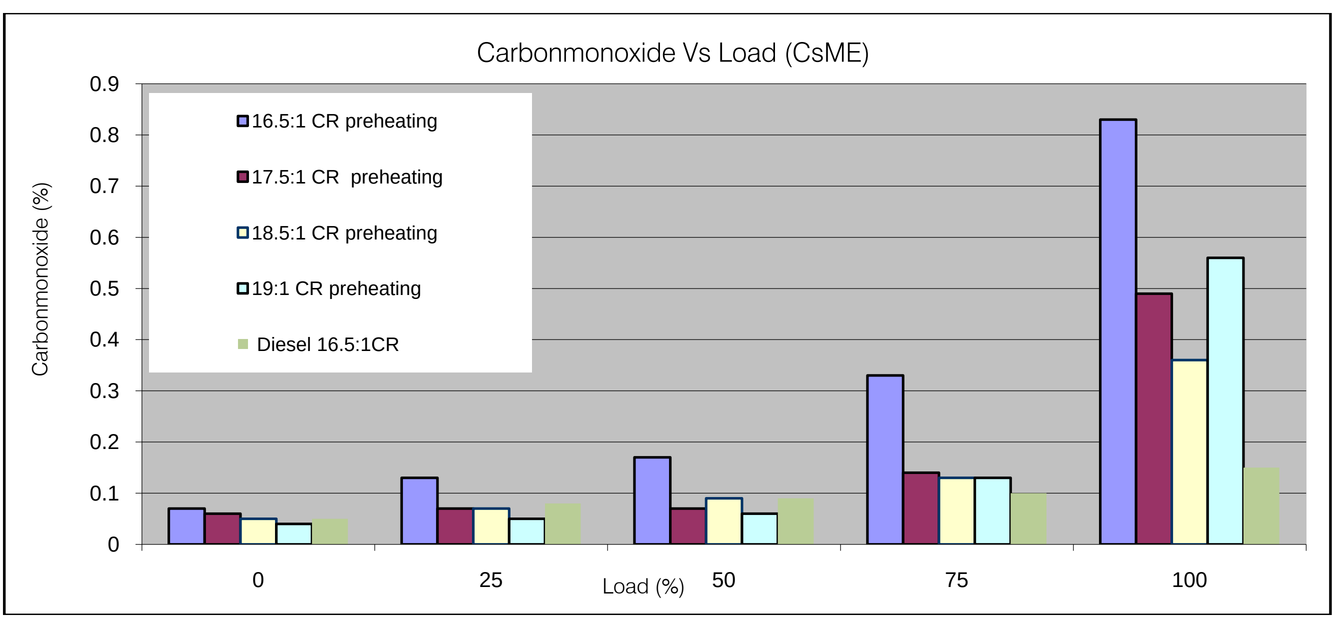

Fig. 6 : Carbon monoxide Vs Load at different compression ratios

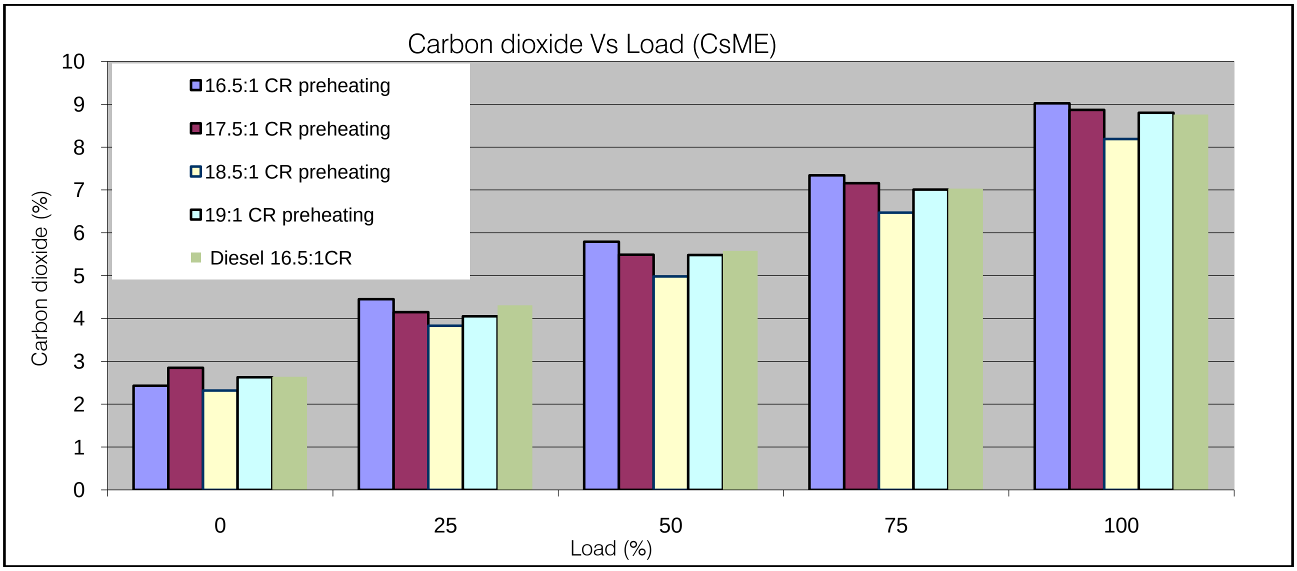

Fig. 7 : Carbon dioxide Vs Load at different compression ratios

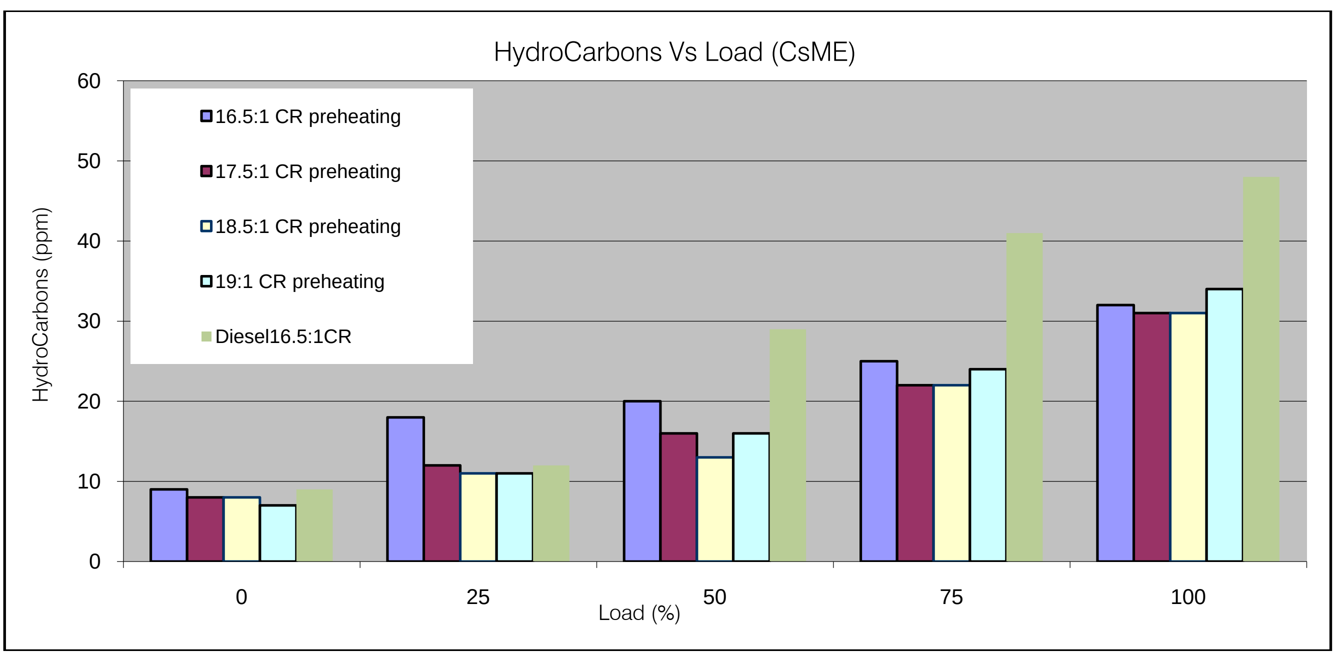

Fig. 8 : Hydrocarbons Vs Load at different compression ratios

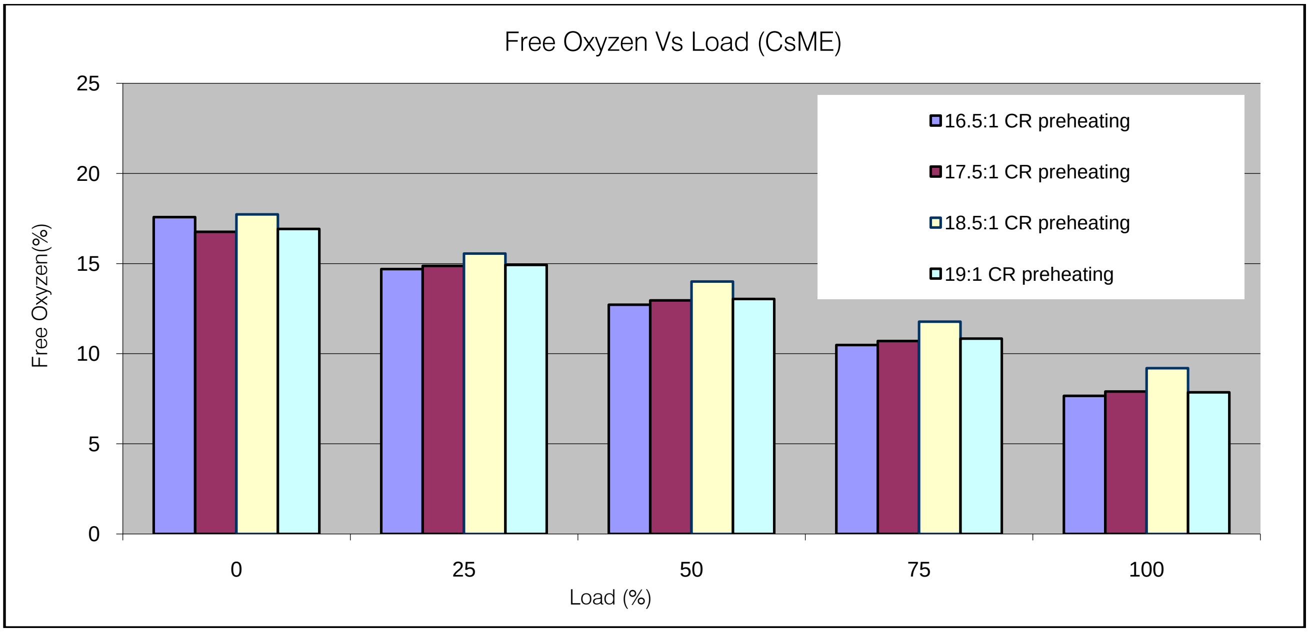

Fig. 9 : Free Oxyzen Vs Load at different compression ratios

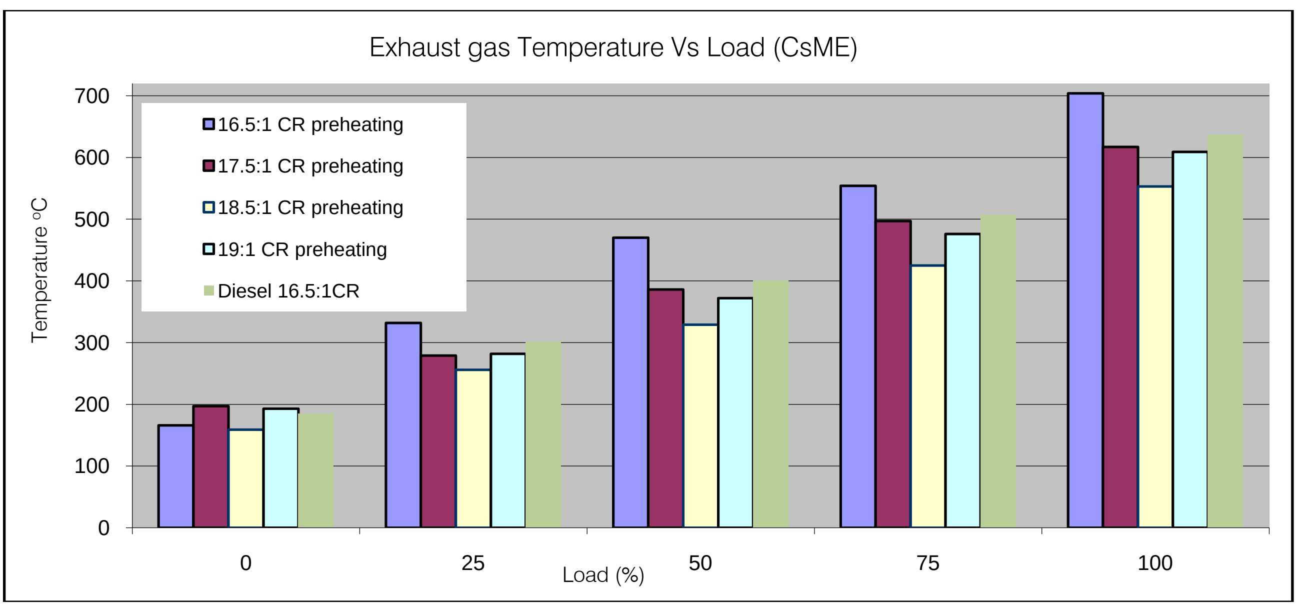

Fig. 10 : Exhaust Gas Temperature Vs Load at different compression ratios

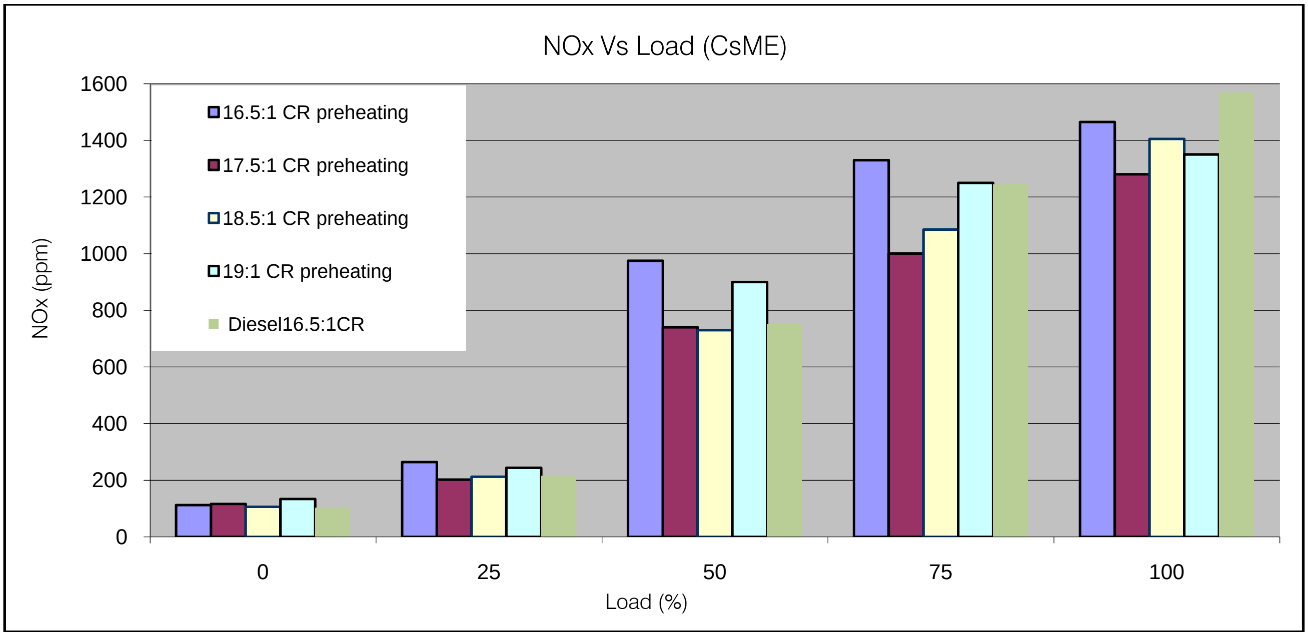

Fig. 11 : NO_x Vs Load at different compression ratios

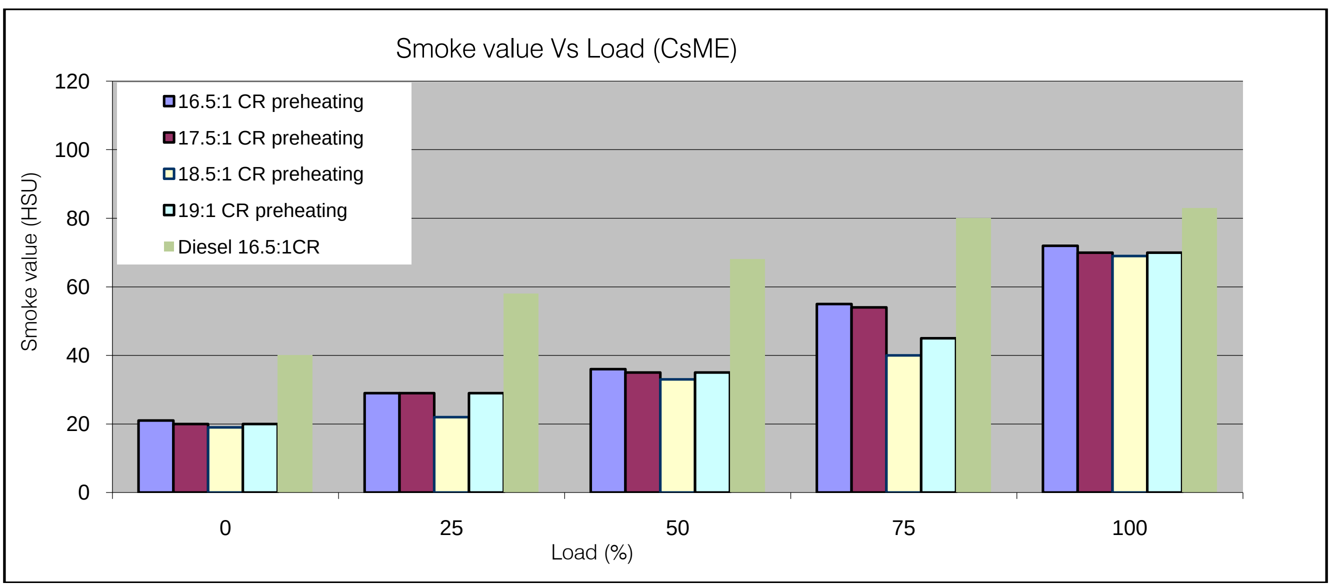

Fig. 12 : Smoke value Vs Load at different compression ratios

IV. Conclusions

The performance characteristic, combustion parameters and emissions in the exhaust are analyzed and compared with conventional fuel. The results are elaborately discussed based on the experimental investigations carried out with the use of cottonseed methyl esters with preheated in variable compression ratio engine. The following conclusions are arrived.

1. With increase in the compression ratio, the temperature and pressure of air which is participating in combustion will be more than normal operating conditions. It influences the physical delay period of combustion of the fuel i.e., the physical delay period is decreased on increasing of compression ratio.
2. For CsME, application at C.R 18.5:1 gives good results. The consumption of diesel at room temperature with C.R 16.5:1 is 1.09285 kg/hr, and the consumption of CsME at C.R 18.5:1 with 52^{0}C preheated temperature is 1.08 kg/hr. This value is almost equal to consumption of petro-diesel even though calorific value of CsME is less than diesel fuel. Preheating and increasing of compression ratio are the reasons for better combustion, and the engine operation under such conditions can be treated as economical.

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3. With preheated CsME operation at full load, the brake thermal efficiency is 32.32 % at C.R 18.5:1 .On diesel operation at 16.5:1 C.R, the brake thermal efficiency is 28.33% which is 3.99% less than 18.5:1 C.R.
4. With preheating, the CO and HC in the exhaust gas are decreased and it indicates better combustion.
5. The value of NO_x with preheating is higher, but it is less than the diesel operation at room temperature. The value of NO_x with diesel operation at room temperature is 1570 PPM and it is 10.5% higher than CsME and C.R 18.5:1 at 52^0C.
6. Brake specific fuel consumption is also low. Thus the engine operation at C.R 18.5:1 with CsME at 52^0C preheating is superior to diesel fuel operation and is preferable for the CsME to adopt in the existing diesel engine.

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