Performance evaluation of PPCI engine using Ethanol as fuel with precharged heating

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***Abstract*- With tremendous increase in population the use of fossil fuels has been increased a lot in last few years. As the number of vehicles is increasing day by day not only depletes their reserve but also leads to emission of harmful pollutants. So it is inevitable to find out some new technology which will increase the efficiency of combustion with less emission of harmful pollutants. Partially premixed compression ignition is the promising technology which uses ethanol as fuel that is giving advantages of both SI and CI engine. This paper investigates the effect of variation in premixed fraction on engine performance parameters like maximum pressure, heat release rate, combustion parameter like exhaust gas temperature and emission of CO2. In this paper, effect of preheating of air on engine performance, combustion and emission is studied and it is found out that maximum pressure and heat release rate is improved.**

***Keywords*: PPCI engine, Heat release rate, premixed fraction, HCCI engine.**

I. Introduction

Today most of automotive industries manufacture petrol and diesel engines. Petrol and diesel engine have different values of thermal efficiency, fuel economy and emissions. As the number of vehicles increases, industry has to apply new technologies which can reduce emissions with a better fuel economy. In SI engine, atmospheric air is mixed thoroughly with fuel which reduces the soot formation. But these engines have limitations of lesser compression ratio to avoid knocking. In a CI engine has no throttling losses. Hence, efficiency and fuel economy are better in case of efficiency. But, CI engines have problems of CO and soot emissions. Therefore it is essential to develop efficient combustion system which will reduce emissions. The pollutants which are responsible for pollution are NOx, unburnt HC, CO etc. CO2 is not considered as a pollutant, but it is also responsible for the global warming.

At present, the main pollutants from IC engines are the NOx, unburned hydrocarbon (HC), carbon mono oxide (CO) and soot. These pollutants are responsible for the local as well as global atmospheric pollution. Therefore, there are laws on emission standards, which limit the amount of each pollutant in the exhaust gas emitted by an automobile engine. CO2 is not considered as a pollutant, but it is also responsible for the global warming. It can be reduced only by reducing fuel consumption which can be obtained only by improving engine efficiency.

Alcohol is obtained from both natural and manufactured sources. That's why alcohols are an attractive alternative fuel. Naturally, it obtained by fermentation process of glucose and manufactured industrially, by hydration reaction. The two most promising form of alcohols are ethanol and methanol.

Ethanol is used as fuel from last many years at different countries. Ethanol is a renewable fuel receiving more attention by many researchers. It has been used for a long time in many countries in the world.

In HCCI engine, fuel and air are mixed before entering the cylinder. This homogneous mixture is compressd to high pressure so that autoignition takes place. Thus it gives advantages of both SI and CI engine. This engine reduces soot emission like gasoline engine whereas improves efficiency like CI engine. It has two major drawbacks of combustion control and knocking. This is avoided by using PPCI engine in which some part of fuel is supplied by port injection and remaining by direct injection.

Objective of the Present Research Work

In present research work, diesel engine is converted in PPCI engine. Ethanol is used as fuel which supplied by port injection where diesel is supplied by direct injection. By varying the supply of ethanol, its effect on performance parameter is studied and compared with values obtained by heating charge before combustion.

II. EXPERIMENTAL DETAILS

A. Experimental procedure [12]

Ethanol was injected in the intake manifold using port fuel injector. Along with intake air ethanol entered to the combustion chamber during the suction stroke. In the compression stroke, ethanol and air mixed homogeneously and got compressed. At the end of compression stroke diesel was injected conventionally. Ethanol is having low calorific value, as compared to diesel hence, diesel was used as compensation. In the present investigation, flow rates 0.21, 0.37, 0.51, 0.58 and 0.79 kg/hr of ethanol injected by port fuel injection. The combustion, performance and emission characteristics were evaluated for all loads with different premixed fraction.

B. Premixed fraction

The premixed fractions defined as the ratio of energy contribution of premixed fuel to whole energy contribution. That is

$$\frac{Primixed\ fuel\ energy}{Primixed\ fuel\ energy + Direct\ injected\ fuel\ energy}$$

whereas,

Premixed fuel energy = (mass flow of premixed fuel)* (calorific value of premixed fuel)

Direct injected fuel energy = (mass flow of direct

injected fuel)* (calorific value of direct injected fuel)

C. Description of the test engine [12]

This section describes the complete experimental setup such as engine, coupled with alternator, emission test bench, data acquisition system, including piezoelectric pressure transducer and crank angle encoder. Some modifications have been done to achieve homogeneous combustion. The experiments were carried out on a single cylinder, four stroke, naturally aspirated CIDI engine and the schematic layout of the experimental arrangement is depicts in Fig. 1.

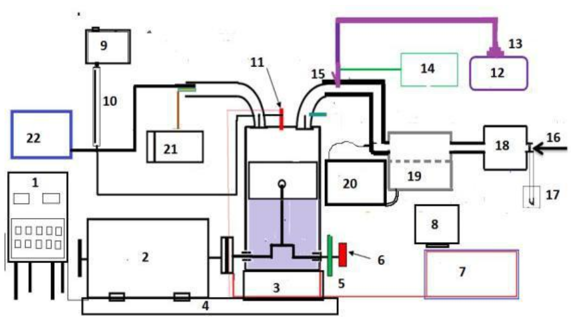

Fig. 1 Schematic layout of experimental set up

1.Load cell	9. Fuel tank	17.Orifice meter
2.Alternator	10. barrette	18.Air box
3.Engine	11.Injector	19.Heater
4.Engine bed	12.Secondary fuel tank	20.Temperature controller
5.TDC sensor	13.Fuel pump	21.Exhaust gas analyzer
6. Encoder	14.ECU	22.Smoke meter
7. DAS.	15. Port injector	
8.Computer	16. Intake air	

The cylinder pressure history, data acquisition and combustion analysis is done using a Lab view based program. All data related to pressure heat release mass fraction burnt power efficiency with respect to load and crank angle provided by this system. A fuel level indicator was used for measuring the diesel fuel consumption. An orifice-meter and a U-tube manometer were used to measure the intake air flow rate of the engine. An air box fixed into the intake manifold of the engine maintains a constant air flow and eliminates cyclic fluctuations.

A K-type thermocouple was installed to measure the exhaust gas temperature. For the analysis of emission AVD DI gas 444 exhaust gas analyser connected to the exhaust pipe. It gives all emission quantity present in gas like NO, CO, CO2, and HC. AVL 437 smoke meter is used to measure exhaust smoke.

D. Engine modification [12]

For achieving the PPCI combined combustion mode, it was required to operate the engine with some modification. In order to this, port fuel injection system and air pre-heater system were included in the intake manifold the fuel premixing system consists of

1. Fuel injector
2. Injector control circuit
3. Program for electronic circuit
4. Fuel pump and fuel tank

A fuel injector is basically an ECU controlled solenoid valve, which open and closes to allow fuel pass through it. Fuel injector releases a controlled amount of pressurized fuel into the system. The injector is fed a constant supply of power and ECU provides a negative trigger to turn it on at the required time and for required interval.

Fig 2 Fuel premixing system Fuel pump and fuel tank [1], Fuel injector [2], Injector control circuit [3], Program for electronic circuit [4]

A program is required for ECU to control the injection timing, which in turn triggers the fuel injector. At the place of ECU unit, a microcontroller was used here to control both the timing and quantity of fuel. The pulse width decides quantity of fuel injected.

An electrical fuel pump of 12 V DC supply is fitted inside fuel tank is used for boosting the premixed fuel from tank to injector. Property of this pump is to maintain a constant pressure inside fuel line if the pressure increases more than a limit pressure, secondary valve attached in pump automatic open and release the excess pressure.

Fig 3 Intake air pre-heating system

Fig. 3 shows the photograph of the intake air pre-heater system used in study. The intake air pre-heater is controlled by temperature controller with feedback control, which keeps constant air temperature in intake manifold. The heater consist heating element, which is inserted into cylindrical box of GI sheet. The heating Fuel injector element wound over the ceramic structure. One inch thick glass wool insulation done outer layer of the heater, that provides both insulation as well as cushioning.

III. RESULTS AND DISCUSSION

Module I: Air without heating is used and its effect on PPCI engine parameters were studied.

A. Combustion characteristics
Combustion characteristics with respect to a premixed fraction, is varying for low load (1.1 kw and 2.2 kW), medium load(3.3 kW) and full load (4.4 kW) operations.
1.1 Pressure crank angle diagram at full load operation

In Fig 4.1, for different premixed fractions pressure variation with crank angle is shown. The start of injection for diesel was set 23oCA before TDC, while ethanol was inducted with the air. The pressure was 70 bar for full load operation.

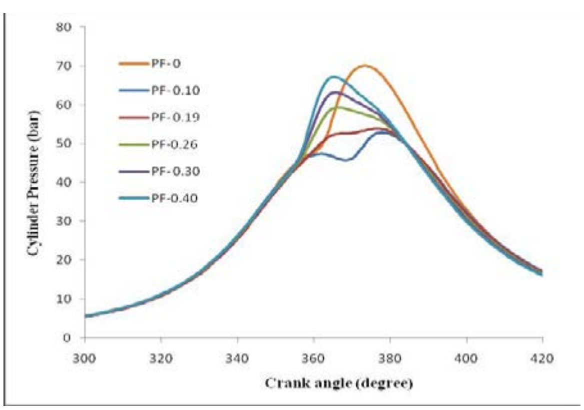

Fig 4.1 Variation of cylinder pressure with respect to crank angle

1.2 Heat release rate with crank angle diagram at full load operation

The variation of heat release rate with crank angle for different premixed fractions at full load is depicted in Fig. 4.2 The heat release from the combustion follows first law of thermodynamics for a closed system.

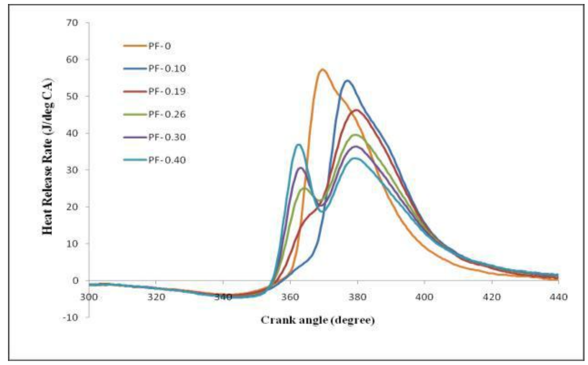

Fig. 4.2 Variation of heat release rate with crank angle at full load

The heat release rate shows the intensity of rapid combustion. Maximum heat release rate for diesel operation at full load is 57.3 J/oCA. Auto ignition of ethanol takes place before diesel ignition at full load. Combustion is divided into two phases, by increasing the premixed fraction first phase HRR increases and second phase decreases. It is due to the increase of fuel burnt in the premixed mode and reduction of fuel burnt in diesel mode. At premixed fraction 0.40, the maximum HRR is 36.89 J/deg in the first phase, while in second phase occur is 33.23 J/deg.

1.3 Pressure crank angle diagram at medium load Fig 4.3 depicts the variation of pressure with a crank angle at medium load for different premixed fractions. The combustion occurs in a single stage. A clear trend is observed from the figure that with increasing premixed fraction, start of combustion is delayed and peak pressure decreases near TDC. The maximum cylinder pressure at the medium load for the diesel operation is 68 bar and the maximum cylinder pressure for all the premixed ratios is almost same with the range of 55-56 bar.

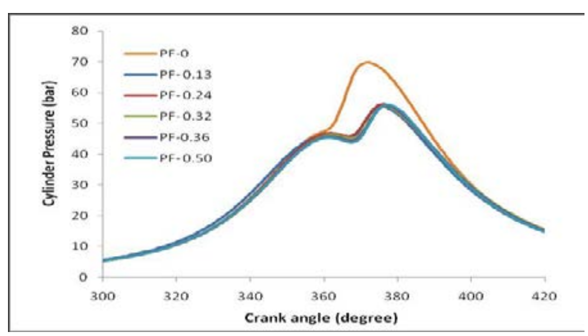

Fig 4.3 Variation of cylinder pressure with crank angle at medium load

1.4 Heat release rate with crank angle diagram at medium load

The auto ignition temperature of ethanol is high and it has not able to reach at self ignition level for medium and low loads. Because of this, ignition is started by diesel fuel. In the premixed mode, diesel burns after diffusion in the mixture of air and ethanol, not only pure air. Moreover, ignition delay increases because of lower pressure and temperature in cylinder due to vaporization cooling of ethanol. Fig. 4.4 shows clearly, as the premixed fraction increases the maximum heat release rate increases. This is due to premixing ethanol and longer ignition delay gets sufficient time to diesel for homogeneous mixing. A maximum HRR found at premixed fraction 0.50 and its value is 63.71 J/^{o}CA.

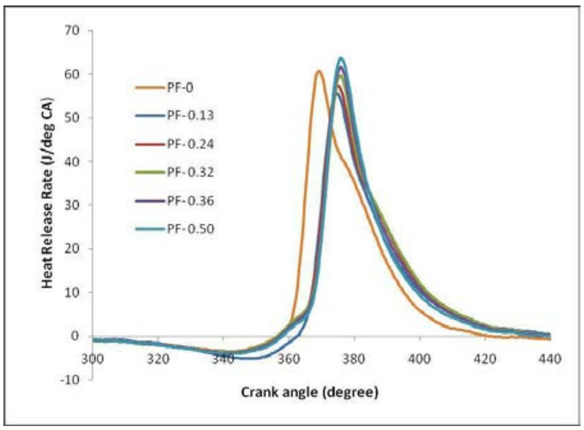

Fig. 4.4 Variation of heat release rate with crank angle at medium load

1.5 Pressure crank angle diagram at low load

Fig 4.5 shows the variation of cylinder pressure with crank angle at low load operation. The pressure curve is found to be similar trend for all the fractions except for the high premixed fractions. The maximum pressure for diesel operation at 2.2 kW load is 63 bar. At higher premixed fraction, the cylinder peak pressure decreases. At 0.55 premixed fraction, the maximum pressure decreased to be about 45 bar. It would be due to partial burning and further increased in premixed ratio misfire occur [14].

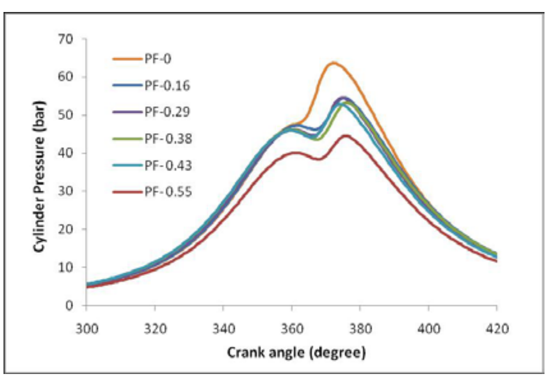

Fig 4.5.Variation of cylinder pressure with crank angle at low load

1.6 Heat release rate with crank angle diagram at low load

For low load operation, by increasing the premixed fraction heat release rate initially increases then decreases. The overall air fuel ratio leaner at low loads, because of this ethanol quenching occurs at a higher premixed fraction. The maximum heat release rate for diesel operation shown is 56.6 J/ oCA and for the premixed fraction of 0.16, 0.29, 0.38, 0.43, 0.55 is about 53.3, 53.4, 55.3, 48.4 and 42 J/ oCA respectively.

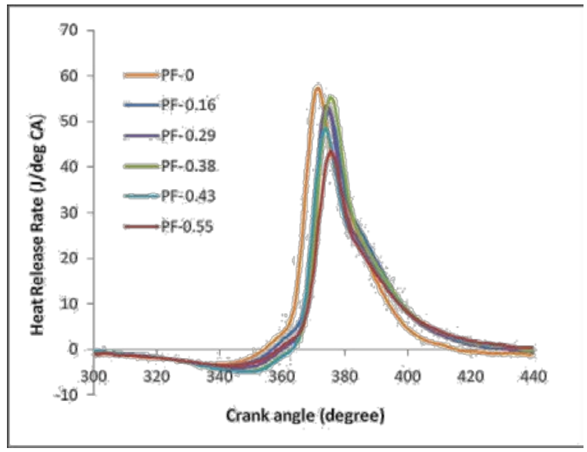

Fig. 4.6 Variation of heat release rate with crank angle at low load.

B. Performance characteristics

2.1 Exhaust gas temperature

The exhaust gas temperature mainly depends upon in cylinder temperature and expansion process. Fig 4.7 shows the variation of exhaust gas temperature with respect to the premixed fraction. The exhaust gas temperature increases with increase load. Figure shows high increment 340oC to 792oC in exhaust gas temperature at full load. It may be to two stage combustion or heat release in expansion process, but it proves high temperature inside the cylinder because of this premixed ethanol auto ignited. For low loads, only marginal increment in the exhaust gas temperature occurs. For medium load, maximum 14 % increment in exhaust gas temperature occurs.

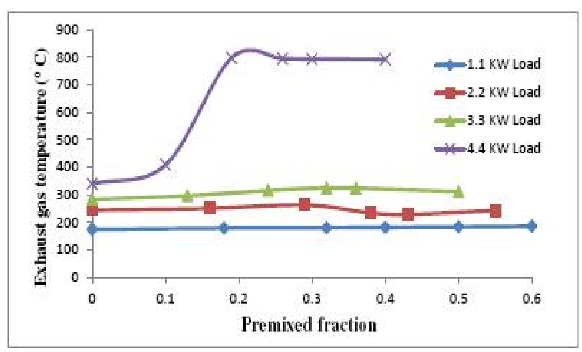

Fig 4.7 Variation of exhaust gas temperature with premixed fraction

C. Emission characteristics

3.1 Carbon dioxide (CO_2) emission

Variation of the carbon dioxide with premixed fraction for all loads is shown in Fig 4.8.

Mainly two factors which are more responsible for the CO_2 are higher temperature in combustion chamber and availability of air to get CO oxidised and form CO_2. The CO_2 emissions have shown almost reciprocal to the CO emissions. Pure diesel operation at premixed fraction 0, CO_2 increases 0.53, 0.93, 1.3, 1.43 percent with increasing loads 1.1, 2.2, 3.3 and 4.4 kW respectively. By inducting ethanol premixed fraction, the CO_2 values are low at higher load. This is due to the effect of either low temperature combustion or complete combustion. At full load CO_2 value reduces by 50%.

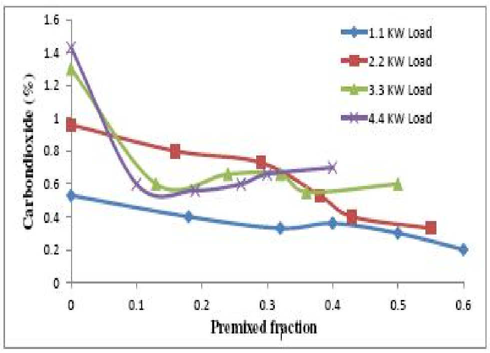

Fig 4.8 Variation of carbon dioxide with premixed fraction

Module II: The combustion, performance and emission parameter for PPCI combustion mode with the naturally aspirated air, heated at 110 degree Celsius.

A. Combustion characteristics

1.1 Pressure crank angle diagram

Figure 4.9 shows the variation of cylinder pressure with respect to crank angle at 2.2 kW load with charge heating. In the first module, results showed that pressure drop near TDC with increasing premixed fraction due to vaporisation cooling of ethanol. After charge heating, pressure drop near the TDC reduces due to less affect of the vaporization cooling on combustion.

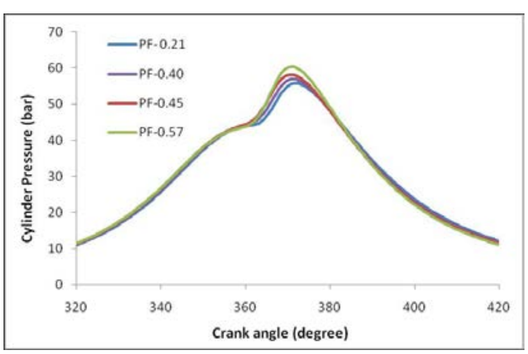

Fig 4.9 Variation of cylinder pressure with crank angle at 2.2 kW load

1.2 Heat release rate with crank angle diagram at low load operation

Fig 4.10 depicts the variation of heat release rate with respect to crank angle. High heat release rate shows intensity of rapid combustion, by increasing the premixed fraction leads to rapid combustion and shorter combustion duration. In comparison with the first module, heat release rate enhanced by using charge heating with respective premixed fraction at 2.2 kW loads. The maximum heat release rate increases up to 47.4 J/ oCA at premixed fraction 0.57.

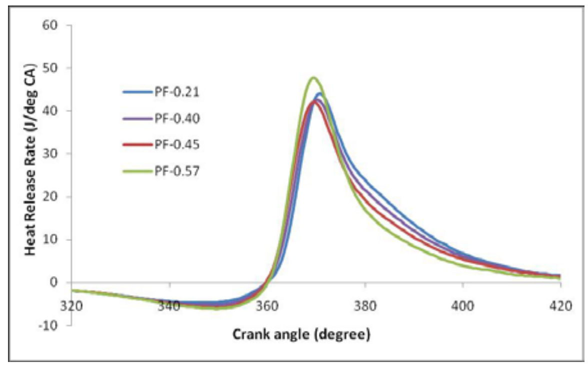

Fig. 4.12 Variation of carbon dioxide with premixed fraction

Variation of the carbon dioxide with premixed fraction for charge heating has shown in Fig 4.12 Carbon dioxide is directly proportional to in cylinder temperature and it is almost reciprocal of the carbon monoxide, increase in carbon dioxide indicates complete combustion. Charge heating improves the combustion performance and increase the in cylinder temperature. At 2.2 kW load, without charge heating carbon dioxide decreased up to 0.4% but here, it increases up to 1%. Again for 1.1 kW load, carbon dioxide percentage reduces at higher premixed fractions as the result of incomplete combustion.

IV. CONCLUSION

The combustion, performance and emission characteristics of 4-stroke, direct injection diesel engine developing power output of 4.4 kW at constant speed 1500 rpm, modified into PPCI combined combustion mode engine. Effect of various premixed fraction were investigated for all load separately. The following are the conclusion.

1. At full load operation, low NO_X, smoke opacity, CO and HC emission achieved up to the premixed fraction0.40. Adverse effect of this is uncontrolled combustion after increase in premixed fraction 0.20.
2. At 3.3 kW load operation, engine gives better combustion, performance and emission characteristics, low NO_X, smoke opacity, CO and HC achieved up to 0.50 premixed fraction. Combustion is completely controlled, ignition start after diesel injection, no adverse effect.
3. At 2.2 kW load operation, low NO_X, smoke opacity but, after increase in premixed fraction more

than 0.3, increase in the BSEC as well as HC and CO emission also increases. It can be used only up to 0.3 premixed fractions, after increasing ethanol quantity, negative effect on all three combustion, performance and emissions characteristics.

4. At 1.1 kW load, ethanol shown completely worst results, inefficient combustion. Low NO_X, smoke opacity but dramatically increased in HC emission, higher BSEC. Energy contribution of ethanol at higher premixed fraction almost negligible.

5. After using charge heating of intake air at 110 ^oC, main advantage goes to 2.2 kW load. It has shown excellent improvement in the combustion, performance and emission characteristics with low NO_X, smoke opacity, CO and HC achieved up to 0.62 premixed fractions. Start of combustion also controlled by diesel injection. No adverse effect on engine.

6. 1.1 kW load is also benefited by charge heating but up to some limit, less than premixed fraction 0.43. It is showing normal combustion property up this limit.

References

[1] Junjun Ma*, Xingcai Lü, Libin Ji, Zhen Huang An experimental study of HCCI-DI combustion and emissions in a diesel engine with dual fuel. International Journal of Thermal Sciences 47 (2008) 1235–1242.

[2] Dong-bo Yang, Zhi Wang⇑, Jian -Xin Wang, Shi-jin Shuai Experimental study of fuel stratification for HCCI high load extension. Applied Energy 88 (2011) 2949–2954.

[3] Horng-Wen Wu⇑, Ren -Hung Wang, Dung-Je Ou, Ying-Chuan Chen, Teng-yu Chen Reduction of smoke and nitrogen oxides of a partial HCCI engine using premixed gasoline and ethanol with air. Applied Energy 88 (2011) 3882–3890

[4] Srinivas Padala , Changhwan Woo , Sanghoon Kook , Evatt R.Hawkes Ethanol utilisation in adiesel engine using dual-fuelling technology. Fuel 109 (2013)597–607

[5] Xingcai Lu*, Yong Qian, Zheng Yang, Dong Han, Jibin Ji, Xiaoxin Zhou, Zhen Huang Experimental study on compound HCCI (homogenous charge compression ignition) combustion fueled with gasoline and diesel blends. Energy 64 (2014) 707e718

[6] Can Cinar *, Özer Can, Fatih Sahin, H. Serdar Yucesu Effects of premixed diethyl ether (DEE) on combustion and exhaust emissions in a HCCI-DI diesel engine Applied Thermal Engineering 30 (2010) 360–365

[7] Jianye Su, Haoyue Zhu, Stanislav V. Bohac Particulate matter emission comparison from conventional and premixed low temperature combustion with diesel, biodiesel and biodiesel–ethanol fuels Fuel 113 (2013) 221–227

[8] Z.H. Zhang, C.S. Cheung, C.D. Yao Influence of fumigation methanol on the combustion and particulate emissions of a diesel engine Fuel 111 (2013) 442–448 B.P. Pundir, Engine Emissions:Pollutant formation and advance in control technology. Alpha Science International Limited, 2007

[9] V Ganesan IC Engine, New Delhi : McGraw-Hill Book Company; 2009

[10] Bahram Bahri , Azhar Abdul Aziz , Mahdi Shahbakhti , Mohd Farid Muhamad Said Understanding and detecting misfire in an HCCI engine fuelled with ethanol applied energy 108 (2013) 24-35

[11] Maurya RK, Agarwal AK. Experimental study of combustion and emission characteristics of ethanol fuelled port injected homogeneous charge compression ignition (HCCI) combustion engine. Appl Energy 2011;88:1169–80.

[12] Pawan Kumar Tiwari. Experimental Investigation of Ethanol fuelled Partially premixed compression ignition (PPCI) Diesel engine.IJMER ISSN (Print) : 2321-5747, Volume-4,