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Experimental Investigation on Copper Coated Ceramic Hot Surface Ignition Engine Using Metanol As Fuel With Different Additives

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ABSTRACT

The concept of using alcohol fuels as an alternative to diesel fuels in diesel engines is one of the recent developments. The scarcity of petroleum fuels due to the fast depletion of petroleum deposits and frequent rise in their costs in the international market have spurred many efforts to find alternatives. Alcohols are quickly recognized as prime candidates to displace or replace high octane petroleum fuels. However, alternatives for the large demand of diesel fuels in many countries were not so evident. Innovative thinking led to the finding of various techniques by which alcohol can be used as a fuel in diesel engines. Amongst the fuel alternatives proposed, the most favourite ones are methanol and ethanol. So far no established method is available to run a normal diesel engine with a compression ratio from 14:1 to 20:1 by using alcohol as a fuel. This is because, the properties of diesel engine fuels differ from the properties of diesel fuels. The specific tendency of alcohols to ignite easily from a hot surface makes it suitable for ignition in a diesel engine . The advantage of this property of alcohols enables to design and construct a new type of engine called surface ignition engine. In this type of engine, the injected fuel ignites not by compression ignition but by contact with a hot surface maintained with in the engine. Since methanol and ethanol are very susceptible to surface ignition, this method is very suitable for these fuels. The hot surface which can be used in surface ignition engine is a ceramic heater with hot surface flush. Hence the present research work carries the experimental investigation on copper coated ceramic hot surface ignition engine with methanol as the fuel and with different additives with an objective to find the best one in terms of performance, emissions and combustion parameters.

Keywords: Ceramic hot surface ignition, Partially stabilized zirconia, Methanol, Copper coating,Additives.

1. INTRODUCTION

During the mid and late 1980's research on alcohol fuels undertaken in the United States, Japan, and Europe expanded greatly. The research covered the entire alcohol production, distribution and utilization process from the section of high-yield cultivators as feed stocks for the production process to the performance of neat alcohol fuels and blends in production passenger vehicles.

The major focus of this paper is the primary alcohol fuel i.e methanol (methyl alcohol).

Methanol (CH_3OH) is originally produced by the distructive distillation of wood. Methanol can also be manufactured from a variety of carbon – based feed stock such as natural gas, coal [1, 2].

On the other hand, alcohols do have a few disadvantages compared to diesel fuel[1]. They have low calorific value and so they require more fuel mass to release the same amount of energy. In addition to it they have higher heats of vaporization. Hence they require more energy to convert the same mass of liquid fuel to vapour state. Along with this the lower (67% by volume) flammability limits of methanol and ethanol are higher than that of diesel. As a result a larger concentration (by volume) of the alcohol fuel vapour must be present for the mixture to ignite compared to diesel fuel. [3]

The low vapour pressure the high heat of vaporization and the higher lean flammability limit of alcohol fuels make them inherently difficult to ignite under cold ambient conditions. Another disadvantage is the low cetane number compared to diesel fuel [3,4]. To overcome these disadvantages, some modifications are proposed for an engine i.e., hot surface ignition for easy ignition.

Table -1 refers to the comparison of properties of fuels studied in this work.

Table 1.Properties of fuels

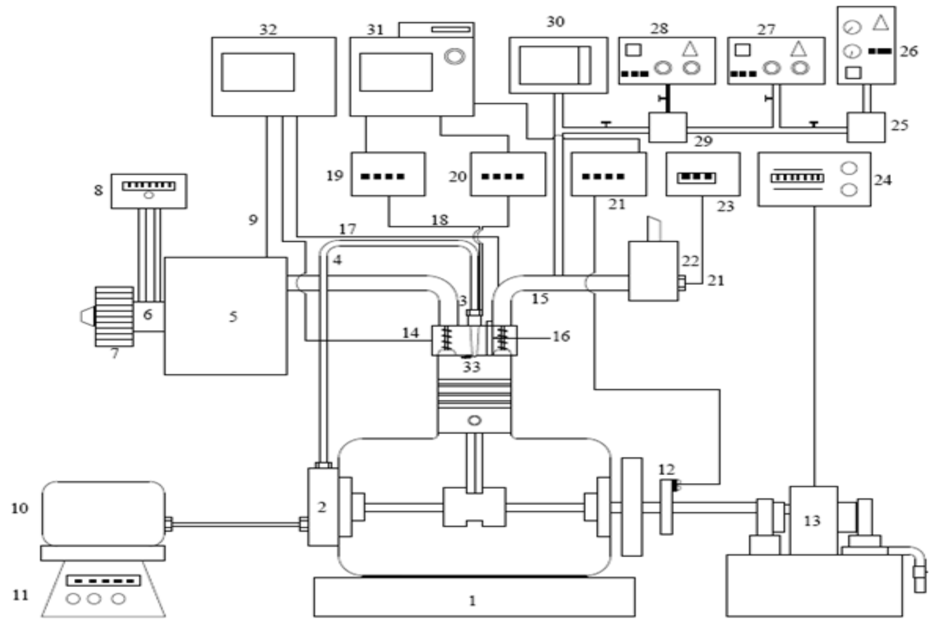
Fuel\characteristics	chemistry	Kinematic viscosity (m^2/sec)	Surface tension(mN/m)	Boiling point ^{0}C	Calorific value(kJ/kg)	Density (kg/l)	Autoignition temp(^{0}C)	Flash point (^{0}C)	Octane number	Cetane number	Stoichio air/fuel Ratio
Diesel	$C_{12}H_{23}$	3.1	23.8	170-340	44500	0.84	180-240	52	-	50-55	14.7:1
Methanol	CH_3OH	0.69	22.07	64.5	19800	0.796	464	11	92	3	6.4:1

2. EXPERIMENTAL WORK

The two most commonly known methods of combustion in an I.C engine are compression ignition and spark ignition. In C.I engines, the working medium, air is first compressed to high pressure and temperature. Then fuel is injected into the combustion chamber where the jet disintegrates into a core of fuel surrounded by an envelope of air and fuel particles created by the automation and vaporization of the fuel and turbulence inside the combustion chamber. During the delay period, the fuel atomize, vaporize and get mixed with air. Its temperature increase leads to a chemical reaction which accelerates until inflammation[5].

A constant speed stationary four stroke surface ignition ceramic heater C.I engine is selected for the experiment. Partially Stabilized Zirconia (PSZ) ceramic heater is fitted inside the cylinder head and connected by a 24 volts D.C battery to ignite the fuel methyl alcohol in the combustion chamber. Because of its very high fracture toughness, it has one of the highest maximum service temperatures (2000^{0}C) among ceramics.. PSZ ceramic heater is used in diesel engines owing to two very notable properties, one is high temperature capability and the other is low thermal conductivity[6]. This means that engine made with zirconia would retain much of the heat generated in the combustion chamber instead of loosing it to the surroundings. Therefore combustion of fuels gets complete resulting in an increase in combustion efficiency and reduction in pollution[7, 8,9].Experimental work shown in figure.1.

The schematic diagram of experimental setup of CHSI Engine is shown in Figure .1.



1. Engine
2. Fuel injection pump
3. Fuel injection nozzle
4. Intake manifold
5. Intake air surge tank
6. Air flow meter
7. Air cleaner
8. Digital manometer
9. Intake air temperature sensor
10. Fuel tank
11. Digital weighing scale
12. Crank angle detector
13. Electric dynamometer
14. Coolant temperature sensor
15. Exhaust manifold
16. Compression pressure Transducer
17. Exhaust gas temperature sensor
18. Injector needle lift sensor
19. Needle lift amplifier
20. Signal amplifier
21. Pulse amplifier
22. Air-fuel ratio sensor
23. A/F meter
24. Dynamometer control panel
25. Dehumidifier
26. HC meter
27. NOx meter
28. CO meter
29. Heater
30. Smoke meter
31. Data Acquisition System (DAS)
32. Data recorder
33. Ceramic heater

Figure 1 . Schematic diagram of experimental setup

2.1. Catalytic coating.

Catalytic coating is done to speed up the reaction rates during combustion. Like catalysts, various catalytic surfaces enhances the chemical reaction and speed up the chemical reaction rates during combustion. In this work we used copper coating on top of the piston ,inner surface of the cylindehead and valves.The copper coated cylinder head ,piston and valves are shown in figure 1-a

Figure 1-a Cylinder Head,piston and valve with copper coatings.

2.2 Additives.

Additives have been developed to increase combustion rates, as anti oxidants, to effect burn rates ,to enable fuels to work under extreme temperatures, reduce harmful emissions and more. Over the years various hybrid compounds and blends have been engineered to create better fuels for industries commercial use and end consumers alike[10,11].

In this work we used four additives with 5% of volume and these are Amyl nitrate ,2-Ethoxyethyl acitate(2EEA),2-Ethyl hexyl nitrate(2EHN) and Ethelene glyol[12,13].properties of additives are given in table-2.

Table-2 Important properties of the additives .

PROPERTIES/ADDITIVES	AMYL NITRITE	2ETHOXY ETHYLE ACETATE	2-ETHYL HEXYL NITRITE	ETHYLINE GLICOL
Chemical formulae	$C_5H_{11}ONO$	$C_6H_{12}O_3$	$C_8H_{17}NO_3$	$C_2H_6O_2$
DENSITY(kg/m^3)	872	973	800	1110
VISCOSITY(cp)	0.46(0.53)	1.397	1.8	2.9
Auto ignition temperature(^{0}c)	209	380	215	398
Calorific valve(k J/kg)	29000	23570	29855	36152
Cetane number	50	61	45	55-60

The relevant parameters such as performance parameters, emission parameters, combustion parameters are calculated for methanol fuel with four different additives. The engine is run to gain uniform speed after which it is gradually loaded .The experiments are conducted at different loads. The engine is run for at least 10 minutes after which data is collected. The experiment is repeated three times and the average value is taken.

Table 3 shows the engine specifications.

Table 3.Engine specifications

MAKE	Kirlosker
MODEL	AV-1
No.of cylinder	1
Bore X stroke(mm)	80X110
Rated output power	3.84kW(5H.P)
Rated speed	1500 RPM
Compression ratio	16.5:1
Injection pressure	Direct Injection
Cooling system	Water cooled
Lubrication system	Force feed
Attachment	Ceramic heater

3. RESULTS AND DISCUSSIONS

The experimental tests are carried out on the copper coated ceramic hot surface ignition four-stroke CI engine using methanol with four different additives and the performance parameters, combustion parameters and emission parameters are calculated. The results are shown below.

3.1 perfrmance parameters.

3.1.1.Brake thermal efficiency:

The variation of brake thermal efficiency with brake power output for four additives of copper coated CHSI engine using methonal as fuel are illustrated in fig 2.

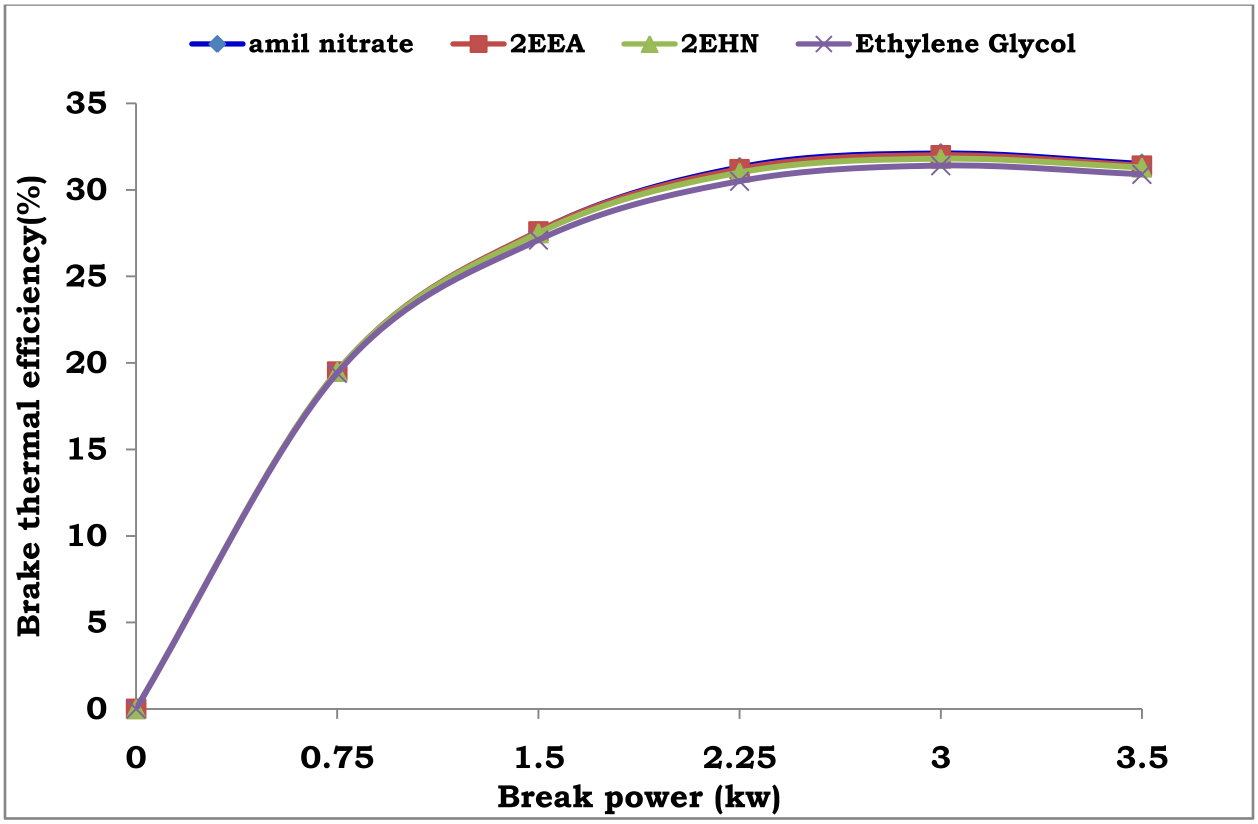


Figure 2. shows the variation of Brake thermal efficiency with brake power for methanol with different additives on copper coated CHSI engine.

It is observed that copper coated CHSI engine with Amyl nitrate as an additive shows maximum efficiency over a wide range of operation, at higher loads. It is seen that, brake thermal efficiency for copper coated CHSI engine with additives has gone up. This is because, the higher cylinder gas temperatures with addition of additives have resulted in better ignition and combustion. Also heat loss from hot surface gets reduce with amyl nitrate as an additive shows maximum efficiency of 32.1%. the brake thermal efficiency for Amyl nitrate,2EEA,2EHN, and Ethylene glycol are 32.1%,32 %,31.9% and 31.4% respectively.

3.1.2 Brake specific fuel consumption:

The variation of bsfc with brake power output for four additives of a copper coated CHSI engine using methanol as fuel in fig 3.

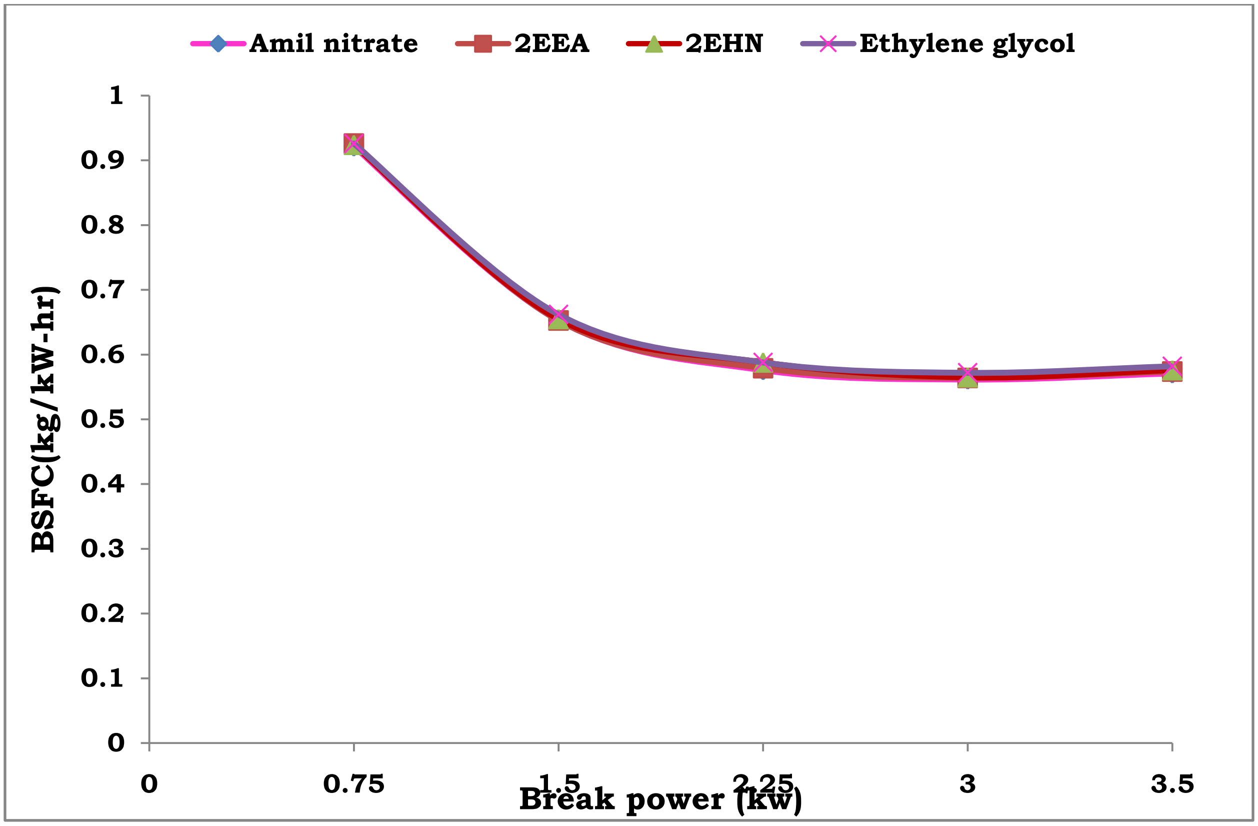


Figure 3. shows the variation of BSFC with brake power for methanol with different additives on copper coated CHSI engine.

The bsfc values are minimum for additives with copper coated CHSI engine when comparing with coated CHSI engine because by adding additives improving fuel burning qualities. The bsfc values for Amyl nitrate,2EEA,2EHN, and Ethylene glycol at maximum load are 0.571kg/kW-hr,0.574 kg/kW-hr, 0.576 kg/kW-hr , and 0.582 kg/kW-hr respectively.

3.1.3 Volumetric efficiency:

The variation in volumetric efficiency with brake power output for four additives of a copper coated CHSI engine using methanol as fuel in fig 4.

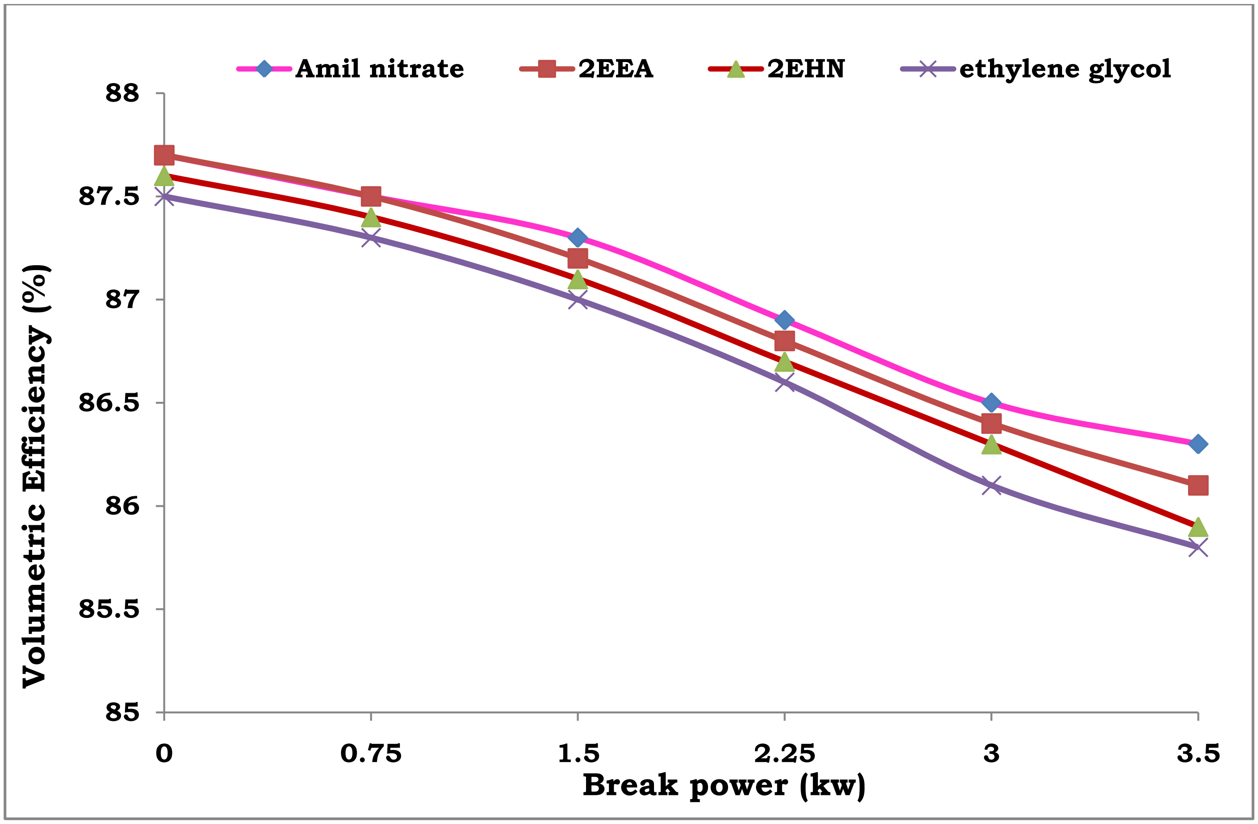


Figure 4. shows the variation of Volumetric efficiency with brake power for methanol with different additives on copper coated CHSI engine.

The volumetric efficiency is more for copper coated CHSI engine with amyl nitrate as an additive. It is found that, copper coated CHSI engine with ethyle glycol shows minimum volumetric efficiency. The volumetric efficiency for amyl nitrate, 2EEA,2EHN,and Ethylene glycol with copper coating on CHSI engine at maximum load are 86.3%, 86.1%,85.9 and 85.8% respectively. The drop in volumetric efficiency affects the combustion.

3.1.5 Exhaust gas temperature:

The fig 5. shows the variation of exhaust gas temperature with brake power for different additives of a copper coated CHSI engine using methanol as fuel.

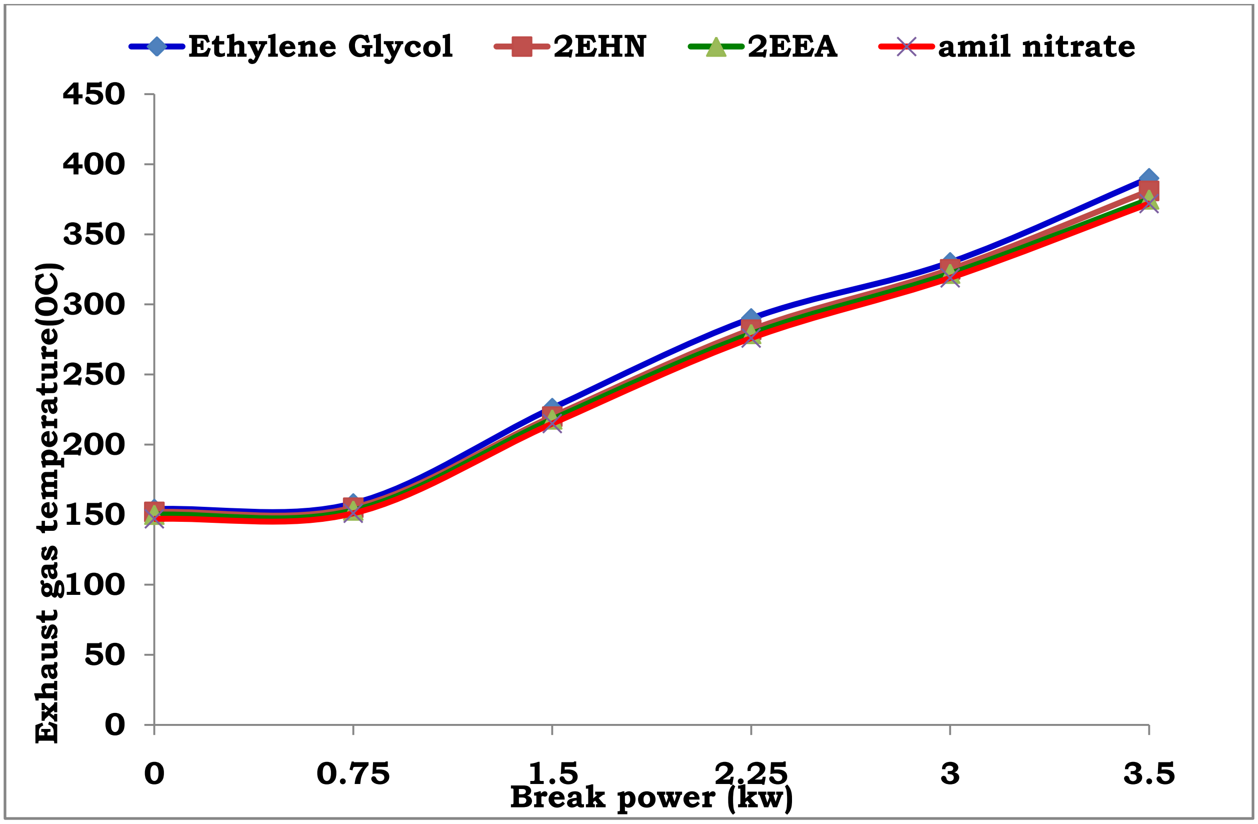


Figure 5. shows the variation of Exhaust gas temperature with brake power for methanol with different additives on copper coated CHSI engine.

By using copper coating in combustion chamber, the exhaust temperature decreases. The copper coated CHSI engine using methanol as fuel with ethylene glycol as an additive exhibits higher exhaust temperature among all the fuel tested i.e. 390^0c and lower for amyl nitrate as an additive and is 372^0c when compared with 2EEA,2EHN as additives at rated load condition. The exhaust gas temperature for amyl nitrate,2EHN,2EEA, and Ethylene glycol at maximum load are 372^0c,375^0c, 381^0c and 390^0c respectively.

3.2 EMISSION PARAMETERS (METHANOL WITH COPPER COATING AND ADDITIVES ON CHSI ENGINE)

3.2.1 Hydro carbon emission

The HC Emission levels with brake power output for the copper coated CHSI engine using methanol as fuel with different additives are shown in fig 6.

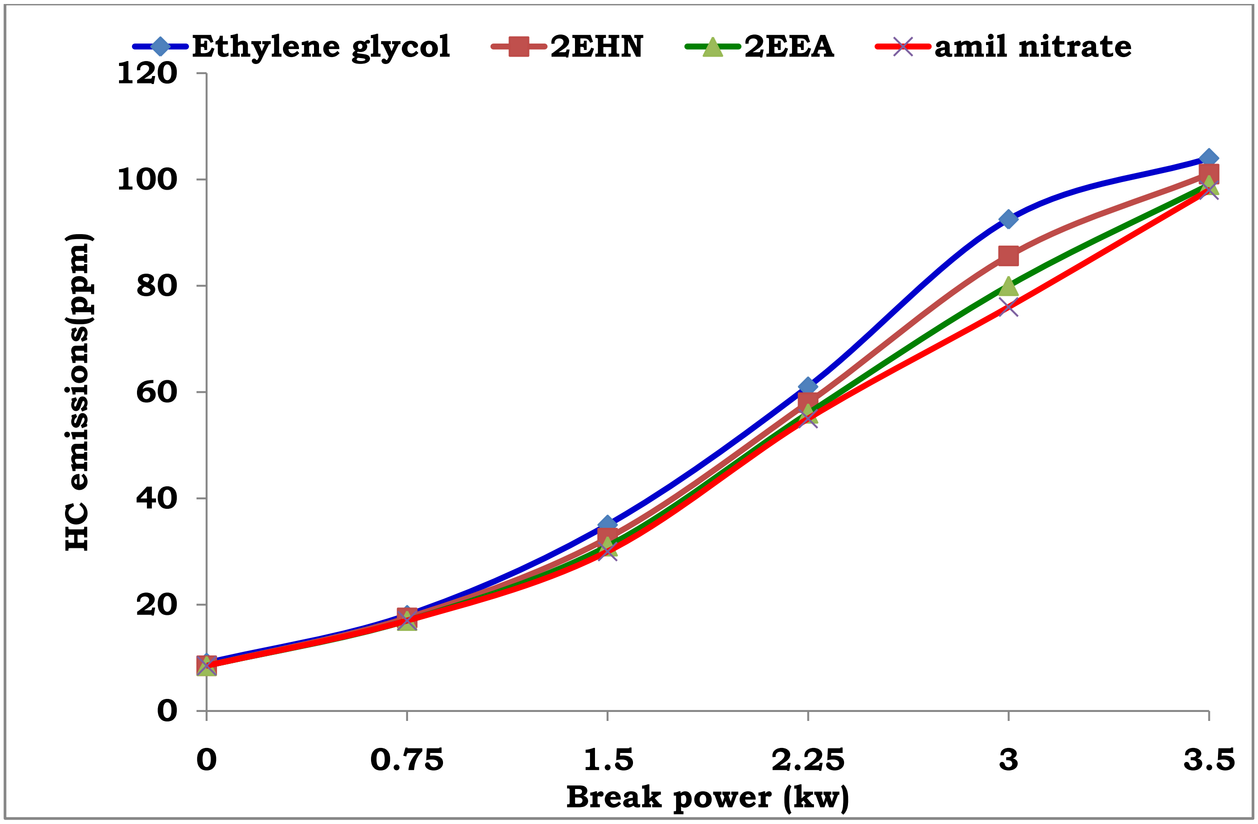


Figure 6. shows the variation of Brake thermal efficiency with brake power for methanol with different additives on copper coated CHSI engine.

It is observed that all additives with copper coated CHSI engine showsa reduction in HC emission level. It is found that, minimum HC emission is for the copper coated CHSI engine with amyl nitrate is an additive and is about 98 ppm at maximum rated load compared to copper coated CHSI engine with other additives . The HC emission levels for all additives are in between the copper coated CHSI engine with amyl nitrated and ethylene glycol as additives. The addition of additives to copper coated CHSI engine will reduce the level of HC emission , because of improvement in combustion as the combustion chamber temperature rise.The HC emission for amyl nitrate,2EHN,2EEA and ethylene glycol at maximum load are 98 ppm, 99 ppm, 101 and 104 ppm respectively.

3.2.2 Carbon monoxide emission

The variation of the CO emission levels with the brake power output for different additives in a copper coated CHSI engine using methanol as fuel is illustrated in fig 7.

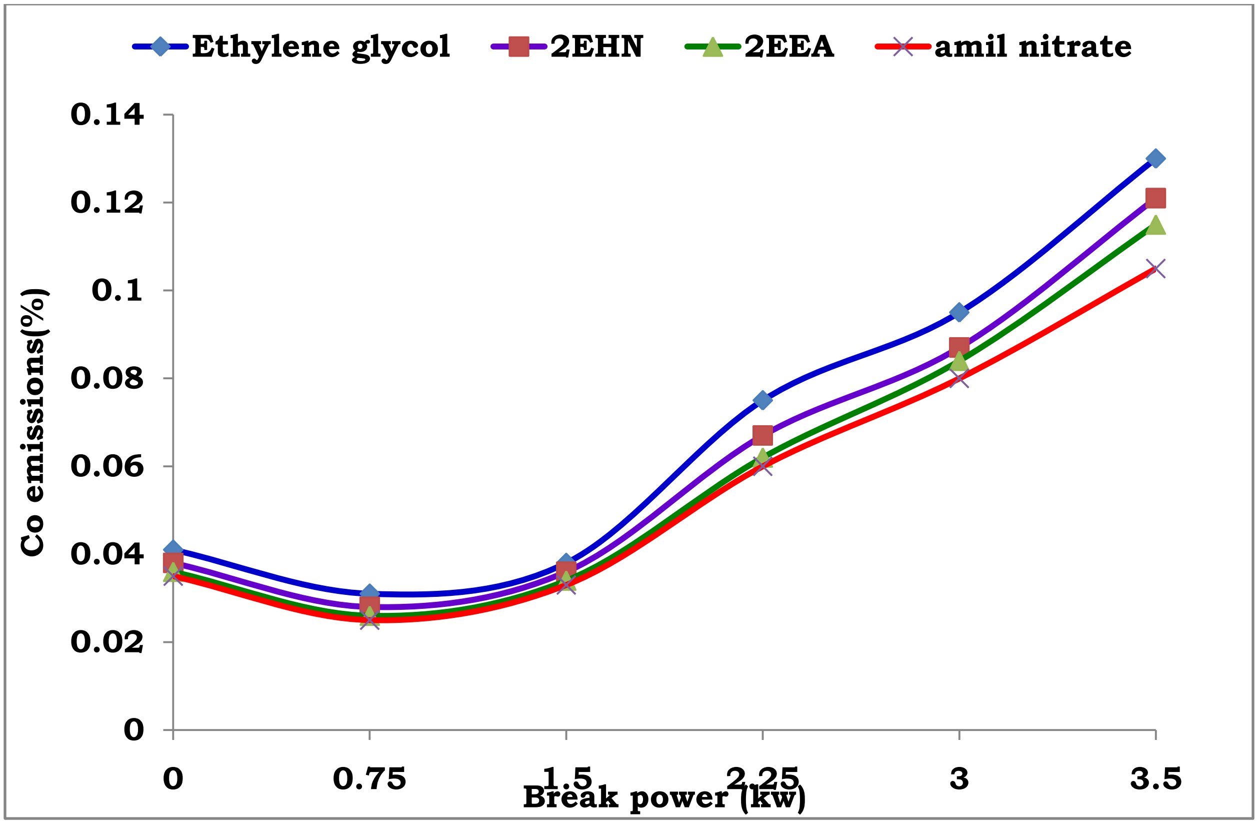


Figure 7. shows the variation of CO emissions with brake power for methanol with different additives on copper coated CHSI engine.

Because of higher combustion chamber temperature, the combustion in the copper coated CHSI engine with additives is more complete and the oxidation of the CO is also improved. The CO emission for amyl nitrate, 2EEA,2EHN,and ethyle glycol at maximum load are 0.105%, 0.115%,0.121% and 0.13% respectively. The engine with copper coated CHSI engine with amyl nitrate as additive gives lowest CO emission. The engine with copper coated CHSI engine with ethylene glycol gives the highest CO emission. The CO emission with copper coated CHSI engine with amyl nitrete as additive is lower and noted as 0.105% at maximum load. The reduction is more pronounced at higher loads than at part loads. The CO emission level for all the other additives are in between copper coated CHSI engine with amyle nitrate and ethyle glycol as additives.

3.2.3 NO_x Emissions.

The variations of the NO_X emission levels with the brake power output for four additives on a copper coated CHSI engine using methanol as fuel is illustrated in fig.8.

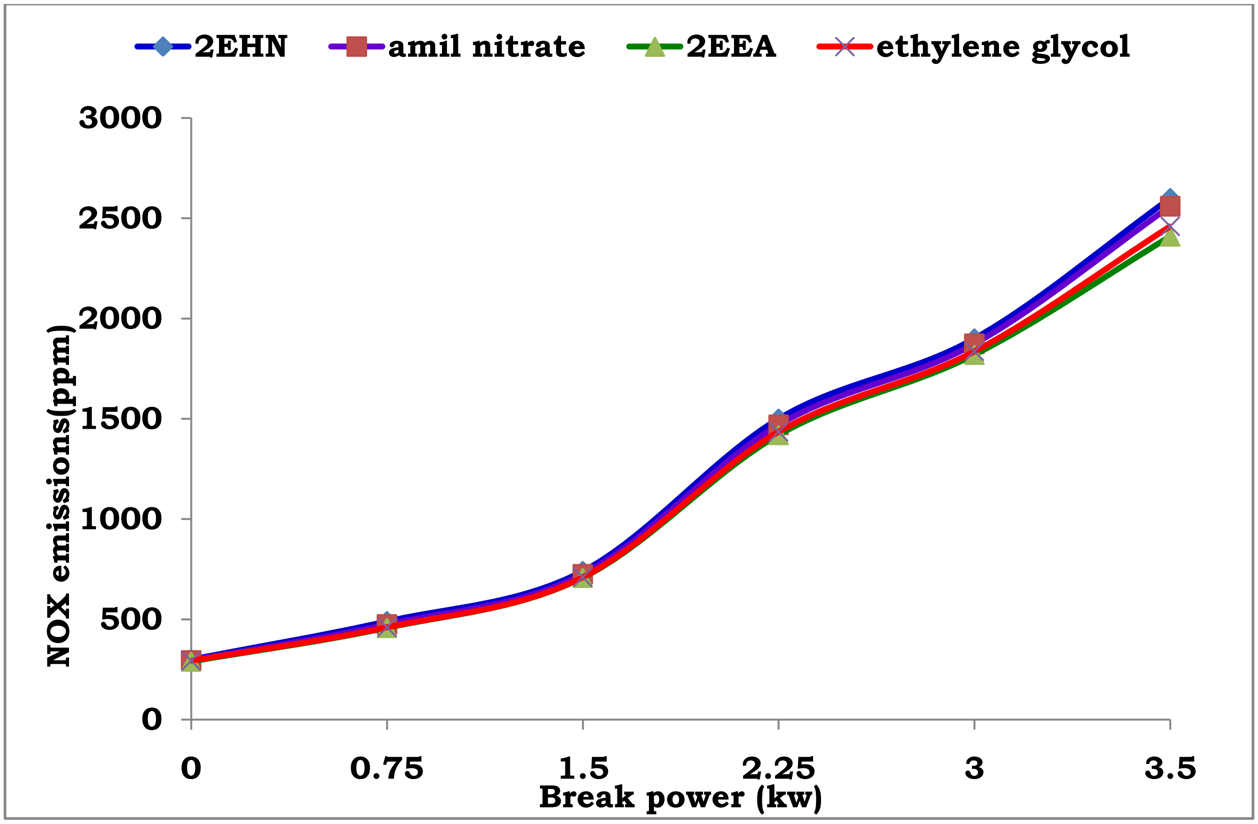


Figure 8. shows the variation of NO_x emissions with brake power for methanol with different additives on copper coated CHSI engine.

Due to higher combustion chamber temperature ,the combustion in the copper coated CHSI engine with additives is more complete and the oxidation of the NO_x is also improved. The engine with copper coated CHSI engine with 2Ethoxy ethyl acetate as an additive gives lowest NO_x emission. The engine with copper coated CHSI engine with 2 Ethyl hexyl nitrate gives the highest NO_x emission. The NO_x emission for 2EHN,Amyl nitrate,Ethylene glycol,and 2EEA at maximum load are 2600ppm,2560ppm,2460ppm and 2410ppm respectively. The reduction is more pronounced at higher loads than at part loads.

3.2.4 Exhaust smoke Emission:

The variation in exhaust smokeemission with brake power for three additives on a copper coated CHSI engine using methanol as fuel is shown in fig.9.

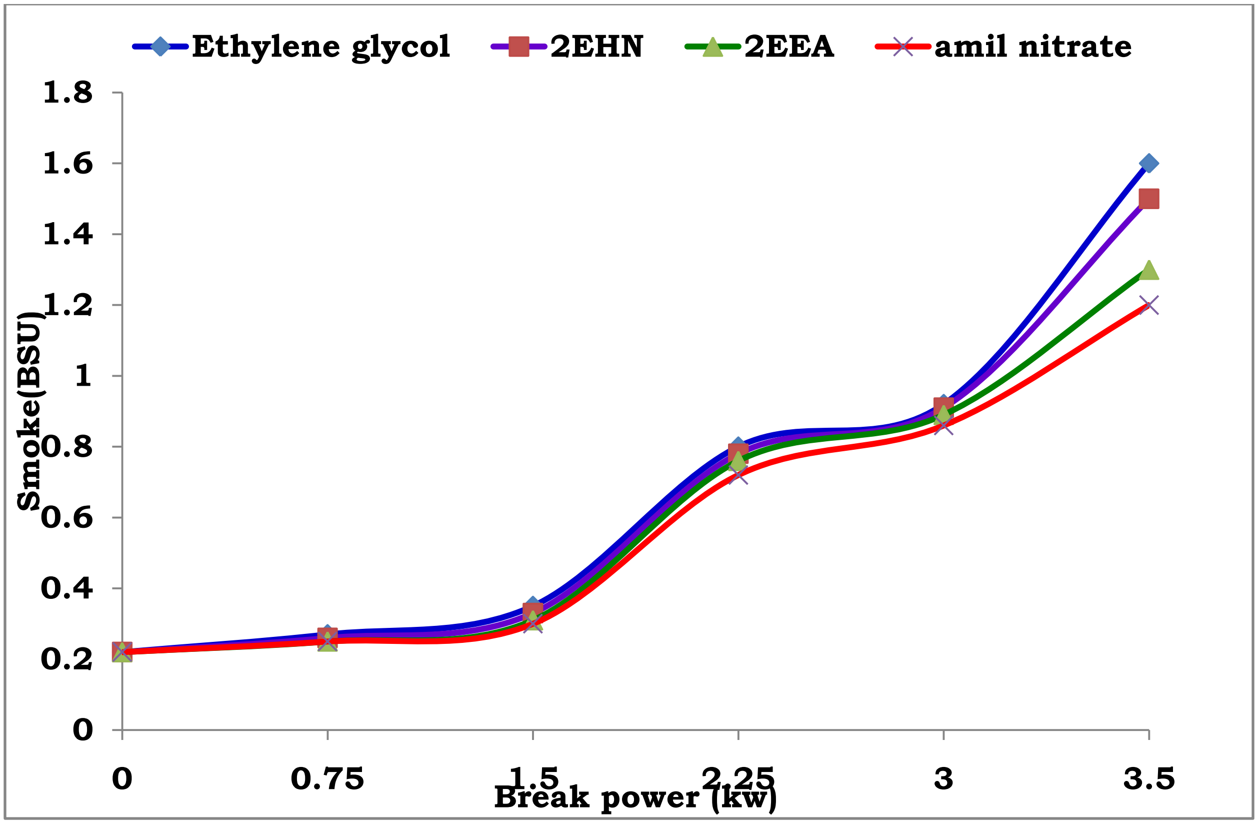


Figure 9. shows the variation of Smoke emissions with brake power for methanol with different additives on copper coated CHSI engine.

The engine with copper coated CHSI engine with engine with amyl nitrate as an additive gives lowest smoke emission. 2EEA,2EHN and ethylene glycol are good in terms of reduced smoke emission. The reason for the reduction of smoke emission with additives may be attributed to the better combustion, due to higher prevailing operating temperatures. At the maximum load, the minimum smoke emission is noted as 1.6 BOSCH units for copper coated CHSI engine with amyl nitrate as an additive when compared to other additives with copper coating. The exhaust smoke emission for amyl nitrate,2EEA,2EHN, and ethylene glycol on copper coated CHSI engine at maximum load are 1.2BSU, 1.3 BSU,1.5 BSU and 1.6 BSU respectively.

3.3 COMBUSTION PARAMETERS (METHANOL WITH COPPER COATING AND ADDITIVES ON CHSI ENGINE)

3.3.1 Cylinder peak pressure:

The variation of cylinder peak pressure with brake power output for three additives in a copper coated CHSI engine using methanol as fuel is illustrated in fig. 10.

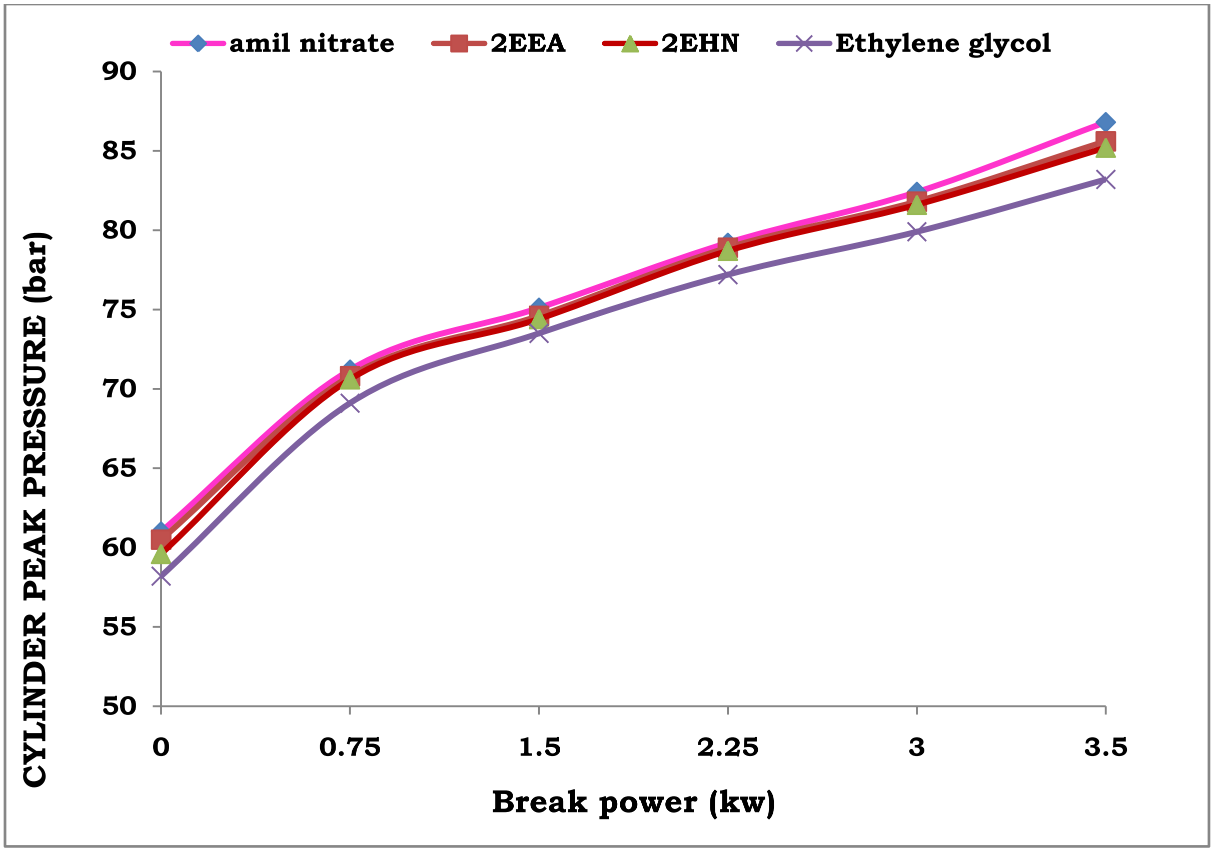


Figure 10. shows the variation of Cylinder peak pressure with brake power for methanol with different additives on copper coated CHSI engine.

Particularly at higher outputs where the gas temperatures accelerate the combustion process, the cylinder peak pressure will increase with the additions of additives to the copper coated CHSI engine. It is found that high cylinder peak pressure is developed by copper coating of 86.8 bar in CHSI engine with amyl nitrate as an additive and low peak pressure of 83.2 bar is observed in copper coated CHSI engine with the ethylene glycol as an additive. The cylinder peak pressure for amyl nitrate,2EEA,2EHN and ethylene glycol on copper coated CHSI engine at maximum load are 86.8 bar, 85.6 bar,85.2 and 83.2 bar respectively.

3.3.2 Ignition delay

The variation of ignition delay period with brake power output for a copper coated CHSI engine using methanol as fuel with three additives is shown in fig.11.

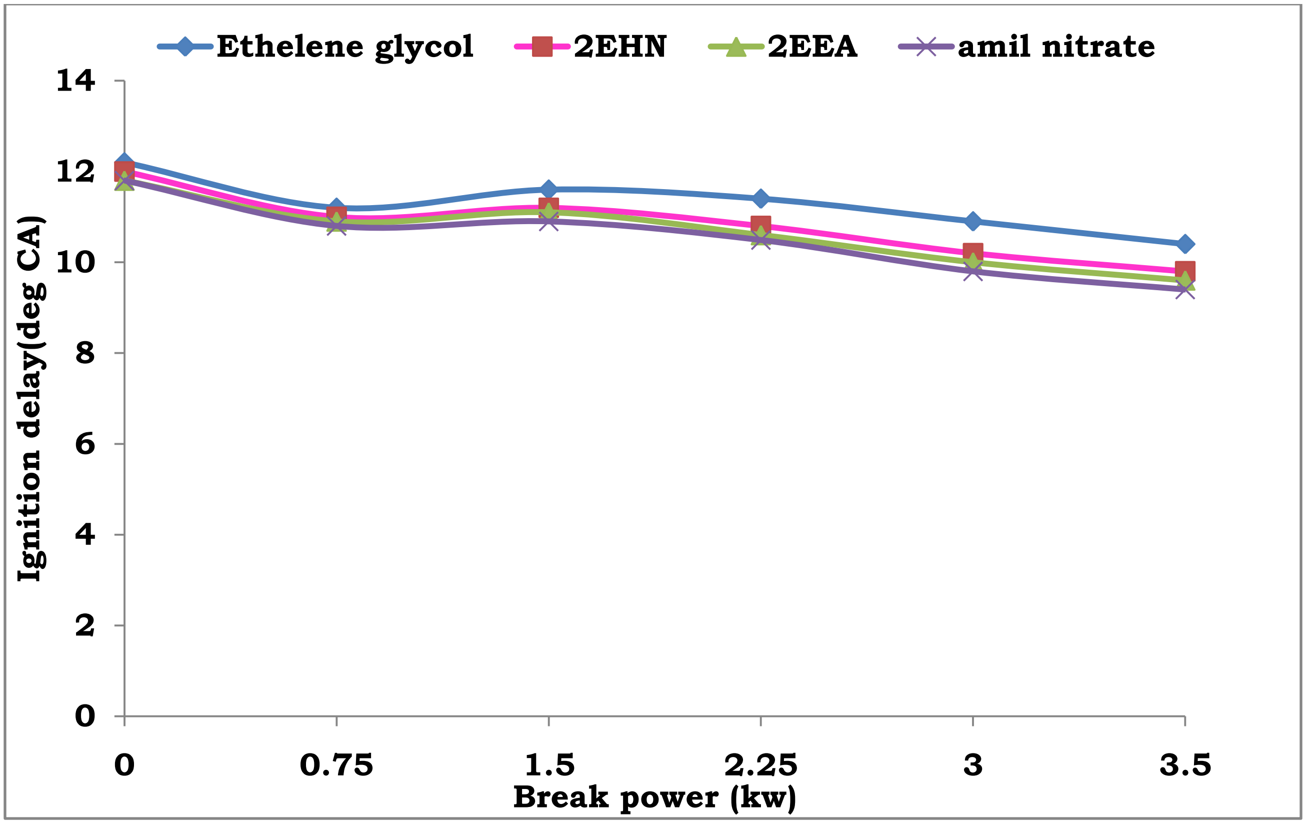


Figure 11. shows the variation of Ignition delay with brake power for methanol with different additives on copper coated CHSI engine.

The copper coated CHSI engine with amyl nitrate shows the lowest ignition delay among all the additives tested. The highest ignition delay is observed in copper coated CHSI engine with ethylene glycol as an additive. Decrease in ignition delay with load for all the additives, because of higher cylinder gas temperature and reduced heat losses from hot surface. The ignition delay is lower for copper coated CHSI engine with amyl nitrate as an additive and it is 9.4^{0}CA. the ignition delay is high at low loads because of sluggish start of combustion. The ignition delay for amyl nitrate,2EEA,2EHN and ethylene glycol on copper coated CHSI engine at maximum load are 9.4^{0} CA, 9.6^{0} CA,9.8^{0} CA and 10.4^{0}CA respectively.

3.3.3 Combustion duration :

The combustion duration is an important parameter which indicates the fatness of combustion. The variation of combustion duration with brake power for copper coated CHSI engine using methanol as fuel with different additives is detailed in fig.12.

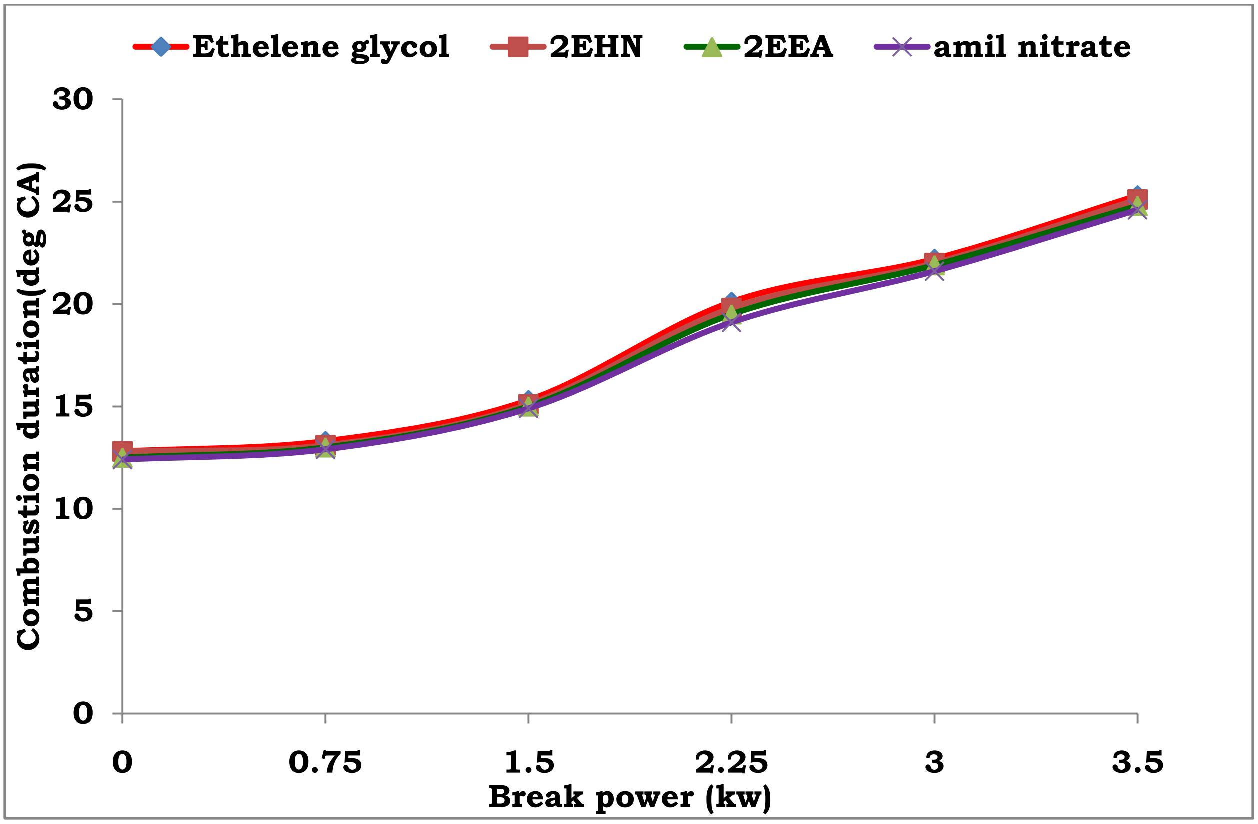


Figure12. shows the variation of Combustion duration with brake power for methanol with different additives on copper coated CHSI engine.

It is found to be low in copper coated CHSI engine with different types of additives. The copper coated CHSI engine with amyl nitrate as an additive shows the shortest combustion among all the additives of copper coated CHSI engine. Other additives with copper coated CHSI engine with amyl nitrate as an additive. The combustion duration of a copper coated CHSI engine with amyl nitrate as an additive is lower and it is 30^0CA at rated load conditions. The combustion duration is found to be low loads due to improper and incomplete combustion. On contrary, the combustion duration is high at high loads due to improved combustion. The ignition delay for amyl nitrate,2EEA,2EHN and ethylene glycol on copper coated CHSI engine at maximum load are 25^0CA, 25^0CA,25.1^0 CA and 25.3^0 CA respectively.

3.3.4 Maximum rate of pressure rise(bar/CA)

The difference in maximum rate of pressure rise with brake power output for three additives of copper coated CHSI engine using methanol as fuel is diagrammatically explained in fig.13

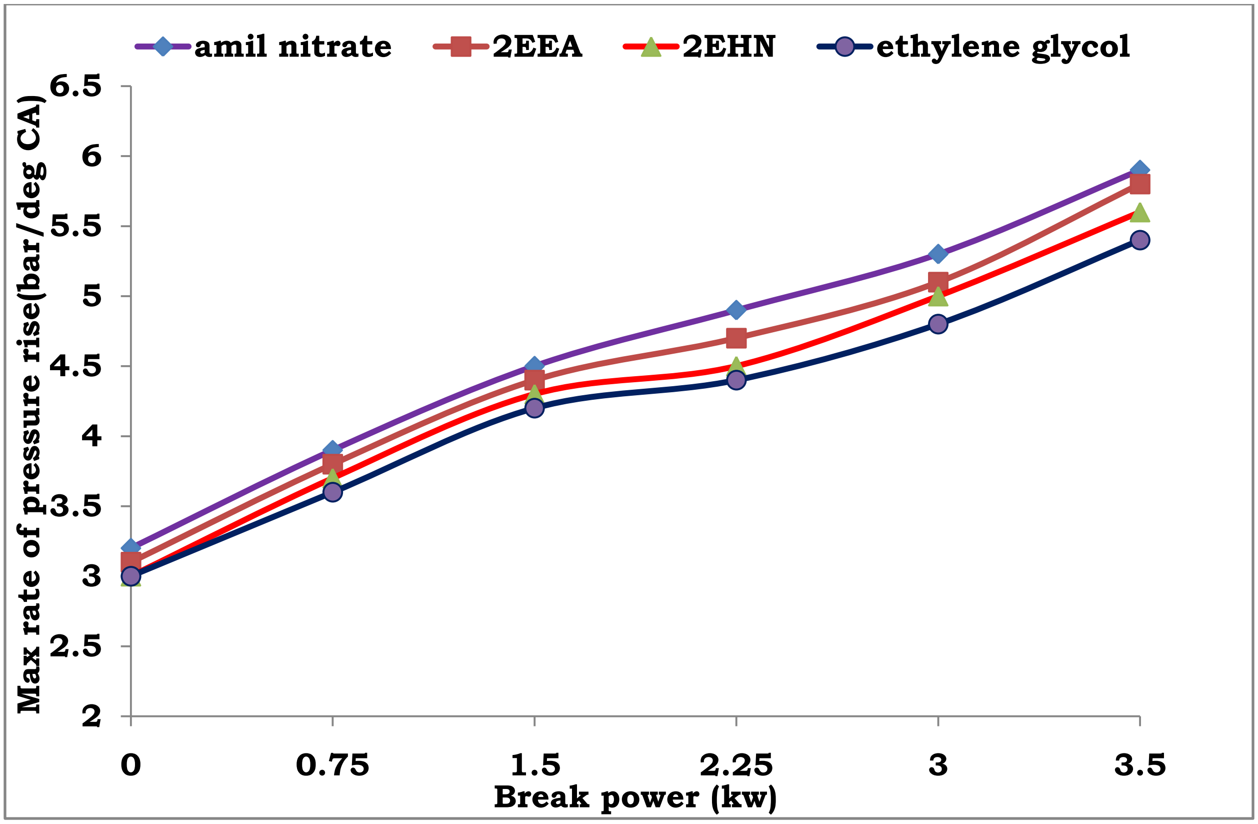


Figure 13. shows the variation of Max rate of pressure rise with brake power for methanol with different additives on copper coated CHSI engine.

It is found that, the maximum rate of pressure rise lower with copper coated CHSI engine with the addition of different additives. This is due to the lower levels of accumulated fuel as a result of lower ignition delay. It is higher for the copper coated CHSI engine with amyl nitrate as an additive and is about 5 bar/^{0}CA at maximum load. The low ranges of the pressure rise with alcohol as fuel in the low output ranges is because of sluggish combustion. The maximum rate of pressure rise for amyl nitrate, 2EEA,2EHN and ethylene glycol on copper coated CHSI engine at maximum load are 5.9 bar/^{0}CA , 5.8 bar/^{0}CA,5.6bar/^{0}CA and 5.4 bar/^{0}CA respectively.

4.Conclusions

The following summaries are consolidated for copper coated CHSI engine with different types of additives using methanol as fuel. Copper coated CHSI engine with amyl nitrate as an additive using methanol as fuel shows better performance, emission and combustion characteristics.

It is observed that, copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive shows maximum brake thermal efficiency of 32.10% over wide range of operation, Ethylene glycol shows 31.4% which is the minimum among other additives.

The BSFC value is 0.571kg/kW-hr for copper coated CHSI engine using methanol as fuel with amilnitrate as an additive is the lowest at full load when compared to other additives because higher calorific value of amilnitrate.highest BSFC value is 0.582kg/kW-hr.

The volumetric efficiency is 86.3% for copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive is the highest at full load when compared to other additives. The drop in volumetric efficiency affects the combustion by reducing the amount of air available combustion. Ethylene glycol as an additive gives minimum volumetric efficiency of 85.8%

The exhaust gas temperature is lower for copper coated CHSI engine using methanol as fuel with amil nitrate as an additive which is 372^0C, and it is higher for Ethylene glycol and is 390^0C.

The copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive shows the lowest HC emission of 98 ppm, where it is higher for ethylene glycol additive i.e 104 ppm.

The copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive gives lowest CO emission which is about 0.105%, and it is higher for ethylene glycolas an additive and is about 0.13%.

The copper coated CHSI engine using methanol as fuel with 2EEA as an additive gives lowest NOx emissions and is about 2410 ppm, where as 2EHN as an additive shows highest NOx emissions of 2600ppm.

It is found that, the lower smoke emission is noted as 1.20BOSCH units for copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive, higher for Ethylene glycolas an additive and found to be 1.6BSU.

The ignition delay for copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive is 9.4^0CA is the lowest over other additives, where as ethylene glycol has highest ignition delay of 10.4^0CA.

The combustion period for copper coated CHSI engine using methanol as fuel at maximum load with amyl nitrate as an additive is lower and it is 29^0CA compared with ethylene glycol as an additive and it has the higher value of 32^0CA.

It is to be noted that, copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive shows a higher peak pressure of 86.8bar, where as lower for ethylene glycol additive and is 83.2 bar.

It is observed that, the maximum rate of pressure rise is lower for copper coated CHSI engine using methanol as fuel with amyl nitrate as an additive which is about 5.9 bar/^{0}CA, and it is higher for ethylene glycol as an additive and found to be 5.4 bar/^{0}CA.

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