An Experimental Study on the Performance and Emission Characteristics of Ethanol-Diesel Dual-Fuelsfor the Homogeneous Charge Compression Ignition Engine

Sung Bin Han[1], Jun Young Park[2] and Yon Jong Chung[3]

[1](*Department of Mechanical & Automotive Engineering,Induk University, 12 Choansan-ro, Nowon-gu, Seoul, 01878, Republic of Korea)*

[2](*Department of Machine Design, Shin Ansan University, 135 Sinansandaehak-ro, Danwon-gu, Ansan-si, Gyeonggi-do, 15435, Republic of Korea)*

[3](*Department of Mechanical Parts System Engineering,Dongguk University Gyeongju Campus,123 Dongdae-ro, Gyeongju-si, Gyeongsangbuk-do, 38066, Republic of Korea)*

sungbinhan@induk.ac.kr

Abstract:*Alcohols are particularly attractive as alternative fuels because they are a renewable resource. Ethanol has been studied in spark ignition application. However, it is verydifficult to fuel compression ignition engines because of the lowercetane number, higher latent heat, and otherchemical properties.This paper describes the performance (torque, brake mean effective pressure, brake horse power, brake thermal efficiency, brake specific fuel consumption rate) and emission (CO, HC, smoke) characteristics of ethanol-diesel dual-fuels engine combustion for the homogeneous charge compression ignition engine.*

Keywords :*Ethanol, diesel fuel, torque, BMEP (Brake mean effective pressure), brake specific fuel consumption, smoke, CO, HC*

I. INTRODUCTION

During the last decades, a substantial effort to develop alternative fuelsources most notably biofuels has been in progress worldwidemotivated by both economic and environmental issues. Diminishingpetroleum reserves and increasing prices, as well as continuouslyrising concern over energy security, environmental degradation andglobal warming have been identified as the most influentialenvironmental ones [1-3].

Ethanol is produced fromsugars andfermentation.Methanol can be producedfrom coal, biomass or even natural gas withacceptable energy cost. The gasification ofbiomass can lead to methanol, mixed alcohols, etc. The biomass industry can produceadditional alcohol fuels by fermenting some agriculturalby-products.

Alcohol has been considered to be an appropriatefuel for vehicles and a substitute for petroleumresources. Substituting alcohol for petroleum hasnot only been experimented in the spark ignitionengine but also in the compression ignition engine.However, the use of alcohol in the compressionignition engine might be difficult because ofcombustion characteristics[4, 5].

Thecetane number ofthe fuel used for the compression ignition engineshould be within the level of 45 thru 66. But thecetane number of alcohol are ethanol 8 andmethanol 3, this makes the ignition of thecompression ignition engine impossible. Also, thisalcoholic fuel has low viscosity than diesel oil andcauses a problem in the lubrication of diesel oilinjection pump. Thus due to all of the above facts,it is not easy to substitute alcohol fuel for commonfuel. To solve these problems, one method is toblend alcohol with diesel oil but this also causesthe phase separation between each oil[6, 7].

Alcohol fuels that can be produced from cellulose continue tobecome more widely used in gasoline engines. This researchinvestigated the application of alcohol to diesel engines withthe aims of improving the combustion of diesel engines andof utilizing alternative fuels. Two methods were compared, amethod in which alcohol is injected into the air intake systemand a method in which alcohol is blended in advance into thediesel fuel. Alcohol is an oxygenated fuel and so the amountof soot that is emitted is small. Furthermore, blended fuelshave characteristics that help promote mixture formation,which can be expected to reduce the amount of soot evenmore, such as a low cetane number, low viscosity, lowsurface tension, and a low boiling point. Ethanol has a strongmoisture-absorption attribute and separates easily whenmixed with diesel fuel[8-10].

Methanol is the liquid fuel that is most efficiently producedfrom thermo-chemical gasification of coal, natural gas, wasteor biomass. Ethanol can also be produced by this process butat lower efficiency and higher cost. Methanol could potentially be produced from natural gas atan economically competitive fuel costs, and with essentiallythe same greenhouse gas impact as gasoline. Waste derivedmethanol could also be an affordable low carbon fuel [11].

Diesel engines have the advantages of high thermalefficiency, lower emission of CO and HC compared withgasoline. However, they have the disadvantage of producingsmoke, particulate matter and NOx and it is difficult toreduce both NOx, and smoke density simultaneously in dieselengine due to tradeoff between NOx and smoke. It follows;therefore, that substantial amount of effort has been directedat providing solutions to these problems. Among variousdevelopments to reduce emissions, the application ofoxygenated fuels to diesel engines is an effective way toreduce smoke emissions.However, the application of methanol in diesel engine wasnot concentrated much due to its poor properties for a fuel inCI engine. Fumigation is a technique by which methanol canbe introduced in the intake air flow by a simple carburetorand vaporizing or injecting alcohol in the intake air stream [12].

Jiang et al.[13] investigated the effects of ethanol fumigation on theperformance and emissions of a four-cylinder,turbocharged diesel engine.They presented the effects of speed, load, alcohol proof, and thefraction of the engine's power supplied by thealcohol. And they found that oxides of nitrogen emissions can be substantiallyreduced by alcohol fumigation. Carbon monoxide emissions increased withalcohol fumigation. The amount of carbonmonoxide increased with increasing alcohol flowrate but there did not seem to be any effect ofproof.Unburned hydrocarbons increased greatly withalcohol fumigation.

Yousufuddina et al. [14] studied the effect ofignition timing and compression ratio on theperformance of a hydrogen ethanol-fuelled engine.From their study they observed that ignition timingis very important operating parameter that affectsspark ignition engine performance and efficiencyand not much previous work was done on hydrogen-ethanol dual fuel engine, thus this studyconcentrates on investigation of ignition timings onperformance characteristics of engine fuelled withhydrogen-ethanol mixtures.

Singh et al.[15] conducted experiment on a single cylinder diesel engine to study the performance evaluation and emission. The variation in performance and emission characteristics ofthe diesel engine when run on various iso-propyl alcoholblends with diesel fuel were investigated as compared to neatdiesel fuel. From their study found that the brake specific fuel consumption of the engine hasincreased owing to the lower energy content of the variousfuel blends. The increase in percentage is in accordance withthe blending percentage of iso-propyl alcohol.The brake thermal efficiency of the diesel engine slightlydecreased for 5% and 10% blend. However it increasedslightly with 15% and 20% blends due to promotedcombustion owing to higher content of oxygen in the fuel.

Consequently ethanolis particularly attractiveas alternative fuel. And it is the potential energy to reduce emissions in internal combustion engines. This paperinvestigates the engine performance and emissioncharacteristics in the compression ignition engine fuelled withdiesel-ethanol dual fuels for the homogeneous charge compression ignition engine.

II. EXPERIMENTAL APPARATUS AND TEST METHODS

To understand the performance and emissions characteristics of fumigation of ethanol fuel in diesel engine, a diesel was retrofitted. In this experiment, a single cylinder, diesel engine was modified into a dual fuels engine. Table 1 shows the main specifications of test engine. Figure 1 shows the schematic diagram of the engine tested.The engine which was compression ignition ignited had a compression ratio of 21.0, singlecylinder, and a displacement of 632 cc. Theperformance was tested by connecting the crankshaft to a DC dynamometer. An engine control system(IC 5460, INTELLIGENT CONTROLS, INC.) wasused to control the fuel injection timing for diesel fuel and sparktiming for ethanol fuel. An air-fuel ratio measurement system(UEGO Sensor, HORIBA 110) was used tomeasure the air-fuel ratio. The air-fuel ratios were the experimental operatingvariables at a part load. The engine speed changedfrom 800 rpm to 2000 rpm. The cooling watertemperature is fixed at 80°C.A piezo-electric pressure transducer, Kistler6061B, was mounted in the cylinder head tomeasure the cylinder pressure.

The ethanol is not blended with the diesel fuel, so it is supplied via another means, the port injection method or fumigation method. The ethanol injectoris fixed to the intake manifold about 10mm aheadof the intake valve. Ethanol is injected during theinduction process, and its quantity is controlled. The average cylinderpressure diagram of the 100 consecutive cycles wasused to evaluate the stability at the rpm.

Table 2 shows the properties of diesel and ethanol. A list offuel properties that compares ethanol and diesel is given in Table 2.Figure 2 shows the variation oflower heating value with ethanol volume %.The lower heating valueof ethanol is lower than that of diesel fuel.It indicates that the lower heating value of the dual fuels will decrease with the increase of theethanol content.Properties of diesel and ethanol show specific gravity, cetane number, viscosity, latent heat of evaporation, and theoretical air-fuel ratio. These properties could change the engineperformance and emission characteristics.

Table 1.Engine specifications.

Cooling system	Water-Cooled
Displacement	632 cc
Bore × stoke	92 × 95 mm
Compression ratio	21.0
Cylinder number	one
Combustion chamber	Pre-combustionchamber
Fuel injection pump	Bosch A-type
Injection nozzle	Pintle type
Nozzle opening pressure	120kg/cm^2
Fuel injection timing	16° BTDCstatic

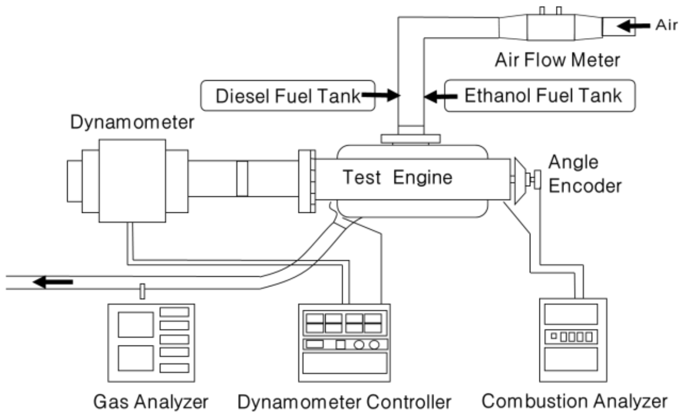

Fig 1.Experimental setup line diagram.

Table 2.Properties of diesel and ethanol.

Fuel	Diesel	Ethanol
Formula	$C_{16}H_{34}$	C_2H_5OH
Specific gravity	0.82-0.85	0.79
Lower heating value (MJ/kg)	42.600	26.808
Cetane number	45-60	8
Boiling point (℃)	210-325	78.4
Viscosity (cSt) at 25℃	2.79	1.1
Latent heat ofevaporation (MJ/kg)	310	863
Theoretical air-fuel ratio	14.6	9.0

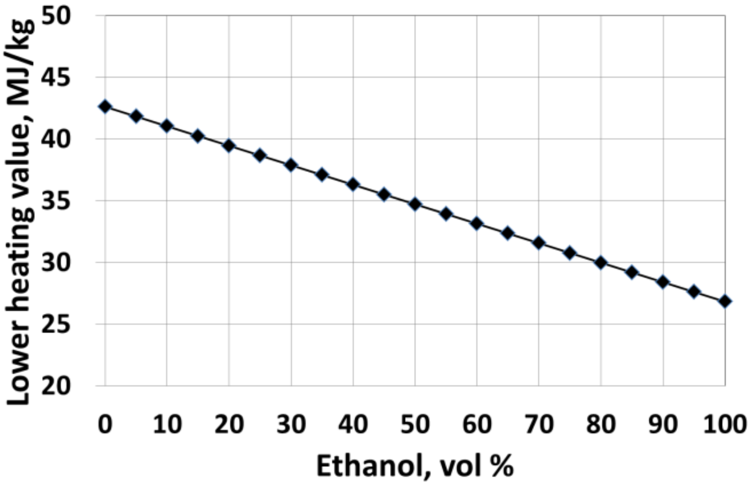

Fig 2.Variation oflower heating value with ethanol volume %.

III. EXPERIMENTAL RESULTS AND DISCUSSION

III. 1.BRAKE MEAN EFFECTIVE PRESSURE, TORQUE, AND BRAKE HORSE POWER

The results of the brake mean effective pressure (BMEP, Figure 3), torque (Figure 4), and brake horse power (HP, Figure 5) for ethanol-diesel dual-fuels at different engine speeds are shown here. The ethanol is not blended with the diesel fuel, so it is supplied via another means, the port injection method.

As reveled from the graphs, that brake mean effective pressure increase with increasing engine speeds. Figure 3 shows the influence of ethanol-diesel dual-fuels on brake mean effective pressure. Whenthe ethanol content in the diesel fuel was increased, the engine brake mean effective pressure decreased for all increasing engine speeds. The brake mean effective pressure of diesel was slightly higher thanthat of EF05, EF10, EF15, and EF20, especially for low engine speedsbecause of the lower heating value of diesel is lower than the ethanol.

Figure 4 shows the torque as a function of engine speed for the ethanol-diesel dual-fuels.Figure 3 is very similar to Figure 4 because the results of torque are based on brake mean effective pressure.According to the increase of ethanol content, the torque of the ethanol-diesel dual-fuels enginedecreased slightly than the diesel engine.

Figure 5 shows the brake horse power as functions of engine speed for the ethanol-diesel dual-fuels.From this figure, it shows the effect of ethanol-diesel dual-fuelson engine power.With anincreasing fraction of ethanol, engine power slightly decreased for all engine speeds. Thebrake horse power of diesel was higher than those of EF05, EF10, EF15, and EF20, especially for high engine speeds.

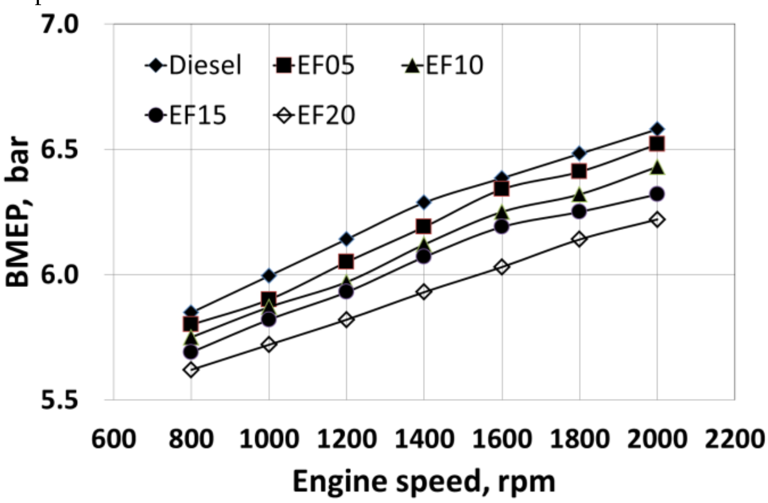

Fig 3.Variation of brake mean effective pressure with engine speed for different ethanol fractions.

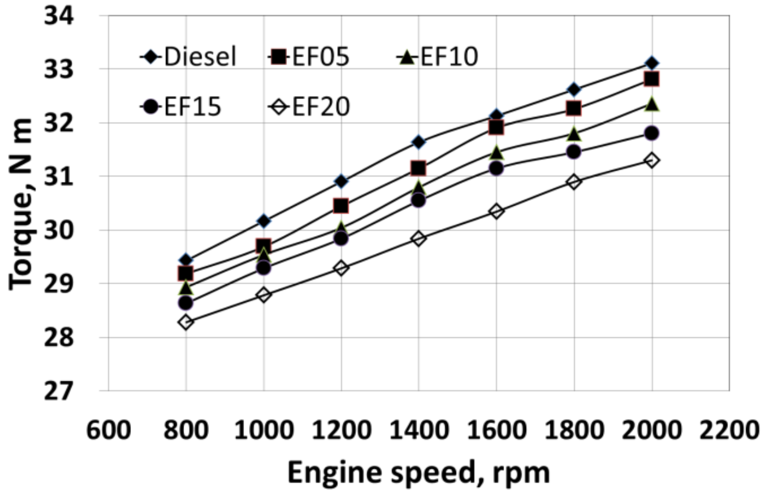

Fig 4.Variation of torque with engine speed for different ethanol fractions.

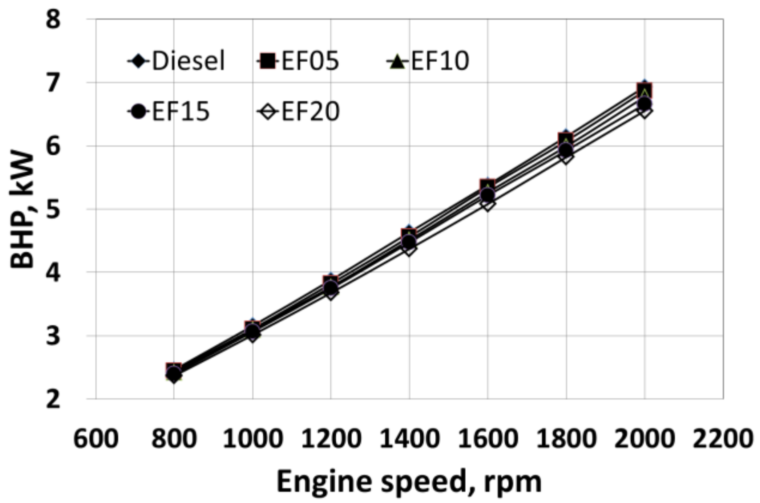

Fig 5.Brake horse power with engine speed for different ethanol fractions.

III. 2.BRAKE SPECIFIC FUEL CONSUMPTION

Figure 6 shows the brake specific fuel consumption rate (BSFC) as functions of engine speed for the ethanol-diesel dual-fuels. Figure 7 shows the brake specific fuel consumption rate (BSFC) as a function of brake mean effective pressure for the ethanol-diesel dual-fuels.The BSFCis defined as the ratio of the rateof fuel consumption and the brake horse power.The BSFC varied depending on both engine torque and the lower heating value of the used fuel.The lower heating value of ethanol is lower compared tothat of diesel, hence rising proportion of ethanol inthe ethanol-diesel dual-fuelsdecreases the lower heating value of the ethanol-diesel dual-fuelswhichresults in increased BSFC.As shown in the Figures 6 and 7, the BSFC increased as the ethanol percentage increased.As shown in Figures,4 and 6the brake torque and the BSFC characteristics haveopposite tendency between lower and higher engine speeds. And the brake horse power is in inverse proportion to the specific fuel consumption rate as shown in Figure 5 and Figure 6.BSFC isshown to increase with higher proportion of ethanol compared to diesel in the entire loadrange.

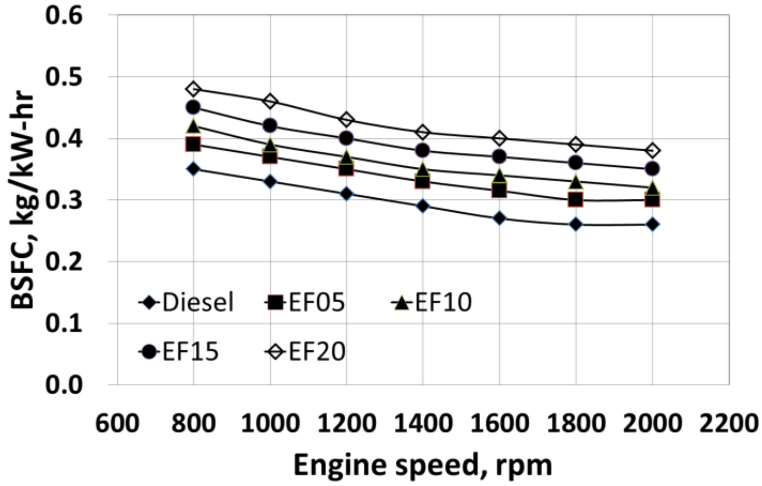

Fig 6.Brake specific fuel consumption with engine speed for different ethanol fractions.

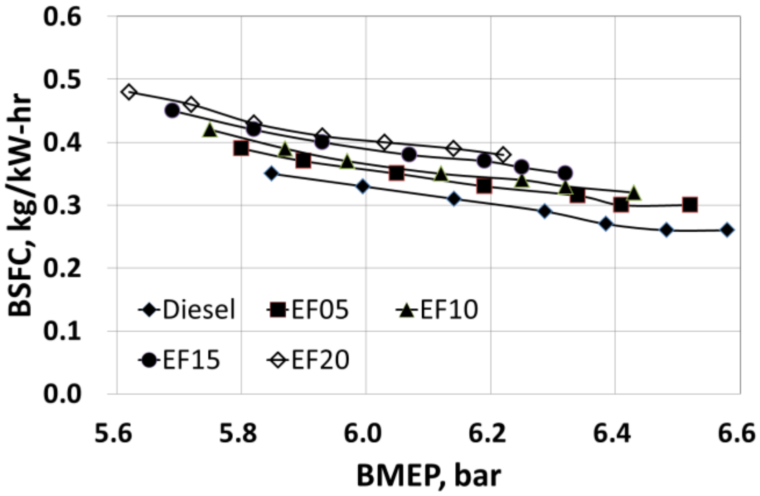

Fig7.Variation of brake specific fuel consumption with brake mean effective pressure for different ethanol fractions.

III. 3.BRAKE THERMAL EFFICIENCY

Figure 8 shows the brake thermal efficiencyversus engine speeds for various percentages of ethanol substitutions at diesel engine for the ethanol-diesel dual-fuels. Figure 9 shows the brake thermal efficiencyas a function of BMEP at the different fuels, ethanol-diesel dual-fuels.

The brake thermal efficiency (η_b) is defined as followed;

$$\eta_b = \frac{Power}{m_f LHV}$$

where the brake horse power is measured in kW, m_f is the mass flow rate of fuel and LHV is the lower heating value of the fuel.

Brake thermal efficiencies of ethanol-diesel dual-fuelsare lower than that with diesel. The brake horse power is in inverse proportion to the specific fuel consumption rate as shown in Figure 5 and Figure 6. Therefore the brake thermal efficiencies areshown to decrease with higher proportion of ethanol compared to diesel in the entire loadrange, engine speed.

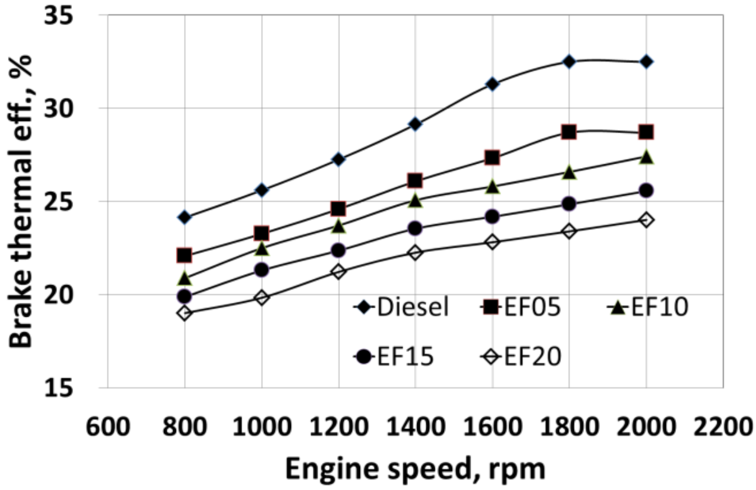

Fig 8.Variation of brake thermal efficiency with engine speed for different ethanol fractions.

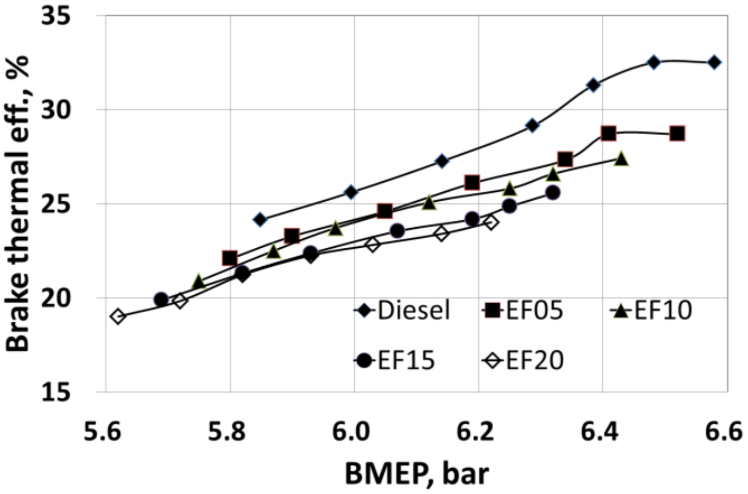

Fig 9.Variation of brake thermal efficiency with brake mean effective pressure for different ethanol fractions.

III. 4.CO EMISSION

CO emission is a toxic gas that is the result of incomplete internal combustion. When ethanol containing oxygen is fumigated or blended with diesel, the combustion of the engine becomes betterand then CO emission is reduced as shown in Figures 10 and 11. Figures10 and 11 show the CO emissionversus engine speeds and BMEP for various percentages of ethanol substitutions at diesel engine for the ethanol-diesel dual-fuels, respectively. As seen in Figure10, thevalues of CO emission at 800 rpm are about 2.53%, 1.21%, 1.23% 1.14% and 1.05% for diesel, EF05, EF10, EF15 and EF20 fuels, respectively. The values of CO emission at 1000 rpm are about 2.72%, 1.35%, 1.24% 1.15% and 1.08% for diesel, EF05, EF10, EF15 and EF20 fuels, respectively. Thevalues of CO emission at 2000 rpm are about 4.23%, 2.73%, 2.65% 2.58% and 2.46% for diesel, EF05, EF10, EF15 and EF20 fuels, respectively.Andas seen in Figures 10 and 11, CO emission is shown to rapidly decrease with higher proportion of ethanol compared to diesel in the entire loadrange, engine speed and BMEP, respectively.

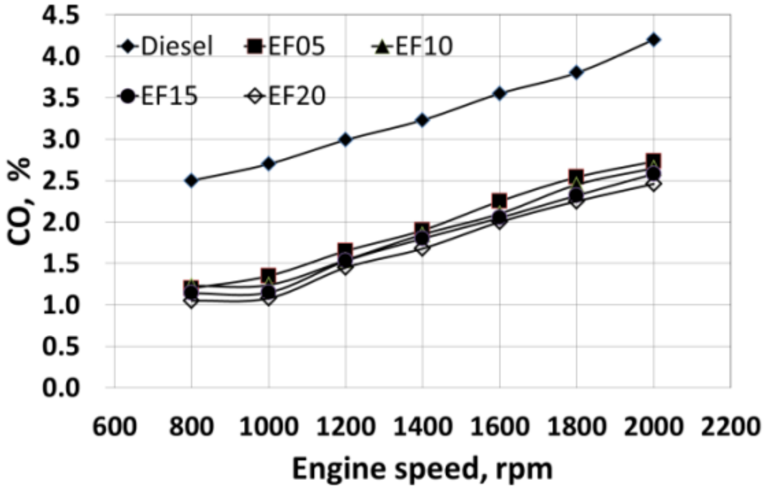

Fig 10.Variation of CO emissions with engine speed for different ethanol fractions.

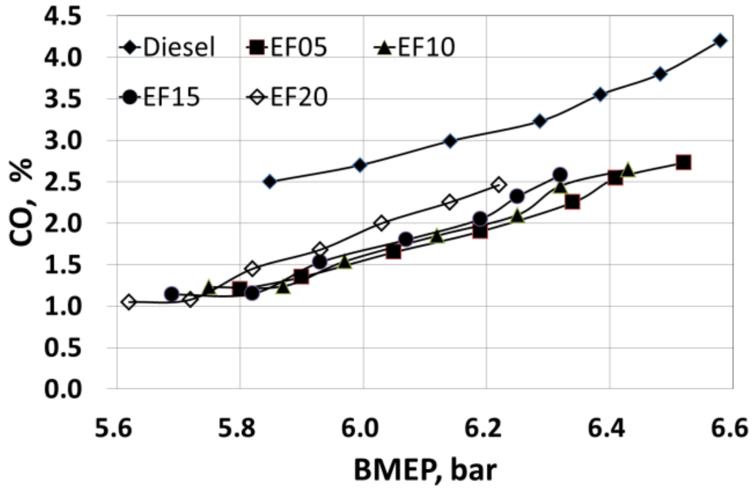

Fig 11.Variation of CO emissions with brake mean effective pressure for different ethanol fractions.

III. 5.HC EMISSION

Figures 12 and 13show the HC emission versus engine speeds and BMEP for various percentages of ethanol substitutions at diesel engine for the ethanol-diesel dual-fuels, respectively.These results presented that ethanol can be treated as apartially oxidized hydrocarbon when they are added to the fumigated fuel. Therefore, HCemission decreases to some extent as ethanol added to diesel increase [6].As seen in Figure12, thevalues of HC emission at 800 rpm are about 21 ppm, 13 ppm, 11 ppm, 9 ppmand 7 ppmfor diesel, EF05, EF10, EF15 and EF20 fuels, respectively. The values of HC emission at 1000 rpm are about 25 ppm, 16 ppm, 13 ppm, 11 ppm and 9 ppm for diesel, EF05, EF10, EF15 and EF20 fuels, respectively. Thevalues of HC emission at 2000 rpm are about 60 ppm, 45 ppm, 40 ppm, 36 ppmand 34 ppm for diesel, EF05, EF10, EF15 and EF20 fuels, respectively.Andas seen in Figures 12,HC emission is shown to rapidly decrease with higher proportion of ethanol compared to diesel in the entire engine speed.

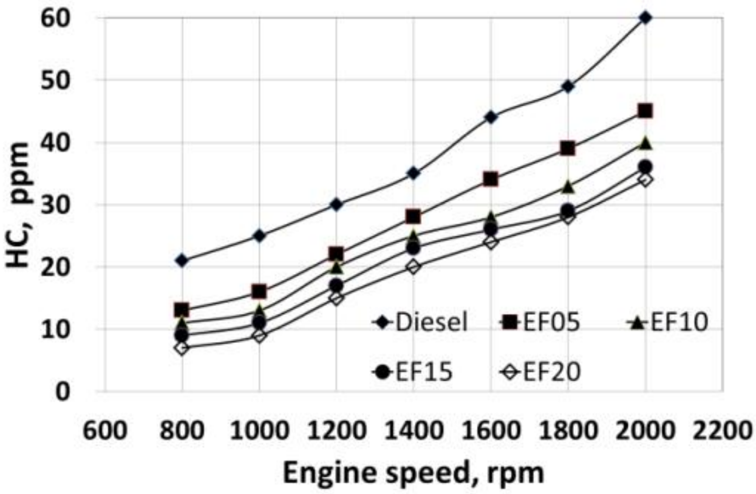

Fig. 12. Variation of HC emissions with engine speed for different ethanol fractions.

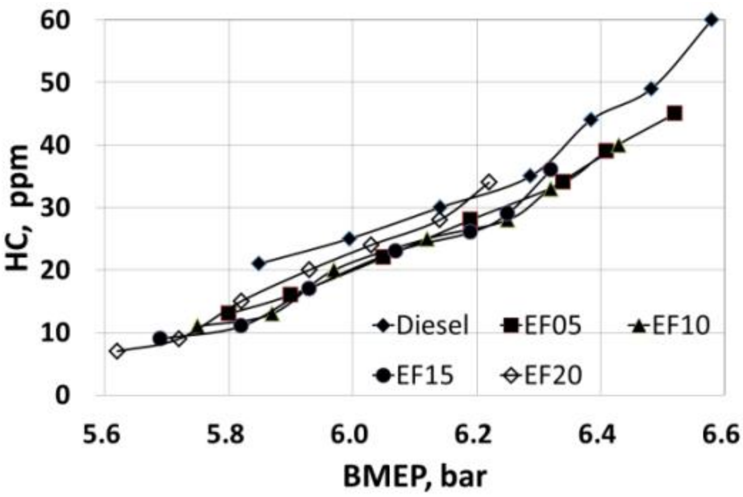

Fig13.Variation of HC emissions with brake mean effective pressure for different ethanol fractions.

III. 6.SMOKE EMISSION

Figures14 and 15show the smoke from the engine in Bosch smoke units (BSN)versus engine speeds and BMEP for various percentages of ethanol substitutions for the ethanol-diesel dual-fuels, respectively. As seen in Figure14, thevalues of smokeat 800 rpm are about 8.80 BSN, 6.32 BSN, 6.15 BSN, 6.05 BSN and 5.91 BSNfor diesel, EF05, EF10, EF15 and EF20 fuels, respectively. The values of smoke at 1000 rpm are about 8.91 BSN, 6.45 BSN, 6.31 BSN, 6.25 BSNand 6.12 BSN for diesel, EF05, EF10, EF15 and EF20 fuels, respectively. Thevalues of smokeat 2000 rpm are about 9.61 BSN, 7.45 BSN, 7.35 BSN, 7.15 BSNand 6.95 BSN for diesel, EF05, EF10, EF15 and EF20 fuels, respectively.Andas seen in Figures 14 and 15, smoke is shown to rapidly decrease with higher proportion of ethanol compared to diesel in the entire loadrange, engine speed and BMEP, respectively.

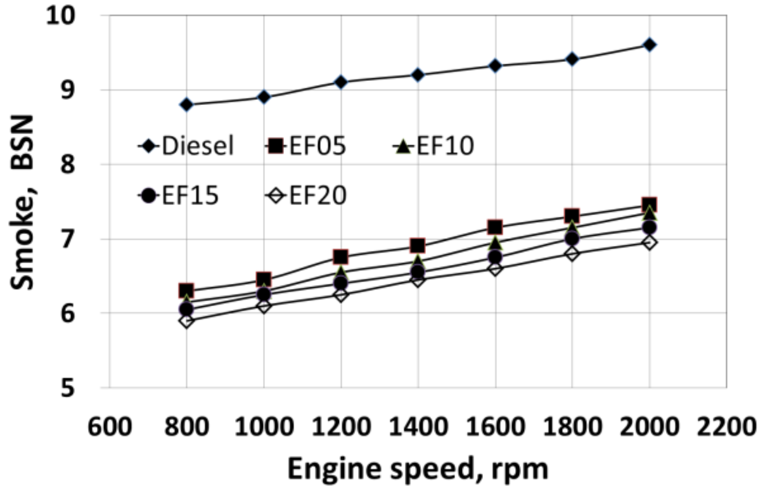

Fig14.Variation of smoke emissions with engine speed for different ethanol fractions.

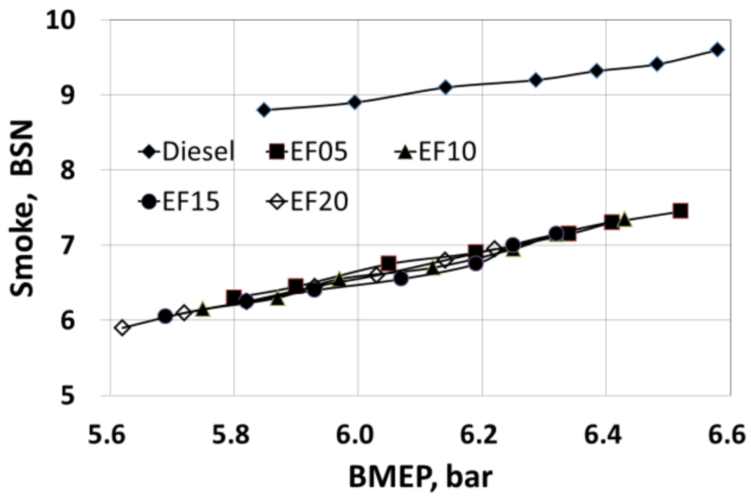

Fig15.Variation of smoke emissions with brake mean effective pressure, for different ethanol fractions.

IV.CONCLUSIONS

The following general conclusions can be drawn from the results presented in this study.

With an increasing fraction of ethanol, engine power slightly decreased for all engine speeds. The brake horse power of diesel was higher than those of EF05, EF10, EF15, and EF20, especially for high engine speeds.

The lower heating value of ethanol is lower compared to that of diesel, hence rising proportion of ethanol in the ethanol-diesel dual-fuels decreases the lower heating value of the ethanol-diesel dual-fuels which results in increased brake specific fuel consumption rate (BSFC).

The brake thermal efficiencies areshown to decrease with higher proportion of ethanol compared to diesel in the entire loadrange, engine speed.

CO emission is rapidly decreased with higher proportion of ethanol compared to diesel in the entire load range, engine speed and BMEP, respectively.

HC emission is rapidly decreased with higher proportion of ethanol compared to diesel in the entire engine speed.

Smoke is rapidly decreased with higher proportion of ethanol compared to diesel in the entire load range, engine speed and BMEP, respectively.

References

[1] A. Deep, Potential utilization of the blend of orange peel oil methyl ester and isopropyl alcohol in CI Engine,*SAE Paper* 2014-01-2778, 2014.

[2] A. Deep, N. Kumar, M. Kumar,A. Singh, D. Gupta, and S. Patel, Performance and emission studies of diesel engine fuelled with orange peel oil and n-butanol alcohol blends,*SAE Paper* 2015-26-0049, 2015.

[3] C. Mishra, P. Mishra, B. Kar, and N. Katiyar, Performance, emission and combustion characteristics of an agricultural diesel engine studies of diesel engine fuelled with blends of calophyllum vegetable oil and isopropyl alcohol,*SAE Paper* 2015-26-0055, 2015.

[4] I. Gravalos, D. Moshou, T. Gialamas, P. Xyradakis, D. Kateris, and Z. Tsiropoulos, Performance and emission characteristics of spark ignition engine fuelled with ethanol and methanol gasoline blended fuels,*www.intechopen.com*, 2011.

[5] H.L. Chum, and R.P. Overend, Biomass and renewable fuels,*Fuel Processing Technology*, *71*, 2001, 187–195.

[6] M.B. Celik, Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for gasoline engine,*Applied Thermal Engineering*, *28*, 2008, 396–404.

[7] S. Prasad, A. Singh, and H.C. Joshi, Ethanol as an alternative fuel from agricultural, industrial and urban residues,*Resources Conservation and Recycling*, *50*, 2007, 1–39.

[8] R. Michikawauchi, S. Tanno, Y. Ito, and M. Kanda, Combustion improvement of diesel engine by alcohol addition - investigation of port injection method and blended fuel method,*SAE Paper* 2011-01-0336, 2011.

[9] M. Christensen, and B. Johansson, Homogeneous charge compression ignition with water injection,*SAE Paper* 1999-01-0182, 1999.

[10] C. Ji, S. Wang, and B. Zhang,Performance of a hybrid hydrogen-gasoline engine under various operating conditions,*Applied Energy, 97,* 2012,584-589.

[11] L. Bromberg, and D. Cohn, Alcohol fuelled heavy duty vehicles using clean, high efficiency engines,*SAE Paper* 2010-01-2199, 2010.

[12] S. Chockalingam, and S. Ganapathy, Performance and emission analysis of a single cylinder constant speed diesel engine fueled with diesel-methanol-isopropyl alcohol blends,*SAE paper* 2012-01-1683, 2012.

[13] Q. Jiang Q, P. Gttikkutti, J. VanGerpen, and D. VanMeter, The effect of alcohol fumigation on diesel flame temperature and emissions,*SAE paper* 900386, 1990.

[14] S. Yousufuddina,M. Masoodb, Effect of ignition timing and compression ratio on the performance of a hydrogen–ethanol fueled engine, *International Journal of Hydrogen Energy*, *34*, 2009, 6945-6950.

[15] A.K. Singh, C. Mishra, V. Vibhanshu, and N. Kumar, Performance evaluation and emission studies of a single cylinder diesel engine fuelled isopropyl alcohol and diesel, *SAE Paper* 2013-01-1132,2013.