An Experimental Investigation of Spark Ignition Engine Fueled with Ethanol/Iso-octane and Methanol/Iso-octane Fuel Blends

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Abstract

Alcohols have been used as a fuel for engines since 19th century. Among the various alcohols, ethanol and methanol are known as the most suited renewable, bio-based and ecofriendly fuel for spark-ignition (SI) engines. The most attractive properties of ethanol and methanol as an SI engine fuel are that it can be produced from renewable energy sources such as sugar, cane, cassava, many types of waste biomass materials, corn and barley. In addition, ethanol has higher evaporation heat, octane number and flammability temperature therefore it has positive influence on engine performance and reduces exhaust emissions. In this study, the effects of unleaded iso-octane, unleaded iso-octane–ethanol blend (E10) and isooctane-methanol blend (M10) on engine performance were investigated experimentally in a single cylinder four-stroke spark-ignition engine. The tests were performed by varying the throttle position, engine speed and loads. Three sets of observations were recorded at (1301 rpm, 16.8 Kg load), (1468 rpm, 15.8 Kg load) and (1544 rpm, 10 Kg load) for all tested fuels. The results of the engine test showed that IP, IMEP, Volumetric efficiency and thermal efficiency was higher for the E10 fuel and BSFC was lower. In general, most suited blend for SI engines has been specified as a blend of 10% ethanol. It was also observed that better performance was recorded during second set of observation for all the tested fuels. It was also found that ethanol–gasoline blends allow increasing compression ratio (CR) without knock occurrence.

***Keywords**: Ethanol-Iso-octane blend, Methanol-Iso-octane blend, Iso-octane, Engine speed, IMEP*

1. Introduction

Alternative fuels are derived from resources other than petroleum. The benefit of these fuels is that they emit less air pollutant compare to gasoline and most of them are more economically beneficial compared to oil and they are renewable. The most common fuels that are used as alternative fuels are natural gas, propane, ethanol, methanol and hydrogen. Lots of works have been done on engine operating with these fuels; few numbers of publications have compared some of these fuels together.

Ethanol and methanol are alcohol- based fuels made by fermenting and distilling starch crops, such as corn. Both ethanol and methanol produce less emission than gasoline and increasing air pollution is one of the most important problems of developed countries today. Exhaust emissions from motor vehicles has a main role in this pollution. It is not sufficient to change the design of motor to cope with the legal regulations, so it is necessary to continue to work on alternative fuel technologies. It is vital that the alternative fuel used must be produced from renewable resources and it must be usable directly without requiring any major changes in the structure of the engine. Alcohols have been used as a fuel for engines since 19th century. Among the various alcohols, ethanol is known as the most suited fuel for spark ignition (SI) engines. Usages of alcohols as a fuel for spark ignition engines have some advantages to compare the gasoline. Both methanol and ethanol have better anti-knock characteristics than gasoline. The engine thermal efficiency can be improved with increasing of compression ratio. Alcohols burns with lower flame temperatures and luminosity owing to decreasing the peak temperature inside the cylinder. So that the heat losses and NOx emissions are lower.

Both methanol and ethanol have high latent heat of vaporization. The latent heat cools the intake air, so the increased charge density and increases volumetric efficiency. However the oxygen content of methanol and ethanol reduces their heating value compared to gasoline. As a disadvantage for methanol and ethanol which reduce the vehicle range per liter of fuel tank capacity [1–6].

Hsieh [7] investigated experimentally the engine performance and emission of a spark ignition engine, using ethanol–gasoline blend fuels in ratios of 5%, 10%, 20% and 30%. The results showed that with increasing the ethanol rate, the heating value of the blended fuel decreased, while the octane number of the blended fuels increased. By using the ethanol–gasoline blended fuels the engine torque and specific fuel consumption slightly increased.

Abdel-Rahman and Osman [8] conducted performance tests on a variable compression ratio engine using different percentages of ethanol in gasoline fuel up to 40%. With increasing of ethanol amount in the blend, the octane number also rise up, but decrease the heating value. The power increment was observed with the addition of the ethanol up to 10% at compression ratio of 10:1. The best compression ratios were found to be 10, 11 and 12 for 20%, 30% and 40% ethanol to give maximum indicated power, respectively.

Palmar [9] found that the octane number had an increment of five and the engine output increased 5% for every 10% ethanol addition to gasoline. Hamdam and Jubran [4] concluded that under partial load the blended fuel containing 5% ethanol had the best engine performance and the thermal efficiency was increased by 4 to 12%.

Badwan [10] studied blended fuels ranging from E10 to E70 and concluded that the highest antiknock capability was obtained with E50. One major objective of using ethanol gasoline blended fuel is its ability to lower the emissions of CO and UHC. Taylor et al[8] compared the performance of four alcohols. They found little difference in combustion efficiency of the four alcohols from gasoline. However, using alcohol can increase charge density because of the evaporative cooling in the intake manifold.

In Bayraktar [11], the most suitable blend for SI engines, from the engine performance and CO emissions points of view, was determined to be 16.5% theoretically and 7.5% experimentally. CO emission was reduced while NO emission was found to increase due to the rising cylinder temperature.

In the experimental study of Al-Hasan [12], the effects of usage of unleaded gasoline–ethanol blends on spark ignition engine performance and exhaust emission were investigated. The results showed that ethanol addition leads to an increase in brake power, brake thermal efficiency, volumetric efficiency and fuel consumption by about 8.3%, 9%, 7% and 5.7% mean average values, respectively. The best result at the engine performance and exhaust emissions was obtained by usage of 20% ethanol fuel blend.

W. Dai [13] did the study of engine cycle simulation of ethanol gasoline blends. In this study, an ethanol model has been developed using a Ford propriety engine CAE tool, GESIM (General Engine Simulation Program) for the simulation of ethanol and ethanol – gasoline blends. GESIM was then validated against experimental data in a 3.0 L V6 2-valve engine. It was concluded that GESIM has successfully predicted the trends of engine burn rates, fuel consumption, exhaust temperature, and various exhaust emissions for E22 and E85 fuels.

C. Wei [14] did the study of air – fuel ratio on engine performance and pollutant emission of an SI engine using ethanol – gasoline blended fuels. The influence of air – fuel ratio (0.6 to 1.4) on torque, brake specific fuel consumption, CO emission, CO2 emission, HC emission, were evaluated for ethanol – gasoline blended fuels under different rotational speeds (3000 & 4000 rpm) and throttle openings. It was concluded that torque output increases slightly at small throttle valve opening when ethanol - gasoline blended fuel was used and CO and HC emission were reduced with the increase of ethanol content in the blended fuel. It was also found that CO2 emission per unit horse power output was similar or less than that for gasoline fuel.

H. S. Yucesu [15] did comparative study of mathematical and experimental analysis of spark ignition engine performance used ethanol – gasoline blend fuel. In this study, ethanol- unleaded gasoline blends (E10, E20, E40, and E60) were tested in a single cylinder, four stroke spark ignition and fuel injection engine by varying the ignition timing, relative air fuel ratio and compression ratio at a constant speed of 2000 rpm and wide open throttle. It was concluded that torque with blended fuels was higher than that of base gasoline in all the speed range and a significant reduction in HC emissions was observed as a result of the leaning effect and additional fuel oxygen caused by the ethanol addition. It was suggested that higher compression ratios can be used with ethanol gasoline blends without knock.

L. Shenghua [16] did the study of spark ignition engine fuelled with methanol gasoline blends. The engine was three cylinders with a bore of 68.5 mm. The methanol was blended with gasoline containing 10, 15, 20, 25, and 30% in volume. The engine power, torque and brake thermal efficiency are measured with the change in speed at WOT condition with the increased fraction of methanol. Engine power and torque decreases while the brake thermal efficiency is improved. The maximum pressure is higher than than that of pure gasoline operation under

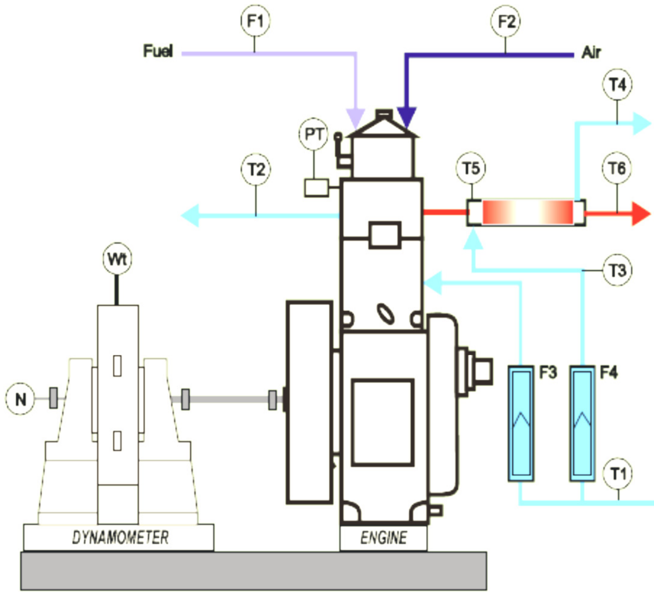

Fig1. Schematic arrangement of the spark ignition engine

F1 Fuel consumption kg/hr

F2 Air consumption kg/hr

F4 Calorimeter water flow kg/hr

T3 Calorimeter water inlet temperature 0K

T4 Calorimeter water outlet temperature 0K

T5 Exhaust gas to calorimeter inlet temperature. 0K

T6 Exhaust gas from calorimeter outlet temperature. 0K

the same engine speed and throttle opening (50% WOT) when engine fuelled with M20.

M. KOc [17] evaluated the effects of unleaded gasoline and unleaded gasoline ethanol blends (E50 and E85) on engine performance and pollutant emissions experimentally in a single cylinder four-stroke spark ignition engine at two compression ratios (10.1 and 11.1) at varying engine speed 1500 rpm to 5000 rpm. The effect of unleaded gasoline- ethanol blends on engine torque, BSFC and HC emission were evaluated at different compression ratio. It was concluded that ethanol addition to unleaded gasoline increase the engine torque, power and fuel consumption and reduce carbon monoxide (CO), nitrogen oxides (NOX) and hydrocarbon (HC) emissions.

Mustafa KOc [18] evaluated the effects of ethanol – unleaded gasoline blends on engine performance and exhaust emissions in a spark- ignition engine. In this study, the effects of unleaded gasoline and unleaded gasoline ethanol blends (E50 and E85) on engine performance and pollutant emissions were investigated experimentally in a single cylinder four-stroke spark ignition engine at two compression ratios (10.1 and 11.1) at varying engine speed 1500 rpm to 5000 rpm. The effect of unleaded gasoline- ethanol blends on engine torque, BSFC and HC emission were evaluated at different compression ratio.

The literature survey shows that using ethanol and methanol in SI engines by blending with iso-octane is more practical than using it alone. If ethanol and methanol production can meet the demand and cost of blended fuels can compete with that of conventional iso-octane, widespread use of E10 and M10 blends can be possible. For this reason, the present study is focused on this topic. Here, the effects of ethanol and methanol addition to iso-octane in 10% concentrations on engine performance are examined by conducting experimental studies.

2. Experimental Analysis

The experiments were conducted at three (1301, 1468 &1544 rpm) engine speeds, with three engine loads (16.82 Kg, 15.8 Kg and 10 Kg) by varying the throttle openings. Three different fuels (Iso-octane, E10, M10) were tested. These fuels were iso-octane, iso-octane ethanol blend E10 and iso-octane-methanol blend M10, the numbers following E and M indicate percentage of volumetric amount of ethanol, methanol. Properties of ethanol, methanol, and gasoline are shown in table 1. Engine indicated power, brake power, friction power, indicated mean effective pressure, brake mean effective pressure, turning moment brake specific fuel consumption, exhaust gas temperature, volumetric efficiency and thermal efficiency were measured during the experiments. No data was taken until speed and load were maintained at 1% of the fluctuation. For each experiment, air fuel ratio was changed to maintain the same speed and load..

Table 1 Comparison of fuel properties

Property	Methanol	Ethanol	Iso-octane
Chemical formula	CH_3OH	C_2H_5OH	C_8H_{18}
Molecular weight(Kg/kmol)	32.04	46.07	114.228
Oxyzen present (wt %)	49.9	34.8	-
Density (g cm^{-1})	792	789	740
Freezing point at 1 atm (^{0}C)	-97.778	-80.0	-107.378
Boiling temperature at 1 atm (^{0}C)	64.9	74.4	99.224
Auto-ignition temperature(^{0}C)	463.889	422.778	257.23
Latent heat of vaporization at 20^{0}C (KJ/Kg)	1103	840	349
Stoichiometric air/fuel ratio (AFR)	6.47	9.0	15.2
Lower heating value of the fuel (KJ/Kg)	20000	26900	44300
Research octane number (RON)	111	108	100
Motor octane number (MON)	92	92	100

Table 2 Specification of the engine

Type	1 cylinder, 4 stroke, water cooled
Cylinder bore and stroke	110 mm, 87.5 mm
Compression ratio	10
Maximum power	4.5 kW at 1800 rpm
Spark variation range	0 – 70 deg btdc
Dynamometer	Eddy current, water cooled, with loading unit
Air Box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 ltr, dual compartment, with fuel metering pipe of glass
Calorimeter	Pipe in pipe
Piezo sensor	Combustion 5000 psi
Crank angle sensor	1 deg, speed 5500 rpm with tdc pulse
Temperature sensor	Type RTD, PT 100 and Thermocouple, type k
Load indicator	Digital, range 0-50 kg, supply 230 V AC
Fuel flow transmitter	DP transmitter, Range 0- 500 mm WC
Air Flow Transmitter	Pressure transmitter
Rota meter	Engine cooling 40- 400 LPH; Calorimeter 25-250 LPH

The setup consists of single cylinder, four stroke, Multi-fuel, research engine connected to eddy current type dynamometer for loading. The operation mode of the engine can be changed from diesel to Petrol or from Petrol to Diesel with some necessary changes. In both modes the compression ratio can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. The injection point and spark point can be changed for research tests. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and hardware interface. Rotameters are provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. Lab view based Engine Performance Analysis software package "Engine soft" is provided for on line performance evaluation.

3. Effect of Ethanol-Iso-octane and Methanol – Iso-octane Blends on Engine Performance

This paper is intended to study engine performance when it utilizes low fraction of ethanol-iso-octane and methanol-iso-octane blends. Three sets of observations were recorded for the different purpose of engine test containing iso-octane, E10 (iso-octane & 10% of ethanol in volume blend) and M10(iso-octane & 10% of methanol in volume blend) fuels. Three sets of observations are namely 1. (1301 rpm, 16.82 Kg load), 2. (1468 rpm, 15.8 Kg load) and 3.(1544 rpm, 10 Kg load).

3.1 INDICATED POWER

Under the same engine speed and load, see in fig. 2, when the engine is fuelled with different fuels (E10, M10, & iso-octane). The indicated power is higher than that of iso-octane for E10 and M10 fuels. It is maximum for E10 and minimum for iso-octane and maximum increment is 20.2, 15.1 and 8.72%, respectively for 1st, 2nd and 3rd set of observation. The engine power of M10 is about 5.71, 4.8, and 2.9 % higher in comparison to iso-octane. It is because of the reason that oxygenated fuels have better combustion efficiency and thermal efficiency. Thermal efficiency of E10 and M10 are nearly 20 and 5% higher than the base fuel. It is also shown in figure that indicated power increases with the increase in engine speed and loads.

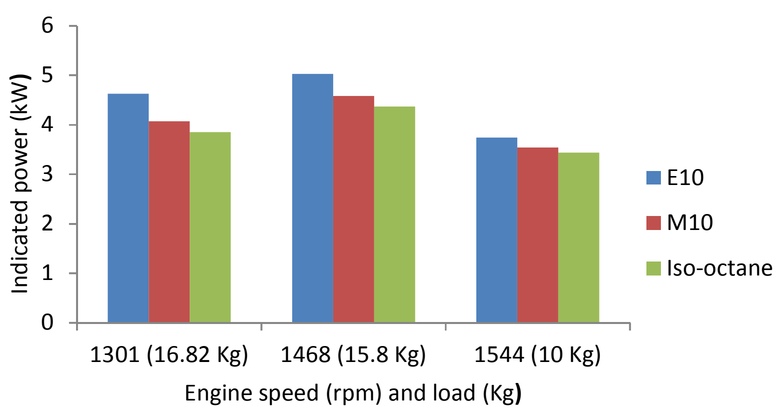

Fig2. The combined effect of engine speed and load on indicated power

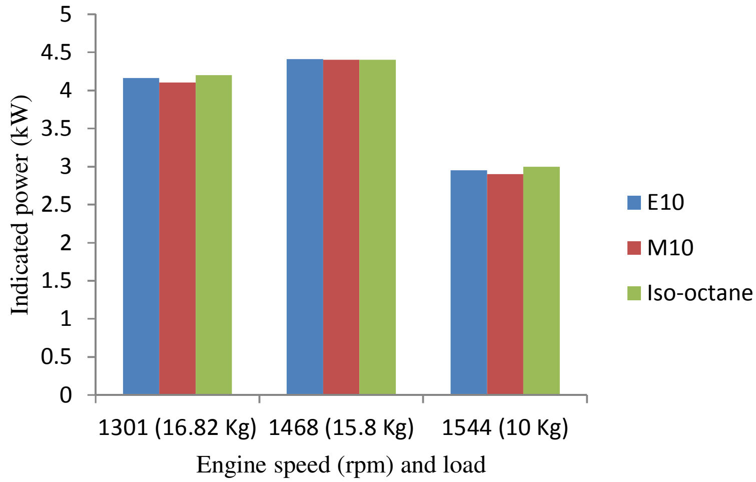

Fig3. The combined effect of engine speed and load on the brake power

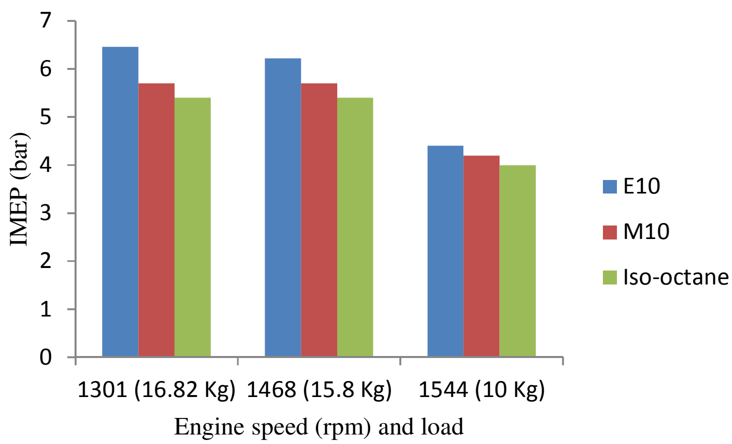

Fig4. Combined effect of speed and load on IMEP

3.2 Brake Power

Fig.3 shows the variation in brake power with respect to combined effect of engine speed and load for all tested fuels. It is shown in the figure that brake power is maximum and equal at medium load and medium speed for all tested fuels. The brake power of M10 is slightly lower than base fuel because of the reason that friction power of M10 is much lower than the iso-octane.

3.3 IMEP (indicated mean effective pressure)

Fig.4 shows the variations in indicated mean effective pressure with the change in engine speed and the load. Figure shows that IMEP increases with the increase in engine speed for all the tested fuels. IMEP is maximum for the E10 fuel and this increment is 19.6, 15.1 and 10% greater than the base fuel at all set of observations, respectively. IMEP for M10 is nearly 5% greater than the base fuel for all set of observations. It is because of the reason that thermal efficiency and volumetric efficiency of E10 and M10 fuels are much higher which results in

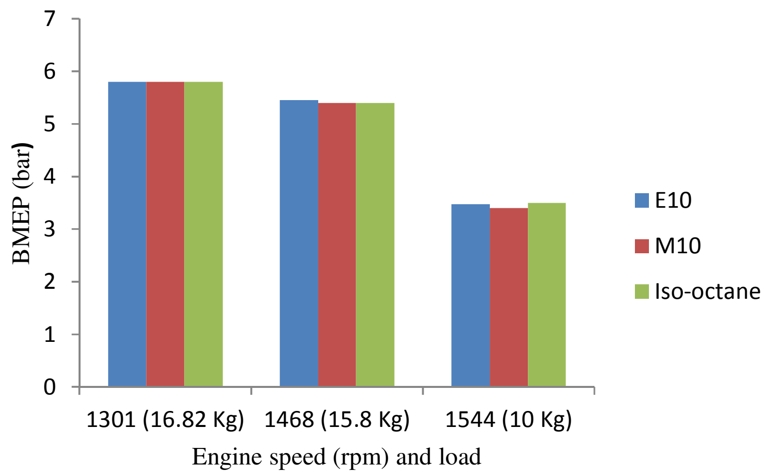

Fig5. The combined effect of engine speed and load on the BMEP of ethanol and methanol fuel blends

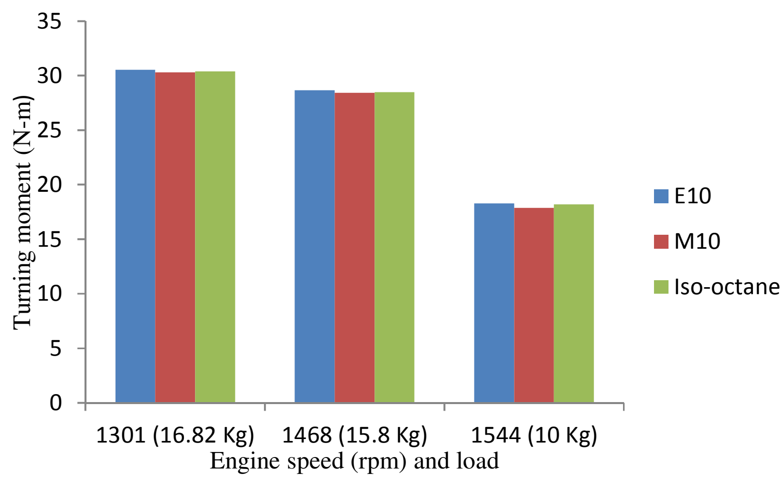

Fig6. The combied effect of engine speed and load on the engine torque for the ethanol and methanol blend fuel

higher indicated mean effective pressure in spite of lower heating value.

3.4 BMEP

The result for the ethanol and methanol blends (Fig.5) show a significant improvement in BMEP during first set of observation when compared with other observations. In naturally aspirated engines, brake mean effective pressure is not stress limited, it then reflects the product of efficiency(ability to induct air), fuel air ratio (effectiveness of air utilization in combustion and fuel conversion efficiency). In supercharged engines BMEP indicates the degree of success in handling higher gas pressures and thermal loading. It is clearly observed from the figure that BMEP increases with the increase in engine load.

3.5 Turning moment

Fig.6 shows the variations in turning moment with the change in speed and load for the E10, M10 and iso-octane fuels. In general, the highest turning moment is observed with the E10. This is explained with several reasons. Beneficial effect of ethanol as an oxygenated fuel is a possible reason for more complete combustion, thereby increasing the torque. In addition, a larger fuel for the same volume is injected to the cylinder due to higher density of ethanol. This results in increase in torque and power. And finally, the latent heat of evaporation of blended fuels is higher than that of base gasoline; this provides lower temperature intake manifold and increases volumetric efficiency. The charge into the cylinder directly affects on torque and power. The average increment in engine torque compared with Iso-octane was about 0.68% for E10 fuel.

3.6 Exhaust temperature

Fig .7 shows the combined effect of engine speed and load on the exhaust gas temperature corresponding to all tested fuels. It is shown in the figure that exhaust temperature is maximum at the medium speed and medium load for all tested fuels. It is also shown from figure that exhaust temperature is maximum for iso-octane for all set of observations followed by methanol. Exhaust gas temperature is minimum for the E10 for all set of observations. The heating value of iso-octane is greater than E10 and M10 and thermal efficiency is low so more heat would be rejected with the exhaust gases. These variations in exhaust temperature can be attributed to increase in thermal efficiency or A/F ratio which affects the combustion temperature. Higher combustion temperature leads to higher exhaust temperature.

3.7 Volumetric efficiency

Fig. 8 represents combined effect of engine speed and load on the volumetric efficiency for all the tested fuels. It is shown in the figure that volumetric efficiency of E10 and M10 is nearly 10% higher than the base fuel for two sets of observation and for third set of observation, volumetric efficiency is much lower and it is because of the reasons that as liqid fuels have high latent heat of vaporization, they produce a cooling effect on the intake charge during vaporization. Therefore, there will be an increase in intake charge density and consequently in volumetric efficiency. A/F ratio is another important parameter that affects volumetric efficiency. When stoichiometric A/F ratio is high that means there is more quantity of air injected in inlet air and results in increased volumetric efficiency. The methanol and ethanol has high latent heat of vaporization than the base fuel and A/F ratio is also high therefore volumetric efficiency of methanol is high at medium speed and loads. The volumetric efficiency of iso-octane is lower than the E10 and M10 and it is because of the reason that latent heat of vaporization of iso-octane is lowest among all the fuels. The latent heat of vaporization of ethanol and methanol is 3.16 and 2.4 times greater than the iso-octane. It is also seen from the figure that at low load and high speed, volumetric efficiency is low for all the tested fuels because of rich fuel is supply.

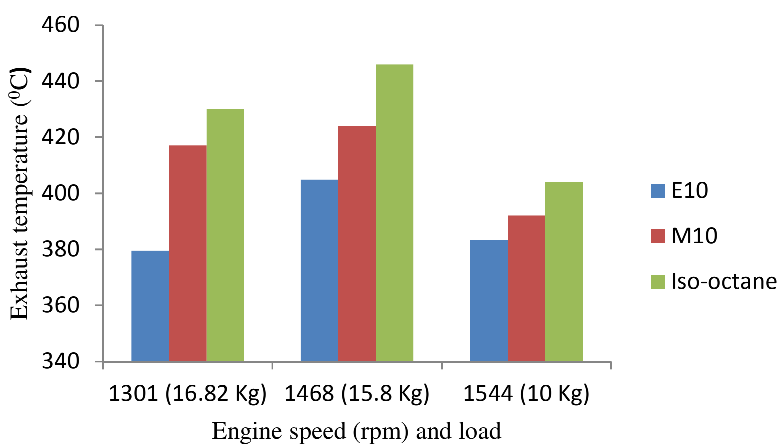

Fig7. The combined effect of speed and load on the exhaust temperature

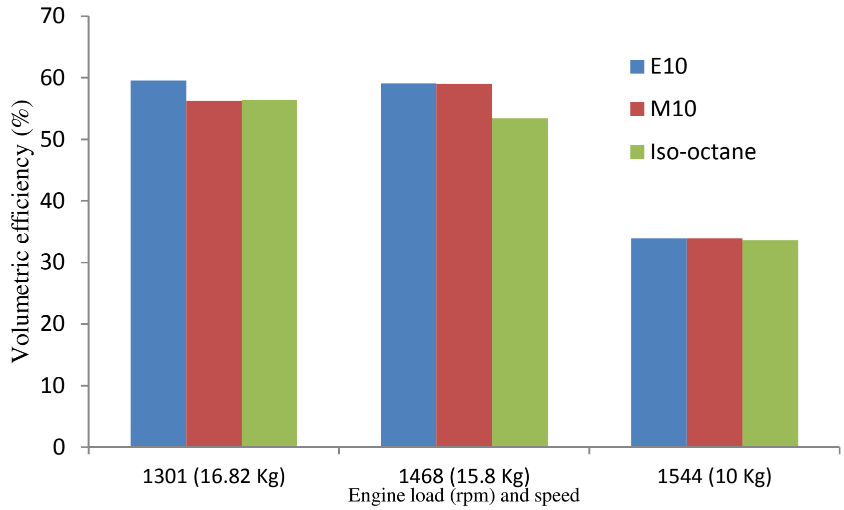

Fig8. The combined effect of engine load and speed on the volumetric efficiency

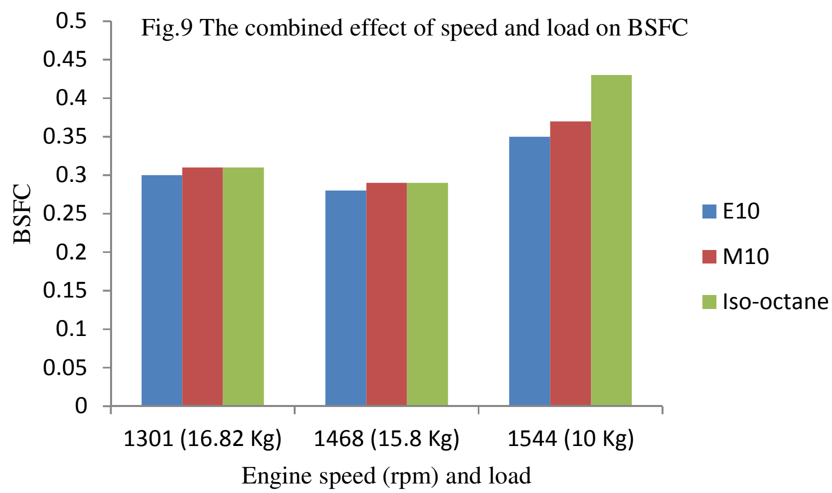

Fig9. The combined effect of speed and load on BSFC

3.8 BSFC

Fig.9 shows the combined effect of engine speed and load at the brake specific fuel consumption for all the fuels. It is well known fact that heating value of fuel affects the BSFC. The lower energy content of ethanol-iso-octane and methanol iso-octane fuels causes some increment in BSFC of the engine when it is used without any modification. The increment mainly depends upon the percentage of ethanol and methanol addition in iso-octane. The heating value of ethanol & methanol are approximately 39.27% &

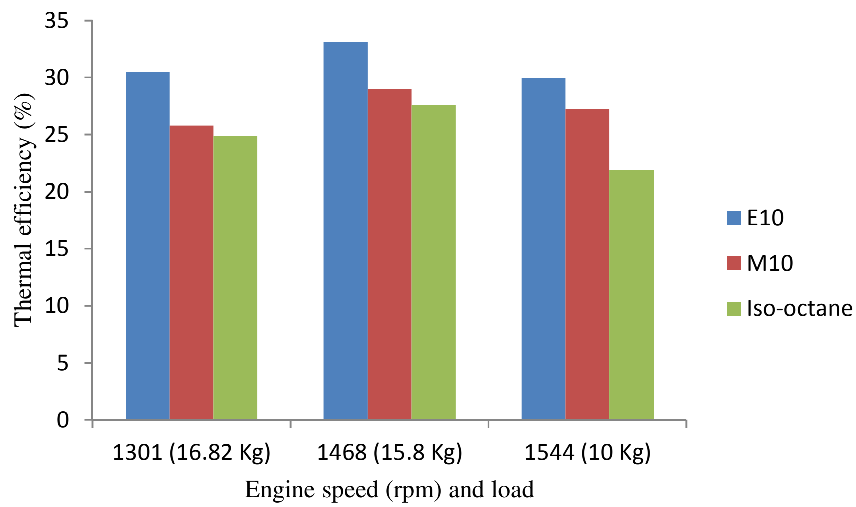

Fig10. The combined effect of engine speed and load on thermal efficiency

54.85% less than the values of iso-octane. Therefore, more blends of fuel are required to produce the same power at the same operating conditions due to its lower heating value in comparison to base fuel. As a result, BSFC increases. However, as mentioned earlier, ethanol and methanol addition to iso-octane makes the engine operation leaner and improves combustion and performance. Therefore, the thermal efficiency of E10 is 22.4, 20 and 36.8% greater than the base fuel and approximately 5% greater for M10 fuel. For these reason, brake specific fuel consumption of blends are lower than those of iso-octane fueled engine

3.9 Thermal efficiency

Fig.10 shows the combined effect of engine speed and load on thermal efficiency for all the fuels. It is shown from the figure that thermal efficiency of E10 and M10 fuels is much higher than the base fuel. It is 22.4,20 and 36.8% higher for E10 and approximately 5% for the M10. It is because of the reason that volumetric efficiency of E10 and M10 fuels are higher than the base fuel. For all sets of observations, volumetric efficiency of E10 is higher followed by M10.

Conclusion:

In this study, engine performance was measured on the utilization of the ethanol- iso-octane (E10) and methanol iso-octane blended fuels (M10) under different engine speed and different loads. General results concluded from this study can be summarized as follows:

1. The value of IP, BP, IMEP, Exhaust temperature, volumetric efficiency and thermal efficiency was higher for the second set of observation for all the tested fuels.
2. Ethanol and methanol addition to iso-octane leads to leaner operation because of increased volumetric efficiency and improves combustion. Consequently, the cylinder pressure and temperature increases.
3. The value of BMEP and turning moment was slightly higher for first set of observations because of higher loads.
4. The value of BSFC was maximum for the third set of observation and minimum for second set for all the tested fuels and its maximum value was for base fuel.
5. IP, IMEP, Volumetric efficiency and thermal efficiency was higher for the E10 fuel.
6. In general, most suited blend for SI engines has been specified as a blend of 10% ethanol. This blend gives better performance at medium speed and medium loads.

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