International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Mathematical Modelling of Engineering Problems
Vol. 6, No. 1, March, 2019, pp. 69-76
Journal homepage: http://iieta.org/Journals/MMEP

Experimental investigation on multi-cylinder SI engine fueled conventional gasoline, ethanol blends, and micro-emulsion as an alternative fuel

Ufaith Qadri*, Mohhamad Marouf Wani

Faculty of Engineering, National Institute of Technology Hazratbal Srinagar, Jammu & Kashmir India Mechanical Engineering Department, Srinagar 190006, India

Corresponding Author Email: ufaith.qadri@gmail.com

https://doi.org/10.18280/mmep.060109

Received: 26 July 2018
Accepted: 3 September 2018

Keywords:
performance, emissions, bio fuels, micro-emulsions, 3-cylinder

ABSTRACT

In this contribution the two alternative fuels, firstly blended fuel of ethanol and gasoline (i.e. E15%+Gasoline 85%), and secondly, micro-emulsion (i.e. Gasoline 90%, E8% and H_2O 2%) were compared with conventional 100% Gasoline fuel for checking the performance, combustion, and emission characteristics of 3-Cylinder SI engine experimentally. The blended fuel containing 15% ethanol with 85% gasoline and the micro-emulsion based fuel which contains H_2O molecule in addition to simple blending were prepared in the lab, and both the fuels were tested experimentally on a 3-cylinder SI engine based test rig in order to find out which alternative fuel is more efficient in terms of performance and emission characteristics. The results depicted that although both the micro-emulsion based fuel and the blended fuel showed reduction in power as compared to conventional 100% Gasoline fuel, but the emissions were least for the micro-emulsion based fuel followed by the blended fuel. The CO, HC, and NOx emission decreased for both ethanol blended gasoline fuel and the micro-emulsion based fuel as compared to the 100% Gasoline. The injected water in the micro-emulsion fuel reduces the temperature inside the combustion chamber which is responsible for this decrease in NOx emission. For combustion analysis, pressure v/s the crank-angle showed slight decrease for the blended fuel (i.e. 15% ethanol with 85% Gasoline) and the micro-emulsion based fuel (i.e. Gasoline 90%, E8% and H_2O 2%) as compared to the conventional 100% gasoline fuel. This can again be attributed to the fact that the micro-emulsion based fuel has a lower combustion chamber temperature compared to the conventional 100% Gasoline.

1. INTRODUCTION

The effect of water injection on the performance of an SI engine with hydrogen as a fuel has been studied by [1]. The problems related to emissions and effects of injected water into the engine cylinder to the air-fuel ratio and combustion were investigated. Experimental engine had one cylinder and four valves, and was manufactured by the Ford Motor Company. Research [1] concluded that water injection is a better technique for reducing NOx emissions. Basically, the injection of water into the spark ignition (SI) helps control the temperature and pressure of the combustion process. Therefore, this method is useful for controlling undesirable emissions. Improvement of the volumetric efficiency of the engine and its output power can also be achieved with the help of water injection technology. Water supply systems or steam systems have been used in gas turbine engines since the last century [2]. In fact, its use in an internal combustion engine running on conventional fossil petroleum fuels is rare. In addition, the water injection system is also seen as a cheaper and simpler solution for increasing the output power of the SI engine. Wu et al. [3] proposed a new concept that combines oxygen injection internal combustion engine cycle and water injection process to improve thermal efficiency. Water is passed through the engine coolant and exhaust system, heated and then injected into the cylinder. The heat waste stored in the exhaust gas has been recovered for work and the achievement is high in thermal efficiency. The calculated results showed that thermal efficiency reached 53% and 67% when the water injection temperature was 120°C and 200 degrees Celsius respectively. In addition, the indicated thermal efficiency has increased in similar test conditions by 32.1% to 41.5%, which has increased both engine load and water injection loads. For many years of water injection technology, self-breeding engine has also been used to control NOx emissions. Kohketsu et al. [4] focused on the effect of NOx and PM emission in traditional diesel engines by using stratified fuel-water sprays. using water injection in combination with EGR, Euro V emission levels could be achieved by heavy duty engines [5]. In addition, this system is also used to increase the working stability under higher compression ratios [6]. Boretti [7] used water injection in combination with turbo charging, with ethanol as a fuel to explore the possibility of reducing the tendency to detonate, increasing the charge efficiency, and controlling the temperature of gases flowing to turbine. The possibility of the engine using higher compression ratios and boost pressures was also investigated by a study reported by Cesur et al. [8] and involved investigations on an original engine in combination with water injection under selected operating conditions. Together with water, steam was injected into the engine. The optimum steam ratio in comparison with the fuel mass was fixed at 20%, with the investigation focusing on the performance and emission parameters. The presence of water injected into the cylinder may improve atomization and mixing which leads to increase in the combustion efficiency and, in effect, higher engine output [9-10].

2. EFFECT OF WATER ON MICRO-EMULSION FUEL AND WORK DONE DURING COMPRESSION STROKE

As the injected water injected vaporizes it conducts the required latent heat from the combustible charge injected into the cylinder leading to a decrease in temperature and in-cylinder pressure. Furthermore, the decrease in the in-cylinder pressure at the end of the compression stroke is useful for improving the engine efficiency as a consequence of the decrease compression work. It is evident that the highest in cylinder pressure was achieved using pure gasoline while there was a decreasing in-cylinder pressure as the quantity of injected water was increased. When water is injected into the intake air flow towards the end of the compression stroke, it becomes heated due to the high temperature of the compressed air in the cylinder. The inert water vapor absorbs part of the heat released and, in effect, lowers the in-cylinder pressure instantaneously. The water addition at suitable times may be used to control in-cylinder pressure.

The vaporized water could lead to increase in pressure due to the phase change. In this situation, the pressure decreases linearly with the amount of injected water. A higher quantity of injected water into the cylinder will cause more heat absorption and pressure decrease as a result. The reduction in pressure is not only helpful for reducing the compression work, but also helps in reducing the suction gas losses resulting from blow-by past the piston rings, especially for engines with high compression ratios. However, the injected water into cylinder along with air fuel mixture can also be taken through piston rings more or less, which could have deteriorating effects on the oil lubrication properties. This problem needs to be considered in detail under different operating conditions via extensive engine testing. The greatest benefit of water injection is an increase in the knock resistance by the cooling of overheated hot spots in the combustion chamber, especially for engines with high compression ratios. Water injection is significant for increasing the conversion efficiency of changing heat energy to pressure within cylinder of an engine leading directly to a lower heat transfer to the cylinder walls

On the whole, water injection is a very effective strategy for reducing NOx emissions, promoting complete combustion and for controlling combustion knock. However, the compatibility of prolonged usage of water in the cylinder has to be studied in detail as water vapor could lead to changes in the combustion process. Water vapours could also weaken the strength of the air fuel mixture, prolonging the combustion duration and ultimately affecting emission control. Modern engines use electronic control units (ECU) for controlling fuel and spark ignition timing. It is necessary for water injection to be controlled by the ECU. This way, ECU could adjust the spark ignition timing and the injected fuel mass once the water injection system is activated. By this means, a programming for water injection control should be an integral part of ECU design or used with other electronic module that is connected to the ECU. Wang et al. [11] experimentally performed a study to investigate the knock suppression and engine efficiency using a dual-fuel gasoline engine fuelled with alcohol-gasoline mixtures at high compression ratios. Storch et al. [12] examined the influences of ethanol-isooctane mixtures on combustion characteristics and soot formation of a SI engine. Huang et al. [13] conducted a study on ethanol direct injection plus gasoline port injection engine in both single and dual fuelled conditions using a turbulence model with detailed engine geometry.

Corsetti et al. [14] reported the results obtained from Fourier transform infrared spectroscopy of ethanol-gasoline blends. Masum et al. [15] investigated the influences of different ethanol-gasoline mixtures on fuel properties, performance and emissions of a SI engine.

Dogan et al. [16] examined the influences of ethanol-gasoline blends on the formation of exhaust emissions and performance characteristics of a SI engine based on the first and second laws of thermodynamics. It was reported that ethanol addition into the gasoline provided reduction in carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen oxide (NO_X) emissions but an increment in hydrocarbon (HC) emission was observed.

Phuang wongtrakul et al. [17] maximized the BTE of a commercial SI engine by optimizing the ratio of ethanol in ethanol-gasoline blends. They reported that 50% ethanol can maximize the BTE with an engine speed of 2000–2500 rpm. Poran and Tartakovsky [18] discussed the concept of a direct injection ICE with thermo chemical recuperation realized through steam reforming of methanol. Li et al. [19] investigated the combustion characteristics and emission formations of a SI engine fuelled with methanol-ethanol-butanol-gasoline mixtures under various equivalence ratios, engine loads and alcohol ratios. It was seen that methanol-gasoline mixtures provide the lowest NOx formation, while ethanol-gasoline mixtures show the lowest HC emissions. Almeida et al. [20] examined the fuel consumption and pollutant emissions from a vehicle operating with gasoline-ethanol blend (E22), hydrous ethanol (E100) and hydrogen produced onboard.

In this investigation experiments were carried out on 3-cylinder SI engine based test rig in order to check its performance and emission characteristics using blends of E 15%+ Gasoline 85%, micro-emulsion blends (Gasoline 90%, Ethanol 8% and H_2O 2%) and conventional 100% Gasoline fuel. The main objective of this research is to reduce the emission from 3-cylinder SI engine and to improve its performance. Moreover, water was added as an additive in micro-emulsion fuel which could potentially help to control the peak temperature during combustion. This reduction in peak temperature reduces the NOx emissions, and proves to be efficient alternative fuel. Other emissions like HC and CO also decreased using alternative fuel micro-emulsion. This reduction is due to in build oxygen atom in ethanol, and water molecule which has oxygen atom present in its molecular structure reduces the CO and HC emissions by complete combustion of fuel forms CO_2 and H_2O molecule.

3. EXPERIMENTAL SET UP OF FOUR STROKE 3-CYLINDER SI ENGINE WITH HYDRAULIC DYNAMOMETER

Engine Analysis software is developed by TECH-ED for testing of performance analysis and combustion analysis of the given Engine Test Setup. Engine analysis soft is designed to install, uninstall and run on Windows 7 and above

- Interface to setup and user with menu and commands
- Configuring as per Engine Test Setup under use
- Test setup measurement and analysis
- Data acquisition and data logging
- Online performance and combustion data calculations
- Report and graph generation and printing.

Table 1. Test rig specification

Engine	4s 3c WC Petrol Engine
Make/Model	Maruti-Omni
Max.Power	27.6kw @ 5000 Rpm
Max.Torque	6.1 Kg M @3000 Rpm
Working Range	10hp @ 2500 Rpm
Bore	68.5 mm
Stroke Length	72 mm
Compression Ratio	8.5:1
Displacement	796 cc
Starting	Self Start
Method of Ignition	Spark Ignition
Orifice dia	20 mm

In fig. 1 there is the sample of micro-emulsion which was prepared in the IC Engine lab used as an alternative fuel in engine in order to check its performance and emission characteristics on 3-cylinder spark ignition engine based test rig. The composition used for the preparation of micro-emulsion fuel was Gasoline 90%, Ethanol 8%, and H_2O 2%. The final composition prepared was crystal clear transparent in colour, and thermodynamically stable. For the preparation of the micro-emulsion fuel magnetic stirrer was used for the blending of ethanol, gasoline, and H_2O.Burrete stand was used for placing the burette in the desired position for dropping the H_2O Continuously in the beaker till it becomes crystal clear and transparent in colour which remains stable at wide operating temperatures.

3.1 Experiment performed on multi cylinder SI engine using micro-emulsion as an Alternative fuel

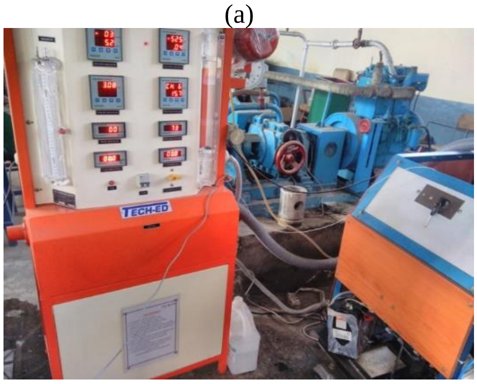
(a)

(b)

Figure 1. (a) Shows the preparation of micro-emulsions by using Gasoline, Ethanol, and H_2O as an additive in the fuel; (b) Shows the final prepared crystal clear thermodynamically stable micro-emulsion

3.2 Description of the test rig

(a)



(b)

Figure 2. (a) 3-cylinder SI engine based Test Rig; (b) Data Acquisition system attached to the PC and collecting the data through encoder

Figure 2 represents the data acquisition system which is connected to the computer and displaying the performance and Combustion parameters for 3-cylinder SI engine based test rig. The specifications of the test rig are given in Table1.The setup consists of three cylinder, four strokes water-cooled petrol engine coupled to hydraulic dynamometer with the help of universal coupling is mounted on a centrally balanced base frame made of ms channels. The set up has stand-alone fully powder coated panel box consisting of air box, fuel tank, manometer, fuel measuring unit, digital indicators and transmitters for measuring various parameters. It is also provided with necessary sensors with transmitters for combustion pressure and crank-angle measurements. All these signals are interfaced to computer through signal conditioner and signal converter for computerization.

3.3 Experimental Results of Gasoline 100%, blended fuel (Gasoline 85% and Ethanol 15%), and micro emulsion based ffuel (Gasoline 90%, Ethanol 8% and H_20 2%)

In Fig. 3 the variation of brake power vs load is given for the Conventional Gasoline, blended fuel, and micro emulsion based fuel in order to see which fuel is more efficient in terms of power output. As seen in Fig. 3 it is clearly defined that the power output is maximum for the conventional gasoline in the SI engine as compared to the other fuels. The most convincing reason for this effect is that gasoline has higher heating value as compared to the ethanol. The micro emulsion based fuel and the blended fuel, have the presence of ethanol and are showing almost the same power. There is a slight increase in the brake power for the micro emulsion based fuel as compared to the blended fuel. This can again be justified by the presence of larger amounts of ethanol (15%) in blended fuels as compared to ethanol present in microemulsion based fuel (8%) which reduces the overall heating value of the fuel and hence a lower brake power [21]. Although the 100% gasoline shows the maximum brake power at the highest loads (almost 50% higher than blended and micro emulsion based fuel), it is also observed that for lower loads the difference is not that pronounced and all the three fuels (i.e. gasoline, blended fuel and microemulsion based fuel) have almost similar brake powers which implies that both blended fuel and micro-emulsion based fuel can be used as an alternative fuel. In plot 4 the indicated power shows increase for conventional gasoline fuel as compared to other alternative fuels, used in blended form.

Power V/s Load

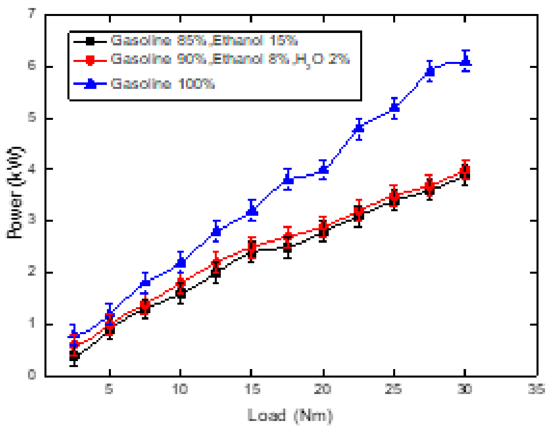


Figure 3. Plot between power and load

In Figure 4 indicated power is the highest power developed inside the engine cylinder. The gasoline has highest calorific value as compared to other fuel like ethanol. The ethanol when added in gasoline improves the efficiency of the engine and reduces the emissions. The micro emulsion fuel also helps in reducing the emissions from the engine and the power obtained is almost same for both the fuels i.e. ethanol blended with gasoline and as micro emulsions fuel [22]. The micro-emulsion fuel used is showing more power than ethanol blended with gasoline.This is due to the reason that micro-emulsion fuel contains less ethanol percentage than blended ethanol with gasoline fuel which is 15%, as less addition of ethanol in micro-emulsion increases the heating value of the fuel which inturn increases the power inside the engine.

Indicated Power V/s Load

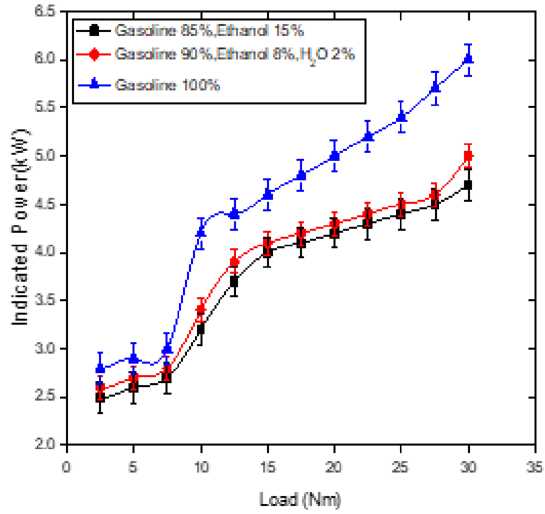


Figure 4. Plot between IP and load

Bsfc V/s Load

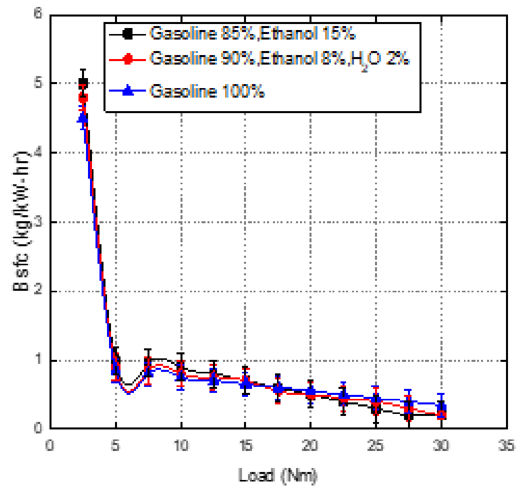


Figure 5. Plot between Bsfc and Load

In plot 5 the graph shows the variation of Bsfc for 100% Gasoline and blended ethanol, and micro-emulsion composition under varying loads. From the plot almost all the fuels shows the decreasing trend of Bsfc with varying loads. Since at the start of the combustion the engine needs more fuel for combustion to initiate and the mixture becomes rich. As we go on increasing the load the Bsfc of the fuel decreases, because the mixture turns more towards the stichiometric to leaner side which results in decreasing the fuel consumption by engine and the efficiency of the engine increases [23]. The Bsfc reduction at higher loads proves to be economical for all the fuels,which helps in reducing the foreign exchange of crude oil and in general the fossil fuel reserves which are diminishing at an alarming rate.So engine needs to be operated at higher loads for reducing the consumption of fuel, and improving its thermal efficiency.

Cylinder pressure V/s Crank angle

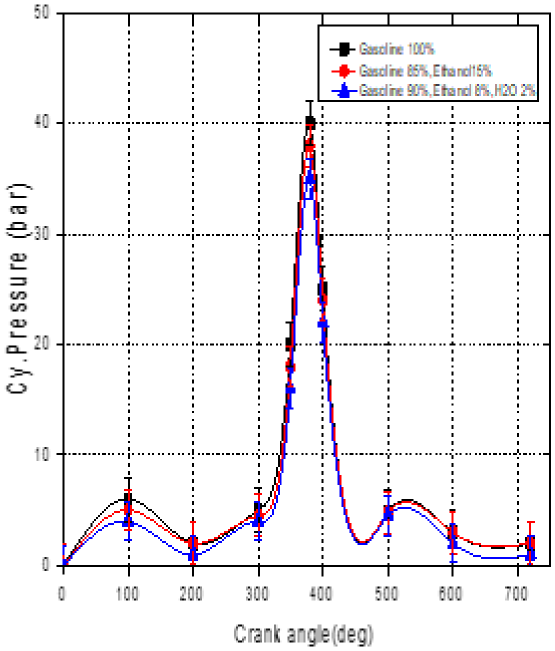


Figure 6. Plot between Cy. pressure and crank angle

In plot 6 there is the relation between cylinder pressure and crank angle for 100% Conventional gasoline, gasoline 85%, ethanol 15%, and micro-emulsion composition of gasoline 90%, ethanol 8%, and H_2O 2% for checking cylinder pressure inside the combustion chamber. It can be seen that the highest pressure is obtained for conventional 100% gasoline as the fuel. Since Gasoline has highest calorific value so peak pressure obtained is highest for gasoline as the fuel as compared to other blended fuels. The addition of water into emulsion obviously as shown in figure 6 reduces peak cylinder pressure. Emulsion with 2% water made negative effects to cylinder pressure. That is because of heat absorption in cylinder by water. Furthermore with the increase of water concentration, burning rate is slightly lower [24]. Also the micro-emulsion fuel takes the enthalpy of vaporization of the fuel, because of H_2O content in the fuel which reduces the peak pressure of the engine slightly lower than conventional gasoline fuel.

Brake thermal efficiency V/s Load

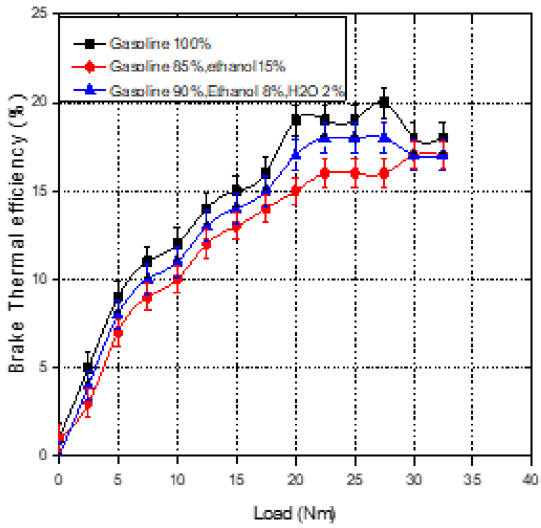


Figure 7. Plot between Brakethermal efficiency and Load

In Figure 7 there is the relation between brake thermal efficiency and Load on the engine. This plot explains how thermal efficiency varies with increase in Load for all the fuels. In the Figure 7, it can be seen that the highest thermal efficiency is for conventional 100% gasoline, with increase in load thermal efficiency also increases. Micro-emulsion also shows increasing trend for the thermal efficiencies. And gasoline 85%, ethanol 15% also shows increasing trend but slightly lesser than other fuels. The possible reason for this decrease in thermal efficiency is that Conventional gasoline has more heating value as compared to ethanol. So Brake power increases for Conventional 100% gasoline which also increases the brake thermal efficiency of the engine [25]. Since micro-emulsion fuel contains more gasoline as a fuel compared to gasoline 85%, so heating value of micro-emulsion fuel increases more than simple blended fuel i.e. (gasoline 85% + ethanol 15%), which results in more power and increases the brake thermal efficiency of the engine.

Volumetric efficiency V/s Load

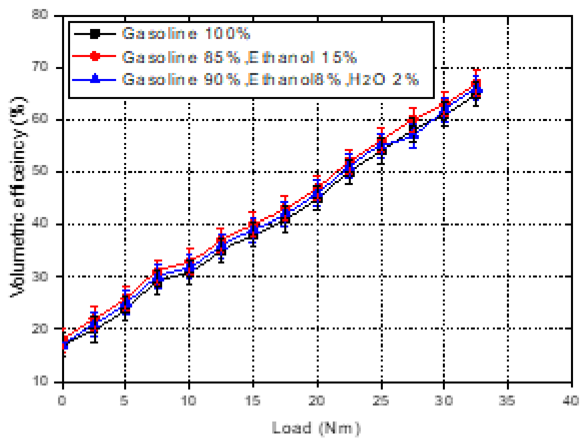


Figure 8. Plot between Volumetric efficiency and Load

In plot 8 there is the variation of volumetric efficiency with Load. It can be seen that the volumetric efficiency shows increasing trend for all the fuels, including micro-emulsion as an alternative fuel used in multi-cylinder SI engine. In the plot it can be easily seen that the volumetric efficiency increases with increase in load, and is slightly more for gasoline 85%, ethanol 15%. This is because of 15% ethanol blend in gasoline increases the latent heat of vaporization of fuel resulting in a cooler fuel-air mixture compared to 100% Gasoline [26]. Since volumetric efficiency is the breathing capacity of the engine by which it actually takes the charge inside the combustion chamber. The more the charge goes inside the engine the more it increases the volumetric efficiency of the engine. So volumetric efficiency plays an important role in increasing the power of the engine, the more charge the more power, and micro-emulsion fuel is also efficient fuel, because of more volumetric efficiency.

In plot 9 there is the relation between mechanical efficiency and load for Conventional 100% gasoline and other blended fuels, including micro-emulsion as an alternative fuel in SI engine. The curve clearly defines that the mechanical efficiency is highest for conventional gasoline engine as compared to other blended ethanol and micro-emulsion. As mechanical efficiency is directly proportional to the brake power of the engine, which is highest for gasoline as the fuel as compared to other alternative fuels so mechanical efficiency shows slight increase in efficiency. Mechanical efficiency is defined as the ratio of brake power and indicated power [27]. Almost all the fuel shows similar kind of trend i.e. increases with increase in load proves to be efficient at higher loads. The mechanical efficiency has direct relation with brake power, since 100% gasoline has more power compared to simple blended fuel and micro-emulsion, so it shows slightly more mechanical efficiency than these fuels, and increases with increase in load.

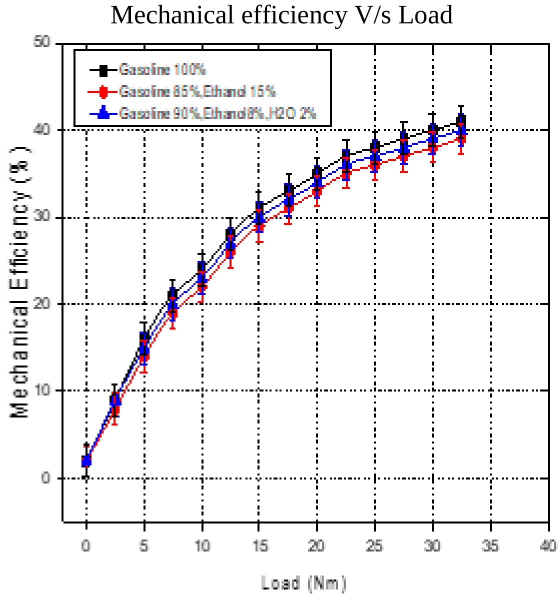


Figure 9. Plot between Mechanical efficiency and Load

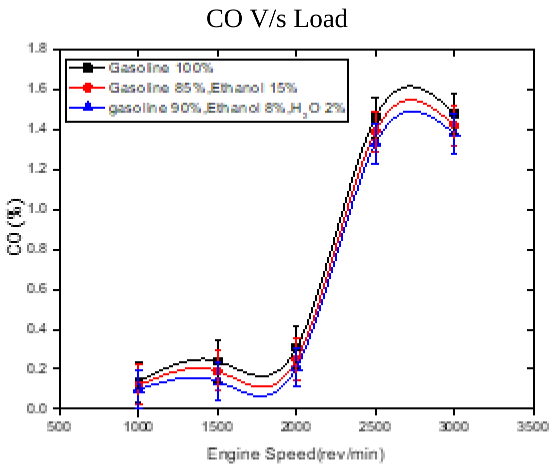


Figure 10. Plot between CO emissions and Engine Speed

In plot 10 there can be easily seen the variation of carbon monoxide emission variations with varying speeds. For all the compositions of blended fuel ethanol and micro emulsion there is the variation in carbon monoxide emissions. At the start of combustion and at lower loads the emissions are less and increasing with increase in speed (rpm). For conventional 100% Gasoline as the fuel there is slightly increase in CO emissions as compared to other blended fuels and micro emulsion. This decrease in CO emissions for blended fuel ethanol and micro emulsion is due to the less number of carbon atoms in ethanol, and also the H_2O molecule in micro emulsion is also responsible for the decrease of emissions. At higher speeds the fuel does not get sufficient air for its complete combustion resulting in higher rate of carbon monoxide emissions. As the engine speed increases the fuel does not complete its cycle per revolution completely resulting in incomplete combustion and increases the rate of CO emissions. The H_2O molecule present in the micro-emulsion increases the oxygen availability in the fuel resulting in complete combustion and reduced CO emissions.

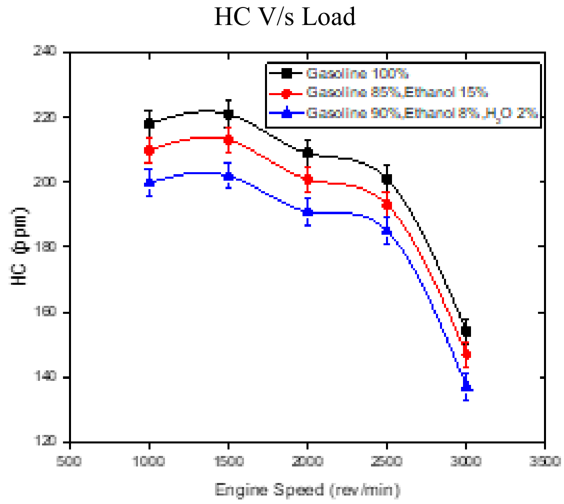


Figure 11. Plot between HC emissions and Engine Speed

In the plot 11 the variation for hydro carbon emissions is shown for conventional Gasoline 100%, Ethanol 15%, Gasoline 85%, and micro emulsion composition. There is the continuous decrease in HC emissions with increase in Engine speed. In this plot there is the decreasing trend for all the compositions of the fuel for hydro carbon emissions.

Hydro carbon emissions are formed more at lower speeds due to incomplete combustion at the start of combustion. As the speed increases the hydro carbon emissions also decreases because of sufficient air for complete combustion of fuel. In the plot above the micro emulsion fuel proves to be more efficient in terms of HC exhaust emissions. Since micro-emulsion fuel contains H_2O molecule and ethanol as a blended component which increases the oxygen concentration inside the fuel resulting in complete combustion, which ultimately reduces the level of hydro-carbon emissions [28].

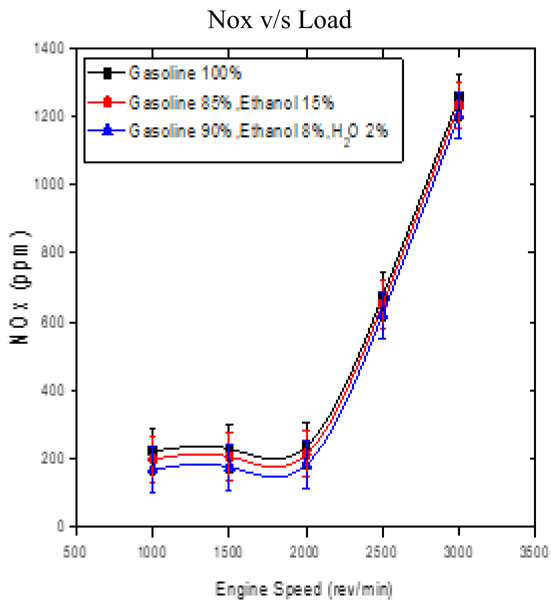


Figure 12. Plot between Nox and Engine Speed

In the plot 12 there is the relation between NOx and Engine Speed. It can be seen that almost all the fuels are showing increasing trend for all the fuels. But micro emulsion composition is showing less emission as compared to blended 15% Ethanol with 85% Gasoline and 100% Gasoline. This increasing trend for the NOx emissions is due to the increase in temperature at higher speeds which is actually responsible for this increase in NOx emissions. The in build oxygen atoms in micro emulsions is responsible for decreasing the enthalpy of vaporization of fuel which finally reduces the temperature inside the combustion chamber, and decreases the NOx emissions as compared to 100% Gasoline as the fuel. The other reason for this decrease in NO_X emissions at lower loads is that at lower loads the engine is not having higher temperature at the start of combustion because of less oxygen availability at lower loads, and the nitrogen molecule of the air does not get sufficient oxygen for the formation of NOx emissions which ultimately gives less NOx [29].

Table 2. Emission Standards of multi cylinder SI engine using gasoline, ethanol and micro emulsions at constant speed of 2000 rpm and at varying load

	Gasoline 100%(g/km)	Gasoline 85%, Ethanol 15%(g/km)	Gasoline 90%,Ethanol 8%,H_2O 2%(g/km)
CO	0.34	0.3	0.2
HC	0.244	0.21	0.1
NOX	0.182	0.15	0.06

In Table 2 we have analysed the experiment of emissions from 3 cylinder SI engine using 100% gasoline, ethanol blends, and micro-emulsions. From the above table it can be easily seen that the emissions shows more reduction for micro emulsions used as an alternative fuel. These are the emission standards from multi-cylinder SI engine which were carried out at constant speed of 2000 rpm and at varying Loads and have met the standards of emission norms Euro 6.

4. CONCLUSIONS

Since the investigation was with 3-cylinder SI engine based Test rig in order to improve its performance and emission characteristics. This investigation leads to the following conclusion

- The conventional 100% Gasoline shows more power as compared to the blended ethanol fuel, and micro-emulsion used as an Alternative fuels.
- Although there was decrease in power for ethanol blended gasoline and micro-emulsion fuel, but emission decreased more for both fuels as compared to conventional gasoline fuel.
- Since micro-emulsion fuel contains H_2O molecule in addition to simple blending, this increases the availability of oxygen in fuel resulting in complete combustion and reduces CO emissions.
- Micro-emulsion fuel also gives less HC and NOx emissions because of H_2O molecule present in the fuel, which reduces the peak temperature of the combustion chamber and results in less formation of NOx emissions.
- The peak pressure obtained is highest for the 100% Gasoline fuel, as compared to 15% ethanol, 85% gasoline, and micro-emulsion compositions. This is due to the higher heating value of Gasoline.
- Since this research is mainly focussed on reducing the emissions from 3-cylinder SI engine as compared to 100% gasoline fuel. So the emission reduced by the use of micro-emulsion are more and it meets the standards of emission norms Barath stage 6 (Euro6).

ACKNOWLEDGMENT

am thankful to the National Institute of Technology Srinagar which provided me the platform for doing this research in the IC engine lab as Research Scholar. I am also thank full to the Research Scholars of NIT Srinagar for encouraging me during this research.

REFERENCES

[1] Nande AM, Wallner T, Naber J. (2008). Influence of water injection on performance and emissions of a direct-injection. Hydrogen Research Engine.zsa 1: 2377-2386 https://doi.org/10.4271/2008-01-2377

[2] Jonsson M, Yan J. (2005). Humidified gas turbines - A review of proposed and implemented cycles. Energy 30: 1013–1078. https://doi.org/10.1016/j.energy.2004.08.005

[3] Wu ZJ, Yu X, Fu LZ, Deng J, Hu ZJ, Li LG. (2014). A high efficiency oxyfuel internal combustion engine cycle with water direct injection for waste heat recovery. Energy 70: 110–120. https://doi.org/10.1016/j.energy.2014.03.095

[4] Kohketsu S, Mori K, Sakai K, Nakagawa H. (1996). Reduction of exhaust emission with new water injection system in a diesel engine. SAE Technical Paper 960033. https://doi.org/10.4271/960033

[5] Şahin Z, Tuti M, Durgun O. (2014). Experimental investigation of the effects of water adding to the intake air on the engine performance and exhaust emissions in a DI automotive diesel engine. Fuel 115: 884–895. https://doi.org/10.1016/j.fuel.2012.10.080

[6] Munsin R, Laoonual Y, Jugjai S, Imai Y. (2013). An experimental study on performance and emissions of a small SI engine generator set fuelled by hydrous ethanol with high water contents up to 40%. Fuel 106: 586-592. https://doi.org/10.1016/j.fuel.2012.12.079

[7] Boretti A. (2013). Water injection in directly injected turbocharged spark ignition engines. Appl. Therm. Eng. 52: 62-68. https://doi.org/10.1016/j.applthermaleng.2012.11.016

[8] Cesur İ, Parlak A, Ayhan V, Boru B, Gonca G. (2013). The effects of electronic controlled steam injection on spark ignition engine. Appl. Therm. Eng. 55: 61-68. https://doi.org/10.1016/j.applthermaleng.2013.02.020

[9] Dryer FL. (1977). Water addition to practical combustion systems—Concepts and applications. Symp. Combust. 16: 279-295. https://doi.org/10.1016/S0082-0784(77)80332-9

[10] Tauzia X, Maiboom A, Shah SR. (2010). Experimental study of inlet manifold water injection on combustion and emissions of an automotive direct injection Diesel engine. Energy 35: 3628–3639. https://doi.org/10.1016/j.energy.2010.05.007

[11] Wang Z, Liu H, Long Y, Wang J, He X. (2015). Comparative study on alcohols–gasoline and gasoline–alcohols dual-fuel spark ignition (DFSI) combustion for high load extension and high fuel efficiency. Energy 82: 395–405. https://doi.org/10.1016/j.energy.2015.01.049

[12] Storch M, Erdenkäufer S, Wensing M, Will S, Zigan L. (2015). The effect of ethanol blending on combustion and soot formation in an optical DISI engine using high-speed imaging. Energy Procedia 66: 77–80. https://doi.org/10.1016/j.egypro.2015.02.041

[13] Huang Y, Hong G, Huang R. (2015). Numerical investigation to the dual-fuel spray combustion process in an ethanol direct injection plus gasoline port injection (EDI+GPI) engine. Energy Convers. Manag. 92: 275–286. https://doi.org/10.1016/j.enconman.2014.12.064

[14] Corsetti S, Zehentbauer FM, McGloin D, Kiefer J. (2015). Characterization of gasoline/ethanol blends by infrared and excess infrared spectroscopy. Fuel 141: 136–142. https://doi.org/10.1016/j.fuel.2014.10.025

[15] Masum BM, Masjuki HH, Kalam MA, Palash SM, Habibullah M. (2015). Effect of alcohol–gasoline blends optimization on fuel properties, performance and emissions of a SI engine. J. Clean. Prod. 86: 230-237. https://doi.org/10.1016/j.jclepro.2014.08.032

[16] Doğan B, Erol D, Yaman H, Kodanli E. (2017). The effect of ethanol-gasoline blends on performance and exhaust emissions of a spark ignition engine through exergy analysi. Appl. Therm. Eng. 120: 433-443. https://doi.org/10.1016/j.applthermaleng.2017.04.012

[17] Phuangwongtrakul S, Wechsatol W, Sethaput T, Suktang K, Wongwises S. (2016). Experimental study on sparking ignition engine performance for optimal mixing ratio of ethanol–gasoline blended fuels. Appl. Therm. Eng. 100: 869–879. https://doi.org/10.1016/j.applthermaleng.2016.02.084

[18] Poran A, Tartakovsky L. (2015). Energy efficiency of a direct-injection internal combustion engine with high-pressure methanol steam reforming. Energy 88: 506–514. https://doi.org/10.1016/j.energy.2015.05.073

[19] Li Y, Gong J, Deng Y, Yuan W, Fu J, Zhang B. (2017). Experimental comparative study on combustion, performance and emissions characteristics of methanol, ethanol and butanol in a spark ignition engine. Appl. Therm. Eng. 115: 53–63. https://doi.org/10.1016/j.applthermaleng.2016.12.037

[20] de Almeida LQ, Sales LCM, Sodré JR. (2015). Fuel consumption and emissions from a vehicle operating with ethanol, gasoline and hydrogen produced on-board. Int. J. Hydrogen Energy 40(2015): 6988–6994. https://doi.org/10.1016/j.ijhydene.2015.03.167

[21] Heywood JB. (1998). Internal Combustion Engine Fundamentals, McGraw-Hill Inc., New York.

[22] Gonca G, Sahin B. (2017). Effects of engine design and operating parameters on the performance of a spark ignition (SI) engine with steam injection method (SIM). Appl. Math. Model. 44: 655–675. https://doi.org/10.1016/j.apm.2017.02.010

[23] Nguyen QA, Wu YY. (2009). Experimental investigations of using water-gasoline emulsions as a NOx treatment and its effects on performance and Emissions of Lean- burn Spark-Ignition Engine. Paper Presented at the Proceedings of the International Conference on Power Engineering, Kobe, Japan.

[24] Jonsson M, Yan JY. (2005). Humidified gas turbines da review of proposed and implemented cycles. Energy 30(7): 1013e1078. https://doi.org/10.1016/j.energy.2004.08.005

[25] Parlak A, Ayhan A, Gonca G, Boru B. (2013). The effects of electronic controlled Steam injection on spark ignition engine. Appl. Therm. Eng. 55(1-2): 61-68. https://doi.org/10.1016/j.applthermaleng.2013.02.020

[26] Rodriguez Anton LM, Gutierrez Martin F, Martinez-Arevalo C. (2015). Experimental determination of some physical properties of gasoline, ethanol and ETBE Ternary blends. Fuel 156: 81–86. https://doi.org/10.1016/j.fuel.2015.04.040

[27] Phuangwongtrakul S, Wechsatol W, Sethaput T, Suktang K, Wong wises S. (2016). Experimental study on sparking ignition engine performance for optimal mixing ratio of ethanol–gasoline blended fuels. Appl. Therm. Eng. 100: 869–879. https://doi.org/10.1016/j.applthermaleng.2016.02.084

[28] Guzmán MA, Katherine Ardila L, Agudelo JR. (2015). Combustion characteristics, performance and emissions of a diesel engine fuelled with water/diesel emulsions. Chemical Engineering Transactions 45: 1039-1044. https://doi.org/10.3303/CET1545174

[29] Mohsin R, Kumar T, Majid ZA, Kumar I, Wash AM. (2017). Assessment of usage of biofuel in aviation industry in Malaysia. Chemical Engineering Transactions 56: 277-282. https://doi.org/10.3303/CET1756047