Experimental Study on the Performances of Spark Ignition Engine with Alcohol-Gasoline Blends as Fuel

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***Abstract*-The excessive use of fossil fuels will certainly lead to the energy crisis and unsustainable condition of the environment in future. In this paper, the performance characteristics have been studied experimentally for a spark ignition engine running with different gasoline-alcohol (ethanol and methanol) blends as alternative fuels. It is observed that the brake thermal efficiency increases by more than 6% with 40% addition of ethanol or methanol to gasoline. Volumetric efficiency also increases due to alcohol addition to gasoline. Brake specific fuel consumption increases approximately by 20% with 30% alcohol addition. The maximum exhaust gas temperature decreases by 14% with methanol and 10% with ethanol for a blending of 40% alcohol with gasoline by volume.**

Keywords-SI Engine; Ethanol; Methanol; Blend; Performance

I. INTRODUCTION

The demand of energy is ever increasing for the industries as well as automobiles. Internal combustion engines are the major sources of energy for automobiles. These engines consume mainly petroleum products like petrol (gasoline) and diesel as fuels. It has been anticipated that the petroleum reserve will be exhausted soon if some alternative fuels, at least partially do not replace petrol and diesel. The alternative fuel should have reasonably good thermal efficiency, low pollution level and should be available for a long time. There are many candidates like natural gas, alcohol and hydrogen. Biogas and natural gas are similar in many ways and form and ideal fuels for Spark Ignition (SI) engines. It has been possible to run internal combustion engines on these fuels with minor modifications in the inlet manifold. But these fuels have been mainly tried for stationary engines and to some extent in automobile engines. Hydrogen gas has been suggested as a universal non-polluting fuel. But ways and means have yet to be formalized for cheap production, storing, transportation and adopting it to internal combustion engines and using it safely. Alcohols, namely methanol and ethanol have shown great promise to be used as transportation fuels.

Methanol can be produced from biomass and coal, but the main source of its production is natural gas. Kowalewicz [1] reviewed and analyzed the use of methanol as a fuel for spark ignition engines. He reported that a neat methanol engine has 30% more efficiency than a regular engine, not only due to high compression ratio but also due to methanol's higher heat of vaporization that cools the air in the engine to a larger extent, thus increasing the density and allowing more air in. This results in a leaner fuel mixture, possibly lowering emission of CO due to more complete combustion. Another benefit of using methanol is that it has a low combustion temperature, which results in less formation of NO_x, a precursor to smog in urban settings. The added advantage of using ethanol and methanol as fuels is that they are renewable biomass fuels. These fuels can also be produced from a variety of materials and waste products like molasses, potato, beet root, cassava, paper industry waste, agricultural waste etc. In spite of many benefits achieved with the use of alcohol as fuel, it has some limitations also which prohibits 100% substitution of gasoline by alcohol. For example, gasoline has a boiling point varying from 31 to 221ºC depending upon its composition, whereas methanol has a boiling point of 65ºC, creating a problem in cold starting applications. Other problems include corrosion of car parts that are made from lead, magnesium or aluminium, and a possibility of explosion since saturated methanol-air mixtures are explosive at ambient temperature. Another main concern with the substitution of gasoline by alcohol is that the heating value of alcohol is much less than that of gasoline. The heating value of methanol is half that of gasoline. Different relevant properties of iso-octane (gasoline with 100 octane numbers), ethanol and methanol are presented in table 1 for comparison.

Bridgeman [2] showed the utilization of ethanol-gasoline blends as a motor fuel and found an increase in power and less gaseous pollutant emissions. El-Eman and Desoky [3] conducted a four-cylinder engine study to investigate the effect of using ethanol as an alternative fuel on a spark ignition engine. Palmer [4] blended gasoline with different amounts of ethanol during testing and observed an increase of engine power by 5% with 10% ethanol in the blend. Abdel-Rahman and Osman [5] used 10%, 20%, 30% and 40% ethanol blended gasoline in a variable compression ratio engine. They reported that the optimum blend rate was found to be 10% ethanol with 90% gasoline.

TABLE 1 PROPERTIES OF ETHANOL AND METHANOL

Sl. No.	Property	IsoOctane	Ethanol	Methanol
1.	Formula	C_8H_{18}	C_2H_5OH	CH_3OH
2.	Boiling Point (°C)	372	351	338
3.	Freezing Point (°C)	-107.4	-117.2	-97.8
4.	Vapour Pressure at 38°C	1.708	-	4.6
5.	Specific Gravity at 16°C	0.703	0.796	0.796
6.	Coefficient of expansion at 19°C and 1 atm	0.00065	0.00065	0.00065
7.	Viscosity at 20°C and 1 atm	0.503	0.600	0.596
8.	Specific Heat of liquid at 25°C and 1 atm (kJ/kg)	0.5	0.6	0.6
9.	Latent heat of vapourisation at 1 atm (kJ/kg)	0.49	1.601	2.01
10.	Octane number			
	Research	100	106	106
	Motor	100	102	92
11.	Energy Density (MJ/kg)	43.995	26.860	20.100
12.	Flash Point (°C)	-	16	14
13.	Flammability limits in air (% vol)			
	Lean	1	4	7
	Rich	6	19	36
14.	Auto ignition Temperature(°C)	495	740	740
15.	Stoichiometric A/F ratio	14.9	9	6.45

Yüksel and Yüksel [6] made a simple modification of the carburettor system and used 60% ethanol and 40% gasoline blend to test the engine performance and emission characteristics of a four-cylinder SI engine. They reported that the torque output of the engine increased slightly whereas the CO, CO_2 and HC emissions decreased greatly with the use of ethanol-gasoline blended fuels. The effect of ethanol addition to gasoline on SI engine performance and exhaust emissions was investigated experimentally and theoretically by Bayraktar [7]. He carried out the experimental works with the blends containing ethanol up to 12% by volume. The best result was obtained for 7.5% ethanol experimentally and 16.5% ethanol theoretically without any modification to the engine design. Liu et al. [8] experimented on a 3-cylinder port fuel injection engine to study the performance and emission characteristics using methanol /gasoline fuel blends. They reported that the engine power and torque decreased with the increase fraction of methanol in the fuel blends without any retrofit of the engine.

They also observed 30% reduction in HC emission and 25% reduction in CO emission when the engine was fuelled with M30 (30% methanol + 70% gasoline).

The literature review reveals that the gasoline-alcohol blends with low proportion of alcohol can be used without any engine modification, but pure alcohol requires major modification to the engine design and fuel system. Hence, the use of gasoline-alcohol blends in SI engine is more practical than using alcohol alone. This motivates the authors to carry out this research work for a comparative study of SI engine performance using gasoline-methanol and gasoline-ethanol blends. The percentage of alcohol in the mixture has been varied up to relatively higher values in comparison to the results available in the literature.

II. ENERGY BALANCE OF ALCOHOL

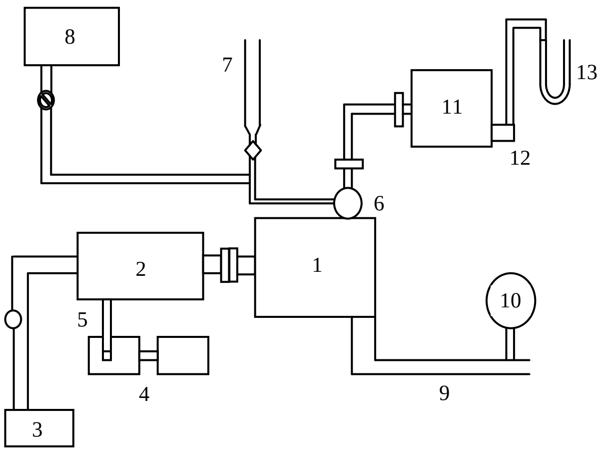
The total fuel energy expended in producing alcohol – including fertilization, farming, harvesting, transport, fermentation, distillation and distribution, as well as the fuel used in building the farm and fuel plant equipment - should not exceed the energy contents of the product. The terms 'input energy efficiency' and 'life cycle energy yield' are commonly used in the literature to assess the renewability of a fuel. Life cycle energy yield is defined as the units of fuel product energy for every unit of fossil energy consumed in its life cycle. If the life cycle energy yield is less than unity (i.e. negative fuel energy balance), many of the expected environmental and sustainability advantages of alcohol fuels would not be realized in a system. According to a study in 1998 co-sponsored by United States Department of Energy and USDA, ethanol yields 1.34 units of energy per unit of fossil energy consumed in its life cycle. A comparative study of energy yield of petroleum based fuels (gasoline and diesel) and biofuels like ethanol and biodiesel were also published in their report as shown in table 2.

TABLE 2 LIFE CYCLE ENERGY YIELD OF BIOFUELS AND PETROLEUM BASED FUELS

Fuel	Energy Yield	Net Energy (loss) or gain
Gasoline	.805	(-19.5%)
Diesel	.843	(-15.7%)
Ethanol	1.34	34%
Biodiesel	3.20	220%

III. EXPERIMENT

The experiments were carried out on a single cylinder, air-cooled, four-stroke, spark ignition, vertical type 'BRIGGS and STRATTON' engine having a fixed compression ratio of 5.3. The engine has a bore of 76.2 mm and a stroke of 82.84 mm. The engine is coupled to an electrical resistance type dynamometer. A single phase 110 volts, 22 amps, 5 kW alternators is used as dynamometer for loading the engine. The fuel was supplied to the engine by gravity from a fuel tank of 6 liters capacity. The engine sucked air directly from the atmosphere through a surge tank of 500 times the swept volume of the engine. The temperature of the exhaust gas has been measured with the help of a thermocouple. The schematic diagram of the experimental set up is shown in Fig.1.



1: Engine, 2: Alternator, 3: Resistive Load, 4: Balance, 5: Loading Arm, 6: Carburetor, 7: Fuel Measuring burette, 8: Fuel tank, 9: Exhaust gas pipe, 10: Exhaust temperature thermometer, 11: Air box, 12: Orifice, 13: Air temperature

Fig. 1 Schematic diagram of test setup

Tests were conducted under steady state condition to study the comparative performances of the engine, using four gasoline-ethanol and four gasoline-methanol blends. Methanol and ethanol were separately mixed with the gasoline. Mixing different percentages of alcohol with gasoline varied the amount of alcohol in gasoline-alcohol blends. The percentages of alcohol considered in this work are 10%, 20%, 30% and 40% by volume.

The ethanol & methanol, used in this experiment were of industrial grade manufactured by M/S Bengal Chemicals, India.

IV. RESULTS AND DISCUSSION

The heating (lower) values and densities of different alcohol-gasoline blends have been calculated by weighted average method. The calculated values of ethanol and methanol have been shown in table 3 and table 4 respectively.

The brake thermal efficiency, the volumetric efficiency, the brake specific fuel consumption and maximum exhaust temperature are calculated from the experimental results for different gasoline-alcohol blends for the assessment of engine performance. The variation of brake thermal efficiency with brake power has been shown in Fig. 2 and Fig. 3 respectively for gasoline ethanol and gasoline-methanol blends respectively.

It is observed that the brake thermal efficiency increases in general with the addition of ethanol or methanol. As the brake thermal efficiency depends upon power, fuel consumption and heating value, the variation of the above-mentioned parameters varies the brake thermal efficiency. The addition of ethanol into gasoline increases brake power and fuel consumption, but on the other hand decreases heating value of the blended fuel [9].

The combined effect is in favour of efficiency. Another reason for the increase of brake thermal efficiency is supposed to be alcohol's advantage during combustion resulting faster burning and higher peak pressure than those of pure gasoline and also during expansion, lower burned gas temperature provides reduced heat transfer to the cylinder walls [10]. Figures 2 and 3 also show that the efficiency is not always increasing with addition of alcohol. The possible reason may be that the existing carburetor is designed for gasoline and hence it is not as efficient with gasoline-alcohol mixture as fuel. Better performance can be achieved by modifying the carburettor in favour of alcohol. The variation of volumetric efficiency with brake power for different percentages of ethanol and methanol in gasoline has been presented in Fig. 4 and Fig. 5 respectively.

TABLE 3 CHARACTERISTICS OF GASOLINE-ETHANOL BLENDS

Fuel % composition by volume	Lower Heating value (MJ/kg)	Density (g/cm^3)	Stoichiometric Air/Fuel Ratio
100% gasoline + 0% ethanol	43.995	0.703	14.90
90% gasoline + 10% ethanol	42.277	0.7123	14.31
80% gasoline + 20% ethanol	38.841	0.7212	13.72
70% gasoline + 30% ethanol	40.559	0.7303	13.13
60% gasoline + 40% ethanol	37.123	0.7394	12.54
50% gasoline + 50% ethanol	35.406	0.7485	11.95

TABLE 4 CHARACTERISTICS OF GASOLINE-METHANOL BLENDS

Fuel % composition by volume	Lower Heating value (MJ/kg)	Density (g/cm^3)	Stoichiometric Air/Fuel Ratio
100% gasoline + 0% methanol	43.995	0.703	14.90
90% gasoline + 10% methanol	41.606	0.7123	14.05
80% gasoline + 20% methanol	36.826	0.7212	13.21
70% gasoline + 30% methanol	39.216	0.7303	12.36
60% gasoline + 40% methanol	34.437	0.7394	11.52
50% gasoline + 50% methanol	32.048	0.7485	10.67

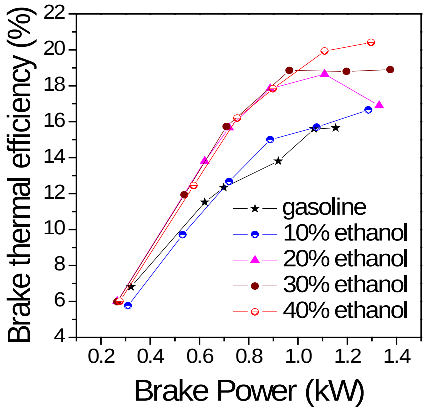


Fig. 2 Brake thermal efficiency vs brake power for different gasoline-ethanol blends

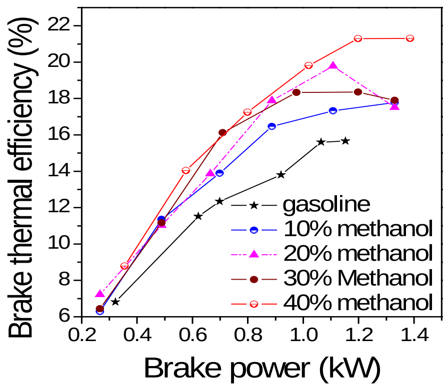


Fig. 3 Brake thermal efficiency with brake power for different gasoline-methanol blends

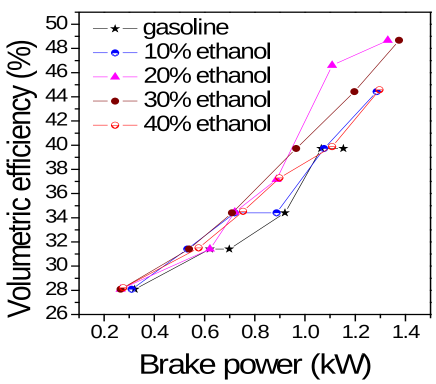


Fig. 4 Volumetric efficiency vs brake power for different gasoline-ethanol blends

The general trend is that it increases with the increase of alcohol percentage in the mixture. The reason is that the latent heats of vaporization of alcohols are more than that of gasoline. High latent heat of vaporization causes more cooling of intake charge that increases the density of the charge resulting in more charge entering into the cylinder, thereby increasing volumetric efficiency [11]. Since the latent heat of vaporization of methanol is more than that of ethanol, the effect is more prominent with methanol [12]. One of the major problems with the gasoline-methanol blends is the water absorption, which causes methanol and gasoline to separate into two different phases. These problems become more severe with higher percentage (>15%) of alcohol. Fig. 5 shows that volumetric efficiency becomes maximum with 10% methanol in the blend, which is lower than the corresponding percentage of ethanol in the blended fuel.

The variation of brake specific fuel consumption (BSFC) with brake power for different percentages of alcohol in the alcohol-gasoline blends has been plotted in Fig. 6 and Fig. 7 for ethanol and methanol respectively.

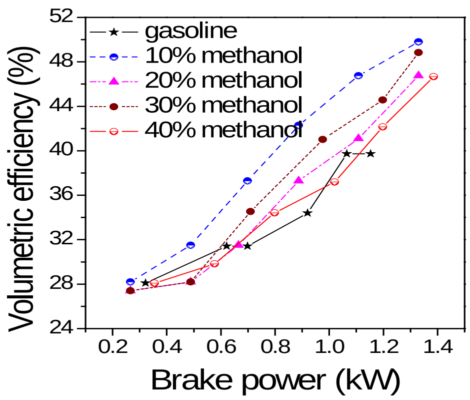


Fig. 5 Volumetric efficiency vs brake power for different gasoline-methanol blends

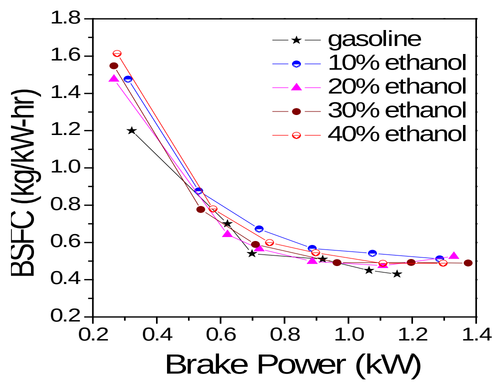


Fig. 6 Brake specific fuel consumption vs brake power for different ethanol-gasoline blends

The figures reveal that brake specific fuel consumption increases with addition of alcohol in both the cases. This happens due to the lower heating values of alcohols in comparison to that of gasoline [13, 14]. As the heating value of methanol is less than that of ethanol, the effect should be more prominent with methanol than with ethanol for the same percentage of alcohol in the gasoline-alcohol mixture. But the present investigation shows similar effect. This may be due to different degrees of phase separation in the alcohol-gasoline mixture and uncertainty in the composition of the alcohol supplied by the manufacturer.

The maximum exhaust gas temperature, somewhat qualitatively indicates the level of pollutant emission from the engine. Hence the maximum exhaust gas temperatures vs. percentages of alcohol in the mixture have been plotted in Fig. 8 for both gasoline-ethanol and gasoline-methanol blends.

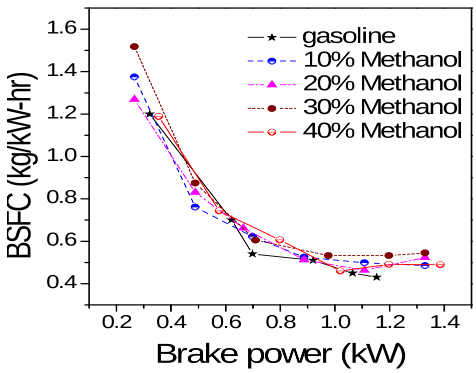


Fig. 7 Brake specific fuel consumption vs brake power for different methanol-gasoline blends

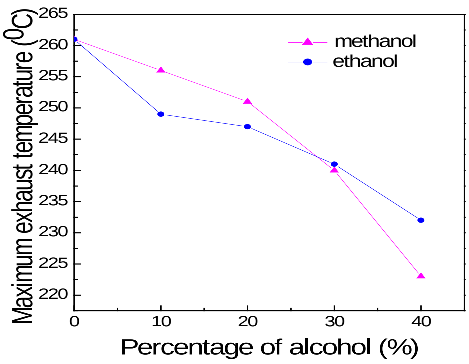


Fig. 8 Maximum exhaust temperature vs. % of alcohol in gasoline-alcohol blends

The figure shows that the exhaust gas temperature decreases with increase in percentage of alcohol in the blends. This is due to the higher values of latent heat of vaporization of alcohols, which decreases the inlet charge temperature and pressure [12]. The values of latent heat of vaporization at atmospheric pressure are 0.49, 1.601 and 2.01 kJ/kg for gasoline (iso-octane), ethanol and methanol respectively. So after compression the charge temperature for gasoline-alcohol mixture becomes less than what would have been for gasoline. Hence temperature of the combustion products becomes less.

V. CONCLUSION

An experimental investigation of the effect of using different blends of alcohol (methanol and ethanol) and gasoline as fuel on the performance of a single cylinder spark ignition engine has been carried out. The percentage of alcohol by volume in gasoline has been varied from 10% to 40%. It is observed that the thermal efficiency of the engine increases with the increase of percentage of alcohol in the fuel. The volumetric efficiency of the engine also increases with the addition of alcohol in the fuel. The effect is more pronounced in case of methanol. However, the brake specific fuel consumption increases with the increase of alcohol in the blended fuels. The exhaust gas temperature is found to decrease with alcohol addition to gasoline. It may be concluded that alcohol-gasoline blends can be used as a fuel for SI engine fuel with the conventional or slightly modified carburetor system.

REFERENCES

[1] A. Kowalewicz, “Methanol as a fuel for spark ignition engines, a review and analysis”, Proc. Institution of Mechanical Engineers, 1993207 (D1), pp. 43- 51, 1993.

[2] O.C. Bridgeman, “Utilization of ethanol gasoline blends as motor fuels. Industrial Engineering Chemistry”, vol. 28, pp.1102-1109, 1936.

[3] S.H. EI-Emam and A.A. Desoky, “A study on the combustion of alternative fuels in Spark-ignition engines”, Journal of Hydrogen Energy, vol. 10, pp. 497-504, 1985.

[4] F.H. Palmer, “Vehicle performance of gasoline containing oxygenates”, International Conference on Petroleum Based and Automotive Applications, London, UK: Institution of Mechanical Engineer’s conference publications, MEP: 33 – 461986.

[5] A. A. Abdel-Rahman and M.M. Osman, “Experimental investigation on varying the compression ratio of SI engine working under different ethanol-gasoline fuel blends”, International Journal of Energy Research, vol. 21,pp. 31-40, 1997.

[6] F. Yüksel and B. Yüksel, “The use of ethanol-gasoline blends as a fuel in an SI engine”, Renewable Energy, vol. 29, pp. 1181-1191, 2004.

[7] H. Bayraktar, “Experimental and theoretical investigation of using gasoline-ethanol blends in spark-ignition engines”, Renewable Energy, vol. 30, pp.1733-1747, 2005.

[8] Liu Shenghua, Eddy R. Cuty Clemente, Hu Tiegang, Wei Yanjv, “Study of spark ignition engine fueled with methanol/gasoline fuel blends”, Applied Thermal Engineering, vol. 27, pp. 1904-1910, 2007.

[9] Al-Hasan, M., “Effect of ethanol-unleaded gasoline blends on engine performance and exhaust emission”, Energy Conversion and Management, vol. 44, pp. 1547-1561, 2003.

[10] M. Bahattin Çelik, Bülent Özdalyan , Faruk Alkan, The use of pure methanol as fuel at high compression ratio in a single cylinder gasoline engine, Fuel, vol. 90, pp. 1591–1598, 2011.

[11] Tribbett, E., Froehlich, E., Bayer, L., “Effects of Ignition Timing, Equivalence Ratio and Compression Ratio on RDH Engine Performance”, Mechanical Engineering Dept., Stanford University. http://rescomp.stanford.edu/~efroeh/papers/RDH_Engine_Performance.pdf.

[12] Eyidogan, M., Ozsezen, A., N., Canakci, M., Turkcan, Ali, “Impact of alcohol–gasoline fuel blends on the performance and combustion characteristics of an SI engine”, Fuel, vol. 89, pp. 2713–2720, 2010.

[13] Costa, R. C., Sodré José R., “Compression ratio effects on an ethanol/gasoline fuelled engine performance”, Applied Thermal Engineering, vol. 31, pp. 278-283, 2011.

[14] Abu-Zaid, M., Badran,O. and Yamin, J., “Effect of Methanol Addition on the Performance of Spark Ignition Engines”, Energy & Fuels, vol. 18, pp.312-315, 2004.

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