Performance and Emission evaluation of Butanol blends in SI Engine

Manish Saraswat1, Ankur Dixit1, Abhishek Goel1 and Nathi Ram Chauhan2
1 Department of Mechanical Engineering, ABES Engineering College, Ghaziabad (U.P) India.
2 Associate Professor, Department of Mechanical Engineering, Indira Gandhi Delhi Technical University for Women, Delhi

E-mail: manish.saraswat@abes.ac.in

Abstract. In recent times, butanol emerges as one of the most promising option to diminish the prolong use of fossil products. The testing of different blends and composition of butanol with gasoline is newest theme of research. In the present work, three different fuels are prepared by using 5%, 10% and 15% blends of butanol with gasoline. The important performance parameters & emission characteristics of a conventional SI engine namely, brake power, torque, brake specific fuel consumption, fuel power, brake specific energy consumption, brake mean effective pressure, un-burnt HC emissions, CO emissions, NOx emissions, and CO2 emissions are tested. Result shows that the butanol blend of 15% is the most appropriate to use as fuel. The experimentally measured values of butanol blends in gasoline confirms that the properties of butanol are quite adaptive with gasoline which implies that no engine modifications required for using butanol blends with gasoline as a replacement to gasoline.

Keywords: Fuel; butanol; blending ratio; emissions; performance.

1. Introduction

It is quite clear that burning of fossils fuel is very hazardous, the ozone layer of earth is depleting very rapidly due to continuous utilization of conventional fuels. Therefore, the availability of alternate (non-conventional fuels) is quite indispensable. In this direction the studies and survey conducted in the past decades on butanol shows brilliant prospects. This chemical agent shows the identical working potential to that of gasoline products such as petrol and diesel. Plenty of works have been done with reference to the accessibility of butanol as a fuel. Irimescu [1] described the advantages of using butanol in port injection SI engines as a fuel as compared to ethanol. Three mixtures containing 10, 30 and 50% iso-butanol blends with gasoline were taken and the fuel conversion efficiency was determined. Results showed that iso-butanol proves to be an attractive fuel to be used in SI engine and it can be blended in higher concentrations with gasoline without modifying the engine as compared to ethanol. Lattimore et al.[2] investigated the effect of fuel properties and compression ratio on combustion, particulate matter emissions and gaseous emissions. The experiments were conducted on single cylinder DISI engine. The tests were conducted at different compression ratios, ranging between 10.7 and 11.5. The fuels used for the investigation were But20 (20% butanol in gasoline) & E20 (20% ethanol in gasoline) along with gasoline which was taken as a reference fuel. The results showed that addition of alcohols reduces the combustion duration. Venugopal [3] experimentally determined the most appropriate concentration of n butanol and gasoline which can be used in four stroke spark ignition engine at different operating conditions through dual injection system. The results indicated that the proper amount of the fuel ratio helps in reducing hydrocarbon emissions.
higher amount of n-butanol reduces the knocking tendency. Szwaja and Naber[4] performed experiments on different blends of butanol with ratios 0%, 20% and 60% with gasoline. They modified the engine in order to provide better air control and fuel injection. Mittal et al. [5] carried out an experimental investigation to study the performance and emission characteristics of butanol blends with gasoline and pure gasoline. The experiment was conducted on a partially insulated single cylinder SI engine. The tests were conducted using 10% and 15% butanol blends with gasoline. The results strongly proved that the combination of engine with ceramic coating and fuels containing butanol along with gasoline can significantly improve engine performance. Giakoumius et al. [6] reviewed exhaust emissions using ethanol and butanol as fuels. They considered various emissions including NOx, CO, particulate matter (PM) and hydrocarbon (HC). Song et al. [7] investigated the effect of injection strategy on mixture formation and combustion characteristics in a DISI optical engine. It was concluded that the maximum cylinder pressure decreased as the timing of injection was decreased. Galloni et al. [8] determined the performance of spark ignition engine with bio butanol blends of 20% and 40% with gasoline. It was found that the output torque and thermal efficiency decreased a bit when the content of alcohol blends was increased. Deng et al. [9] conducted experiments on single cylinder (SI) engine taking 30% and 35% blended butanol with gasoline as fuels. The results showed that butanol is providing higher resistance to knocking and is more efficient for proper combustion to take place. Irimescu et al. [10] analyzed performance parameters and emission characteristics of small scale generator which is being powered by iso-butanol and gasoline were used as fuels. Chen et al.[11] carried out experimental study using turbocharged engine which is injected by gasoline directly and n-butanol/gasoline were used as fuels. 15%, 30% and 50% n-butanol blends were used and their effect on combustion and performance parameters were observed. Irimescu [12] investigated the effect of using isobutanol as fuel and compared its characteristics with pure gasoline. It was observed that when the engine was being fueled with iso-butanol the conversion efficiency of fuel was decreased up to 9% at full load and 11% at part loads. He et al. [13] conducted their experiments in HCCI engine to improve the thermal efficiency. Shukla et al.[14] investigated the stability of blend, performance of engine and the various emissions. They used 5% and 10% n-butanol blends with gasoline which were prepared with the help of splash blending method. Dernotte et al. [15] performed the experiments in port fuel injection spark ignition engine using different blends of butanol with gasoline. It was found out that the 40% blend of butanol with gasoline helps in reducing hydrocarbon emissions to the greatest extent while there was no major change in the emissions of NOx except 80% butanol blend with gasoline. Ramey [16] reviewed butanol as the alternate fuel which can be used in spark ignition (SI) engines and how it can reduce cost, increase production and can prove to be a safer fuel. The comparison of various processes associated with the production of bio butanol and the various substrates used in this process. The best substrate alternative was also provided, which can be used for the production of butanol [17]. Singh et al.[18] provided a comparison of various physio-chemical properties, corrosion properties, stability, performance of engine and various emissions along with noise, 10% blend of butanol in gasoline and 10% blend of ethanol in gasoline were used as fuels. It was found out that 10% blend of butanol in gasoline proved to be better in all aspects as compared to 10% blend of ethanol. Singh et al.[19] conducted experiments on 5%, 10%, 20%, 50% and 75% blends of butanol with gasoline and evaluated engine performance, combustion characteristics and various emissions on medium duty (SI) engine. It was concluded that butanol blends have a bit higher brake specific fuel consumption as compared to gasoline. Alasfour [20] studied the engine performance using blends of methanol, butanol along with gasoline. It was observed that bsfc for butanol blended with gasoline was higher than using methanol blends.

The published literature confirms that numerous works has been done to explore the prospects of butanol as fuel. It is found out that a lot of research work has been done using ethanol and methanol as SI engine fuels. The use of butanol in SI engine is a new concept but less work has been carried out using only butanol as SI engine fuel. The production of butanol is an expensive process and a lot of studies are still in process to find out the cheaper methods for the production of butanol. Moreover, the various works associated with using butanol gasoline blends are merely to justify it as a replacement of gasoline. No work has been carried out considering the cost aspect as
well. Hence, the present work focuses to test three different fuels having 5%, 10% and 15% blends of butanol with gasoline. The above mentioned main performance indices and emission characteristics of a SI engine are tested and the economic analysis have also been performed.

2. Results & Discussion

The results for above mentioned performance and emission parameters are obtained during the testing of SI engine. The engine tested in this experiment was 4S Honda G300-272 cc side valve air cooled horizontal shaft single cylinder having a bore of 76 mm & stroke of 60 mm. The cylindrical combustion chamber with a compression ratio of 6.5:1 is maintained. The 4S naturally aspirated, air-cooled SI engine is rated at 5 HP at 3600 rpm nominally. The instruments for measuring the engine performance are; air consumption box viscous flow meter used to measure the air flow of the engine. Engine emissions was measured by AVL emission analyser, fuel mass flow rate was measured using stopwatch and calibrated glass tube unit, the fuel consumption is determined by measuring the time taken for the engine to consume given volume of fuel 10ml. The photograph of the experimental set up is shown in Fig. 1.
The various technical specification of the engine are listed in the table 1 below:

| Engine Details | 4 Stroke, Side Valve Engine, Honda G300 |
|----------------|----------------------------------------|
| Value of Displacement | 272 cc                                |
| Stroke X Bore       | 60 X 76 mm                             |
| Rated H.P           | 5 HP/3600 rpm                          |
| Dimensions          | 383 X 405 X 464 mm                     |
| Weight              | 23.5 kg                                |
| Fuel                | Gasoline start                         |

2.1 Brake Thermal efficiency

Fig.2 shows the blending percentage of butanol in a proportion of 5:10:15. Since, the calorific value for butanol is higher in comparison to the other two alcohols it allows greater replacement of fossil gasoline. Main significant role is the lowest oxygen percentage which creates better burning conditions of fuel. Through the graphs plotted for comparison B10 blend of butanol shows great performance of thermal efficiency in comparison to the other blends respectively. It is observed closely that the calorific value and presence of oxygen play important role in alcohol blending. A further increment in blends of butanol shows similar results as viewed in case of methanol and ethanol [16].

Fig 2: Brake thermal efficiency of butanol blends.
2.2 Brake specific fuel consumption
Fig. 3 shows better thermal efficiency of B5 as a result of complete combustion and thus B5 shows a least bsfc. The particular results of the other two blends are also checked as expected with the help of brake thermal efficiency graph which shows that the brake specific consumption is quite higher for them. It is observed that the low calorific value of butanol blends need higher fuel supply for generating the same power at a given rpm. Similarly, the bsfc for butanol at 10% shows least bsfc. Hence, the lower calorific values of blending of different butanol results into a higher fuel consumption while considering bsfc rather than fuel consumption which certainly gives better analytical results.

![Fig 3: Brake specific fuel consumption for butanol blends.]

2.3 Brake specific energy consumption
Fig. 4 shows the variation of brake specific energy consumption (bsec) with speed. It can be easily seen from the trend that the bsec found to decrease as the speed is increased. The maximum decrement is observed for But 15 to show the difference between various blends of butanol with gasoline. The variation of bsec with different engine speeds is shown it decreases for all test fuels with an increase in the engine speeds with maximum at 1000 rpm and minimum at 2000 rpm. Brake specific energy consumption is defined as the product of brake specific fuel consumption (bsfc) and calorific value. Since it is the energy to be used by the engine, it is in the form of input energy and therefore, it should be low. High brake specific energy consumption would mean that large amount of energy is too supplied to produce same amount of power in the engine. The value of brake specific energy consumption is decreased with increase in content of butanol in butanol-gasoline blends. It is due to the reason that of improved oxygenated level of these fuels which results in complete combustion of the blends.
2.4 Un-burnt Hydro carbon (UHC) emissions

Fig. 5 shows the variation of un-burnt hydrocarbon emissions with speed. The figure clearly shows that hydrocarbon emissions decreasing for increase in speed. The maximum decrease is observed for But 15. Un-burnt Hydro carbon (UHC) emissions occur primarily due to incomplete combustion and misfiring of engine. It is dependent upon various operating and design variables. The fig shows a reduction in hydrocarbon emissions with increasing speeds. At higher engine, combustion is superior as compared to lower speeds and the engine produces more power thereby reducing hydrocarbons emissions. Hydrocarbon emissions for 15% blend of butanol with gasoline are lesser as compared to 10% and 5% blends of butanol with gasoline. This is because of the enrichment of oxygen which is caused by adding higher amount of butanol and thus complete combustion takes place for higher content of butanol blend 15.
2.5 Carbon monoxide (CO) emissions

Fig. 6 shows the variation of carbon monoxide with speed. It can be seen from the trend that the emissions for But 15 are minimum and increasing with speed. The emissions are maximum for But 05. An increase in the carbon monoxide emissions with increasing speed is observed. This is due to the fact of availability of time which is much shorter for combustion of fuels at the time of higher speeds. Carbon monoxide (CO) emissions for 15% blend of butanol with gasoline are lesser as compared to 10% and 5% blends of butanol with gasoline. This is because of the enrichment of oxygen which is caused by adding higher amount of butanol and thus complete combustion takes place for higher content of butanol blend, i.e., But 15. However, the carbon monoxide emissions for butanol are lesser in comparison to pure gasoline. This is because of the presence of extra oxygen is present in these blends as compared to gasoline which results in complete combustion of the blends.

Fig 6: CO emission for blends of butanol blends

2.6 Nitrogen oxide (NOx) emissions

Fig. 7 shows the variation of Nitrogen oxide with speed. It can be seen from the line graph that NOx emissions are increasing with increasing speed. The maximum emissions are observed for But 05 and minimum for But 15. An increase has been noticed in the nitrogen dioxide emissions with increasing speed. NO formation in the combustion chamber of engine is mainly because of the presence of availability of oxygen which leads to higher cylinder temperature in combustion chamber. NOx emissions increase with increasing speed. Since the temperature is lower at lower engine speeds, therefore, NOx emissions are also lower. At higher engine speeds, an increase in cylinder temperature and addition of oxygen in the fuel causes higher NO formation. This is because of the fact that butanol has higher latent heat of vaporization which results in lower temperature as compared to gasoline which in turn reduces the temperature of combustion and results in reduced NO emissions.
3. Conclusions

From the experimentally measured values of butanol blends in gasoline, it was found that the properties are similar to that of gasoline which implies that there would be no engine modifications required for using butanol blends with gasoline as a replacement to gasoline.

Brake specific fuel consumption and brake specific energy consumption are decreasing which indicates that these blends would require less fuel and less energy to liberate same amount of power. This is desirable property of a fuel since less fuel consumption would lead to less cost and more efficiency as compared to gasoline. Further, it can be concluded that the emissions which include hydrocarbon, carbon monoxide and nitrogen dioxide are decreasing which indicates that the emissions using up to 15% blends of butanol would be lower. This shows that it can be used as a renewable source of energy with the advantage of being less pollutive as compared to gasoline.

References

[1] Irimescu, A. (2011). Fuel conversion efficiency of a port injection engine fueled with gasoline isobutanol blends. Fuel and Energy Abstracts (Vol. 36).

[2] Lattimore, T., Herreros, J., Xu, H., & Shuai, S. (2015). Investigation of compression ratio and fuel effect on combustion and PM emissions in a DISI engine. Fuel (Vol. 169). https://doi.org/10.1016/j.fuel.2015.10.044

[3] Venugopal, T., & Ramesh, A. (2014). Performance, combustion and emission characteristics of a spark-ignition engine with simultaneous injection of n-butanol and gasoline in comparison to blended butanol and gasoline. International Journal of Energy Research (Vol. 38). https://doi.org/10.1002/er.3113

[4] Szwaja, S., & Naber, J. (2010). Combustion of n-butanol in a spark-ignition IC engine. Fuel (Vol. 89). https://doi.org/10.1016/j.fuel.2009.08.043

[5] Mittal, N., Leslie Athony, R., Bansal, R., & Kumar, C. (2013). Study of performance and emission characteristics of a partially coated LHR SI engine blended with n-butanol and gasoline. Alexandria Engineering Journal (Vol. 52). https://doi.org/10.1016/j.aej.2013.06.005
[6] Giakoumis, E., D. Rakopoulos, C., Dimaratos, A., & Rakopoulos, D. (2013). Exhaust emissions with ethanol or n-butanol diesel fuel blends during transient operation: A review. Renewable and Sustainable Energy Reviews (Vol. 17). https://doi.org/10.1016/j.rser.2012.09.017

[7] Song, J., Kim, T., Jang, J., & Park, S. (2015). Effects of the injection strategy on the mixture formation and combustion characteristics in a DISI (direct injection spark ignition) optical engine. Energy (Vol. 93). https://doi.org/10.1016/j.energy.2015.10.058

[8] Galloni, E., Fontana, G., Staccone, S., & Scala, F. (2016). Performance analyses of a spark-ignition engine firing with gasoline–butanol blends at partial load operation. Energy Conversion and Management (Vol. 110). https://doi.org/10.1016/j.enconman.2015.12.038

[9] Deng, B., Fu, J., Zhang, D., Yang, J., Feng, R., Liu, J., … Liu, X. (2013). The heat release analysis of bio-butanol/gasoline blends on a high speed SI (spark ignition) engine. Energy (Vol. 60). https://doi.org/10.1016/j.energy.2013.07.055

[10] Irimescu, A., Vasiu, G., & TrîfTordai, G. (2014). Performance and emissions of a small scale generator powered by a spark ignition engine with adaptive fuel injection control. Applied Energy (Vol. 121). https://doi.org/10.1016/j.apenergy.2014.01.078

[11] Wang, C., Xu, H., Herreros, J., Wang, J., & Cracknell, R. (2014). Impact of fuel and injection system on particle emissions from a GDI engine. Applied Energy (Vol. 132). https://doi.org/10.1016/j.apenergy.2014.06.012

[12] Irimescu, A. (2012). Performance and fuel conversion efficiency of a spark ignition engine fueled with iso-butanol. Applied Energy (Vol. 96). https://doi.org/10.1016/j.apenergy.2012.03.012

[13] He, B., Liu, M.-B., & Zhao, H. (2015). Comparison of combustion characteristics of n-butanol/ethanol–gasoline blends in a HCCI engine. Energy Conversion and Management (Vol. 95). https://doi.org/10.1016/j.enconman.2015.02.019

[14] Dernotte, J., Mounaïm-Rousselle, C., Halter, F., & Seers, P. (2010). Evaluation of Butanol-Gasoline Blends in a Port Fuel-injection, Spark-Ignition Engine. Oil & Gas Science and Technology (Vol. 65). https://doi.org/10.2516/ogst/2009034

[15] Ramey, D. (2007). Butanol: The other alternative fuel. Procs. NABC’s 19th Annual Meeting: Agricultural Biofuels: Technology, Sustainability and Profitability.

[16] Bhan Singh, S., Dhar, A., & Agarwal, A. (2015). Technical feasibility study of butanol–gasoline blends for powering medium-duty transportation spark ignition engine. Renewable Energy (Vol. 76). https://doi.org/10.1016/j.renene.2014.11.095

[17] N. Alasfour, F. (1997). Butanol - A single cylinder engine study: Engine performance. International Journal of Energy Research (Vol. 21). https://doi.org/10.1002/(SICI)1099-114X(199701)21:1<21::AID-ER231>3.0.CO;2-K