Comparative analysis of the Performance and Emission Characteristics of ethanol-butanol-gasoline blends

Sumit Taneja¹; Dr. Perminderjit Singh²; Gurtej Singh³
¹,²Research Scholar, Mechanical Engineering, PEC University of Technology, Chandigarh, 160012, INDIA
³Professor, Mechanical Engineering, PEC University of Technology, Chandigarh, 160012, INDIA

E-mail: sumit4088@gmail.com

Abstract. Global warming and energy security being the global problems have shifted the focus of researchers on the renewable sources of energy which could replace petroleum products partially or as a whole. Ethanol and butanol are renewable sources of energy which can be produced through fermentation of biomass. A lot of research has already been done to develop suitable ethanol-gasoline blends. In contrast very little literature available on the butanol-gasoline blends. This research focuses on the comparison of ethanol-gasoline fuels with butanol-gasoline fuels with regard to the emission and performance in an SI engine. Experiments were conducted on a variable compression ratio SI engine at 1600 rpm and compression ratio 8. The experiments involved the measurement of carbon monoxide, carbon dioxide, oxides of nitrogen and unburned hydrocarbons emission and among performance parameters brake specific fuel consumption and brake thermal efficiency were recorded at three loads of 2.5kgs (25%), 5kgs (50%) and 7.5kgs (75%). Results show that ethanol and butanol content in gasoline have decreased brake specific fuel consumption, carbon monoxide and unburned hydrocarbon emissions while the brake thermal efficiency and oxides of nitrogen are increased. Results indicate that butanol-gasoline blends have improved brake specific fuel consumption, carbon monoxide emissions in an SI engine as compared to ethanol-gasoline blends. The carbon dioxide emissions and brake thermal efficiencies are comparable for ethanol-gasoline blends and butanol-gasoline blends. The butanol content has a more adverse effect on emissions of oxides of nitrogen than ethanol.

Key words: CAD - Crank Angle Degrees, Ethanol blends, NOₓ - oxides of Nitrogen

1. Introduction
Alcohols being oxygenated fuels have been developed as a strong alternative to gasoline by researchers. Earlier researches have shown that alcohols can reduce engine emissions as well as enhance engine performance [1]. The technical and economic feasibility of alcohols also play a part in selection of alcohol as an additive to gasoline. It is observed that the alcohols act as octane number enhancer in gasoline which improves its combustion and hence reduces the emissions [2]. Lower alcohols having carbon atoms up to three can improve engine knock resistance when added to gasoline, however higher alcohols shows degraded knock resistance in gasoline engines. Many researchers have focused their prime interest on ethanol as an additive to gasoline. A lot of research has already been carried out on ethanol-gasoline blends. It has been experienced that engine performance and emissions improve in a gasoline engine while using ethanol-gasoline blends.
Generally, brake specific fuel consumption, brake power and brake thermal efficiency get improve as the ethanol content is increased to a certain level in the gasoline [3-4]. However, a different outcome was observed in terms of decrement of brake specific fuel consumption as reported by [5]. Ethanol is considered as a clean fuel and various studies prove its implementation in the gasoline engines. Ethanol has 34.73% oxygen content by mass which improves the combustion of gasoline in the fuel blends. An extra atom of oxygen ensures the reduction of emissions of hydrocarbons and oxidation of carbon monoxide as observed by [6-8]. Oxides of nitrogen are considered as the most undesirable emissions and its significance can be rated by the stringent emissions level as mentioned in European Union VI Emission Norms. Many researchers found that there is an increase in concentration of oxides of nitrogen with increasing ethanol percentage in the gasoline [3][6]. Although there are several studies which shows that ethanol, when added up to a certain limit in gasoline, decreases the NOx emissions [8][11][12]. A few studies also stated that NOx emissions depend on the operating conditions rather than the percentage of ethanol in fuel [5]. In addition to that it was reported by [8] that ethanol content allows gasoline engines to operate at higher compression as the knocking resistance of fuel improves.

Butanol is a higher alcohol and nearly bears the similar physical attributes to ethanol. Butanol is also a by-product of fermentation process in which acetone-butanol-ethanol (ABE) is produced. Butanol possesses higher heating value than ethanol that encourages researchers to adapt butanol in engines as a fuel. A number of studies showed that carbon monoxide and hydrocarbons in emissions decreased using butanol-gasoline blends [14-17]. NOx formed at high temperatures, were found to increase on blending butanol with gasoline as reported by [16-17]. However, opposite results were obtained for NOx as studied by [14][18]. A number of studies observed no significant changes in NOx for butanol-gasoline blends [13].

2. Experiments

2.1 Materials
Ethanol and butanol were purchased from local chemicals supplier. Marketed gasoline was purchased from a fuel station under the regulations of the Government of India. Marketed gasoline in India contains 5% of ethanol as per the policy defined for petroleum products.

2.2 Preparation of Blends
Initially, marketed gasoline was treated with water to wash out ethanol contained in it. The marketed gasoline then separated through conical separating funnel to get pure gasoline. Seven test fuels were prepared at the time of experiments in chemistry lab. G100 represents pure gasoline that is blended with ethanol and butanol to obtain the test fuels. Test fuels prepared were G100, E5, E10, E15, B5, B10 and B15 where E and B designate ethanol and butanol blend, respectively followed by their respective percentages in the gasoline.

| Test Fuel | HHV (KJ/kg) | Density (kg/m³) |
|-----------|-------------|-----------------|
| G100      | 42.9        | 760             |
| E5        | 42.095      | 761.5           |
| E10       | 41.29       | 763             |
| E15       | 40.485      | 764.5           |
| B5        | 42.38       | 762.5           |
| B10       | 41.86       | 765             |
| B15       | 41.34       | 767.5           |
The calorific value of all test fuels was measured on the Digital Bomb Calorimeter and density of all
the test fuels was measured through the conventional method. A known volume of the test fuels was
taken in a flask and mass of the considered volume was weighed in a mass balance set-up to obtain the
fuel density. Fuel properties of all the test fuels are listed in the Table 1.

2.3 Experimental set up
The engine used in this study was a vertical single cylinder, four-stroke, water-cooled, multi-fuel
engine with variable compression ratio. Compression ratio for gasoline mode of the engine was from
5:1 to 20:1. Engine specifications are given in Table 2.

| Make          | Legion Brothers       |
|---------------|-----------------------|
| Compression Ratio | 5:1 to 20:1, Variable |
| No. of Cylinder | 1                     |
| Cooling system | Water cooled           |
| Spark Timing   | 0-70°, Variable        |
| Fuel Mode      | Petrol/Diesel          |
| Speed          | 1450-1600 rpm          |
| HP             | 3 to 5 HP              |
| Lubrication    | Forced                 |
| Bore           | 80 mm                  |
| Stroke         | 110 mm                 |

The engine shown in figure 1 was attached with an Eddy Current Dynamometer (Powermag) to
achieve the specified loads. Eddy current dynamometer was fixed to a strain gauge type load cell for
measuring applied load to the engine. Exhaust gas calorimeter was equipped with K type
thermocouples to measure the temperature at different points. The exhaust emissions were measured
by QRO 401 five gas analyser (Qrotech Make). Engine equivalence ratio was measured by analysing
the exhaust contents with a precision of 0.001%. Fuel consumption rate was determined by a system
consisting of a burette with two optical sensors. A differential pressure sensor was used to measure air
flow rate.

2.4. Experimental procedure
For all test fuels, a single test run was made for each case. Pure gasoline (G100) was selected as
reference fuel for evaluating the performance and emissions of other blended fuels. For experiments,
loading at dynamometer was taken as a variable. Three different loads of 2.5 kgs, 5.0 kgs and 7.5 kgs
were considered for the experiments. During the experiments engine speed was maintained at constant
1600 rpm. The compression ratio for the experiments was chosen to 8:1. Spark timing was already
preset to 23° before top dead center (BTDC). The temperature of water running through engine and
calorimeter was adjusted at 60° C. The engine operating parameters such as brake specific fuel
consumption and brake thermal efficiency have been measured. Engine emissions such as carbon
monoxide, carbon dioxide, oxides of nitrogen and unburned hydrocarbons have also been measured.
3. Results and Discussions

3.1 Performance Characteristics

3.1.1 Brake Specific Fuel Consumption

It is evident from Figure 2(a) and 2(b) that the BSFC has decreased with the increase in the load for every test fuel. BSFC is dependent on brake power and fuel consumption rate. This result suggests that the increase in brake power have dominated more the effect of increase in fuel consumption with the increased load [17]. Although heating value of ethanol is lower than gasoline, still ethanol-gasoline blends have exhibited lower BSFC in comparison to pure gasoline. One fact is that ethanol has higher heat of vaporization that makes the vapors of ethanol to absorb heat during combustion and leads to a cooling effect on the charge. This in turn makes the charge more dense. A dense charge produces more brake power [3]. But this trend changed for E15 which has higher BSFC with respect to E10. This
shift in trend indicates that the lower heating value started to dominate the effect of higher heating latent heat of ethanol in the test fuel E15. Lower heating value means an increase in fuel consumption to produce same brake power [7].

From the Figure 2(b) it has been seen that adding butanol to gasoline has the same effect on BSFC as that of ethanol. This could be understand by the fact that butanol has a higher laminar flame velocity than that of pure gasoline which reduces the combustion duration to produce the same power as by pure gasoline [19]. B15 has shown the least BSFC. On comparing B15 with E15 it seems higher heating value of butanol (33 MJ/kg) as compared to ethanol (27 MJ/kg) resulted into lower BSFC of B15 [14].

3.1.2 Brake Thermal Efficiency

From the Figure 3(a) and 3(b) it can be seen that BTE has increased with increase in load for all the test fuels. Increase in load pushes more fuel to evaporate in the cylinder during compression stroke. This in turn decreases the charge temperature and consequently reduces the compression work. As the compression work is reduced, the net brake power increases [4, 20].

Increasing ethanol content in the test fuels exhibits a better BTE than pure gasoline. This trend could be explained by the fact that the higher value of latent heat of vaporization of the ethanol increases the cooling effect on the fuel charge in the combustion chamber and it reduces the compression work [12]. The improvement in the BTE for ethanol-gasoline blends is continued till E10 test fuel. After that BTE has decreased for E15. Addition of ethanol in the gasoline increases the volatility and latent heat of the fuel blend. This results in drop of the charge temperature of the fuel blend. At the same time, further addition of ethanol in the fuel blends led to the decrement in the drop of the charge temperature as the specific heat of ethanol is higher than gasoline. Thus, adding ethanol to the fuel blend has two contradictory effects on the charge temperature. After 10% of ethanol in fuel blend, the effect of higher specific heat dominates and the drop in charge temperature decreases. Hence less work is obtained resulting in lower BTE for E15 as compared to E10 [12].

![Figure 3(a). BTE variation with load for G100, E5, E10 and E15 at CR 8](image1)

![Figure 3(b). BTE variation with load for G100, B5, B10 and B15 at CR 8](image2)
Brake thermal efficiency has increased with the increase in butanol in the test fuels as shown in the Figure 3(a). These results may be analyzed on the basis of the fact that butanol has low saturation pressure (0.33 psi) as compared to that of gasoline (4.5 psi). Lower saturation pressure of butanol allows its vapor to evaporate more. This results in decrease of charge temperature which in turn reduces the compression work. Hence, net output work increases and BTE increases [21].

3.2 Emission Characteristics

3.2.1 Carbon Monoxide Emissions

All the fuels used have shown decrement in the concentrations of CO emissions with the load as can be seen in the Figure 4(a) and 4(b). This could be possible due to the fact that increasing engine load also increases the combustion temperature and leads to complete combustion. Another possible reason for the reduction in the concentrations of CO emissions could be the high level of excess oxygen at high loads as compared to that at low loads [4]. The ethanol-gasoline blended fuels have shown lower CO emissions as compared to that of pure gasoline (G100). As the ethanol percentage blended in the gasoline increases from E5 to E15, the emissions further decrease as evident from the emissions data. E15 has shown the least CO emissions at every load than that of E5 and E10. Ethanol has less carbon than pure gasoline. Also adding ethanol to gasoline increases the oxygen in the fuel, hence oxygen-to-fuel ratio is increased for the same fuel dispersion pattern as for pure gasoline. Consequently, combustion becomes more complete for the blended fuels [3, 4].

![Figure 4(a). CO emission variation with load for G100, E5, E10 and E15 at CR 8](image)

![Figure 4(b). CO emission variation with load for G100, B5, B10 and B15 at CR8](image)

Butanol-gasoline blends have shown lower CO concentrations as compared to that for pure gasoline in Figure 4(b). This happens due to the fact that the butanol-gasoline blends have higher A/F ratio and lower carbon content in comparison of pure gasoline. Thus, the fuel-air lean mixture of butanol-gasoline blends ensures complete combustion of the fuel [16]. B15 has shown the least CO emissions.
Corresponding to the same percentages of ethanol and butanol in the gasoline, butanol-gasoline blends have shown lower CO emissions than the ethanol-gasoline blends. This is due to the fact that butanol has lower latent heat of vaporization (578.4 kJ/kg) and higher calorific value (33 MJ/kg) as compared to that of ethanol (latent heat of vaporization and calorific value of ethanol are 840 kJ/kg and 27 MJ/kg, respectively). These may result in higher combustion temperature when butanol is added to gasoline. Higher is the combustion temperature, more effective is the combustion and hence lower are the CO emissions [21].

3.2.2 \( \text{NO}_x \) Emission

\( \text{NO}_x \) emissions have increased for all the blends with increase in the load as evident from figure 5(a) and 5(b). This increase in \( \text{NO}_x \) concentrations may be due to the fact that with increase in the load, in-cylinder temperature increases. The concentration level of \( \text{NO}_x \) emission has increased with increased ethanol content in the gasoline. Ethanol causes fast flame propagation and combustion in fuel which in turn increases the combustion temperature. Hence \( \text{NO}_x \) emissions increase with the increased ethanol content in the gasoline [6].

Addition of butanol in the gasoline has increased the concentration level of \( \text{NO}_x \) in the emissions as compared to the \( \text{NO}_x \) emission for pure gasoline as shown in the Figure 5(b). Butanol has faster flame propagation than that of pure gasoline which leads to a higher combustion gas temperature for butanol-gasoline blends. Another basis for this result could be formed on the fact that butanol has higher oxygen content and lower stoichiometric air-fuel ratio as compared to pure gasoline [22]. \( \text{NO}_x \) are found to be higher for the same butanol content as compared to that for ethanol in the gasoline at medium and peak loads. Because of lower latent heat of vaporization of butanol (578.4 kJ/kg) in the fuel blends, the vapours of butanol would absorb less heat from the combustion zone and thereby the cooling effect would be lower. Hence, the cylinder temperature would be higher in case of butanol-gasoline blends. In addition to that, higher heating value of butanol also leads to a higher cylinder temperature which increases the concentration of \( \text{NO}_x \) in the emissions [21].

Feng et al [22] have also cited the lower latent heat of vaporisation of butanol as the primary reason for the increase in NO\(_x\) emissions.

![Figure 5(a). \( \text{NO}_x \) emission variation with load for G100, B5, B10 and B15 at CR 8](image1)

![Figure 5(b). \( \text{NO}_x \) emission variation with load for G100, B5, B10 and B15 at CR 8](image2)
4. Conclusions

- BSFC has decreased for all the test fuels with increase in the load. The addition of ethanol in gasoline has decreased the BSFC. E10 has shown the highest percentage drop in BSFC. 7.2%, 16.4% and 10.2% drop in BSFC was observed for E10 w.r.t. pure gasoline at 2.5 kgs, 5.0 kgs and 7.5 kgs loading respectively. It is observed that there is a slight increase in the BSFC for E15 as compared to E10. This exception is a result of two factors i.e. heating value and latent heat of vaporization of the ethanol. For butanol-gasoline test fuels, BSFC has decreased with butanol addition to the base fuel. B15 has shown the highest percentage drop of 10.4% and 6.3% at 5.0 kgs and 7.5 kgs load respectively with respect to pure gasoline. Also B15 has shown better BSFC reduction at all loads. It is because of higher heating value of butanol as compared to ethanol.

- Brake thermal efficiency has increased for all the blends with increase in the load. On comparing the ethanol-gasoline test fuels with pure gasoline, the results have shown that ethanol content has improved the brake thermal efficiency. E10 has recorded the highest BTE at all loads. The percentage rises in BTE for E10 are 10.2, 21.5 and 8.31% at the loads 2.5, 5.0 and 7.5 kgs respectively, as compared to the pure gasoline. Then a slump in BTE is noted for E15. Butanol addition has exhibited a same effect as that of ethanol content in the test fuels. B15 has given the most improved BTE than any other butanol-gasoline blends. The BTEs are comparable for butanol and ethanol-gasoline fuels.

- CO emissions have decreased with increase in the engine load. It has been observed that the impact of both of the increased ethanol and increased butanol content in the gasoline have further decreased the CO emissions as compared to pure gasoline. The drop in CO emissions for E15 at the loads 2.5 kgs, 5.0 kgs and 7.5 kgs are 14.5%, 21.1% and 33.6% respectively, with respect to the pure gasoline. CO emissions have the highest percentage drop for B15 at all loads. At loads 2.5 kgs, 5.0 kgs and 7.5 kgs, percentage drops in CO emissions for B15 are 19.2%, 36.9% and 53.9%, respectively, with respect to the pure gasoline. It can be concluded that the butanol content in test fuels has improved CO emissions over the ethanol contents in the pure gasoline.

- NO\textsubscript{x} emissions have increased with increase in the load due to higher cylinder temperature at higher loads. B15 has exhibited the highest percentage rise of 234.4% in NO\textsubscript{x} emissions at the peak load with respect to the pure gasoline. In general, it has been noticed that content butanol have affected NO\textsubscript{x} emissions more than ethanol content. It can be concluded that ethanol-gasoline blends have shown better results in NO\textsubscript{x} emissions as compared to butanol-gasoline blends. Butanol’s higher latent heat of vaporization must have caused these trends.

5. References

[1] Demirbas A 2009 Bioalcohols as alternatives to gasoline Energy Sources Part A 31 1056–1062.
[2] Demirbas K & Sahin A 2010 Gasoline fuel blends for otto engines and gasoline fuel additives Energy Sources Part B 5 243–249.
[3] Talal Yusaf, Najafi Gand David Buttsworth 2009 Theoretical and experimental investigation of SI engine performance and exhaust emissions using ethanol-gasoline blended fuels Proceedings of ICEE 2009 3rd International Conference on Energy and Environment
[4] Wen-Yinn Lin, Yuan-Yi Chang, and You-Ru Hsieh 2009 Effect of ethanol-gasoline blends on small engine generator energy efficiency and emission J. Air & Waste Manage. Assoc. 60 142–148.
[5] Wei-Dong Hsieh, Rong-Hong Chen and Ta-Hui Lina 2002 Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels *Atmospheric Environment* **36** 403–410.

[6] Wang X, Chen Z, Jimin Ni, Saiwu L and Zhou H 2015 Effects of hydrous ethanol gasoline on combustion and emission characteristics of a port injection gasoline engine *Case Studies in Thermal engineering* **6** 147–154.

[7] Ghazikhani M, MohdHatami, Behrouz Safari and Davood Ganji 2013 Experimental investigation of performance improving and emission reducing in a two stroke SI engine by using ethanol additives *Propulsion and Power Research* **2**(4) 276–283.

[8] Topgul C, Yucesu H, Cinar C and Koca A 2006 The effects of ethanol–gasoline blends and ignition timing on engine performance and exhaust emissions *Renewable Energy* **31** 2534–2542.

[9] Ceviz M A and Yuksel F 2005 Effects of ethanol–unleaded gasoline blends on cyclic variability and emissions in an SI engine *Applied Thermal Engineering* **25** 917–925.

[10] Elfasakhany A 2014 The effects of ethanol-gasoline blends on performance and exhaust emission characteristics of SI Engine *International Journal of Automotive Engineering* **4**(1)

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

[12] Al-Hasan M 2003 Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission *Energy Conversion and Management* **44** 1547–1561.

[13] Dernotte J, Moutaim-Rousselle C, Halter F and Seers P; 2010 Evaluation of butanol–gasoline blends in a port fuel-injected SI engine *Oil& Gas Science and Technology- Rev. IFP* **65**(2) 345-351.

[14] Singh E, Shukla M K, Pathak S, Sood V and Nishan S 2014 Performance & noise characteristics of n-butanol/gasoline blend in constant speed SI engine *Int. J. of Engineering Research & Technology* **3**(11) 993-999.

[15] Elfasakhany A 2014 Experimental study on emissions and performance of an ic engine fuelled with gasoline/n-butanol blends *Energy Conversion and Management* **88** 277–283.

[16] Feng R, Yang J, Zhang D, Deng B and Xiaoqiang L 2013 Exp study on SI engine fuelled with butanol–gasoline blend *Energy Conversion and Management* **74** 192–200.

[17] Mittal N, Athony RL, Bansal R and Ramesh C 2013 Performance and emission characteristics of a partially coated LHR SI engine blended with n-butanol and gasoline *Alexandria Engineering Journal* **52** 285–293.

[18] Gu X, Huang Z, Cai J, Gong J, Xuesong W and Lee C 2012 Emission characteristics of a si engine fuelled with gasoline-n-butanol blends in combination with EGR *Fuel* **93** 611–617.

[19] Shashank S.N. and Kumar G.N; 2013 Comparison of ethanol and n-butanol blends with gasoline: A computational study *Energy Sources Part A* **36** 375-380.

[20] Ansari FT, Verma AP and Chaube A 2013 Effect on performance of SI engine using ethanol under varying compression ratio *Int. J. of Engineering Research & Technology* **2**(12) 375-380.

[21] Varol Y, Öner C, Öztop HF and Altun S 2014 Comparison of methanol, ethanol, or n-butanol blending with unleaded gasoline on Exhaust Emissions *Energy Sources Part A* **36** 938–948.

[22] Feng R, Fu J, Yang J, Wang Y, Deng B, Liu J and Zhang D 2015 Combustion and emissions study on motorcycle engine fuelled with butanol-gasoline blend *Renewable Energy* **81** 113-122.

[23] Schifter I, Diaz L, Rodriguez R, Gomez JP, Gonzalez U. 2011 Combustion and emission behavior for ethanol-gasoline blends in a single cylinder engine. *Fuel* **90** 3586-92.

[24] Schifter I, Diaz L, Gomez JP, Gonzalez U. 2013 Combustion characterization in a single cylinder engine with mid-level hydrated ethanol-gasoline blended fuels *Fuel* **103** 292-298.