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Assessment Study of Butanol-Gasoline Blends in Variable Compression Ratio Spark Ignition Engine

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In comparison to the other alcohols, the most attractive alternate for gasoline is butanol. Butanol is better in comparison to other alcohol because it has very promising physical and chemical properties which are favorable for its blending with gasoline. When blending of butanol and gasoline is done then butanol is perfectly miscible in every proportion. The moisture in the atmosphere is not absorbed by the butanol as it is hygroscopic in nature. The experiments and data analysis were conducted over 5%, 10%, and 15% butanol and gasoline blends for assessing their performance parameters in a Variable Compression Ratio SI Engine. The APEX Variable Compression Ratio multi-fuel engine was selected for experiments. The performance of the fuel and engine was evaluated by comparing the parameters like Brake Specific Fuel Consumption, Brake Thermal Efficiency and Exhaust Gas Temperature of gasoline-butanol blend with gasoline as bench mark fuel. The complete analysis of butanol-gasoline blends reveals the similar characteristics as gasoline.

Keywords: Butanol, Fuel Efficiency, Exhaust Gas Temperature, Performance Analysis, Variable Compression Ratio

Introduction

The investigation of ethanol and methanol has been done rigorously and concluded that ethanol and methanol usually suffer from the problem of absorbing moisture from an environment which provides harms to an environment and SI engine[1-2]. Due to this reason, butanol is an optimum alternate fuel to be utilized in gasoline in SI engine as it offers numerous advantages in comparison to ethanol and methanol. Butanol is miscible in nature and it can be produced via number of methods and from the variety of feed stocks like sugar, potato, and agricultural waste etc.[3-6]. The physio-chemical characteristics of butanol make it viable to be blended and gasoline[7-8]. Butanol has similar properties like that of gasoline. The basic physio-chemical characteristics of butanol blends are listed in Table 1. The comparison of basic properties of butanol and gasoline is shown in Table 1. Rice *et al.*[1] evaluated the 4-cylinder spark ignition engine by using the blends of butanol, methanol and ethanol on the basis of Carbon mono oxides, Nitrogen oxides and unburnt hydrocarbons emissions. If the UBF emissions were taken into consideration then the emissions of gasoline and butanol were similar and on the other hand methanol and ethanol produce higher emissions. Wallner *et al.*[2] concluded an insignificant difference in the level of emissions amongst 10% butanol and 10% ethanol with respect to petrol. Deng *et al.*[3] found that addition of butanol up to (35% blending ratio) that with knocking for higher combustion, ignition timing could be advanced or improved. This provided in better engine performance in perspectives of consumption of fuel, power and emissions of HC and Co emissions but there is not proper information about the emissions of NOx. Alasfour[4-6] determined the effect of pre-heating of air before inlet and ignition timing on NOx emissions. Yacoub *et al.*[7] examined the behavior of gasoline-alcohol with Variable Compression Ratio. Blends with the composition of 5% O_2 gave superior emissions of NOx among all alcohol blends injected inside the engine. Lower UHC and CO emissions are encountered due to the lesser enthalpy of vaporization

Table 1 — Typical properties of butanol and gasoline

Property	Gasoline	Butanol
Physical Form	Neat Liquid	Neat Liquid
Melting point	-56.8° C	-115° C
Boiling point	26.66-225° C	118° C
Relative density	0.719 g/cm^3	0.81 g/cm^3
Flashpoint	-45° F (37° C)	35° C

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along with advanced flame temperature. Gautam *et al.*[8-9]concluded that alcohol blends show that due to higher knock resistance all the alcohol blends shows lesser brake specific fuel emissions. This is due to the reason that knocking resistance depends on oxygen content in the fuel. Dernotte *et al.*[10] examined the performance of butanol by blending up to 80% with gasoline and derived that B80 and B60 delivered 47% and 18% enhancement in UHC emissions in contrast of gasoline in SI engines. They also concluded that there is a blend which does not produce the lower Carbon mono oxide emissions was B80 in comparison to emissions delivered by gasoline. Butanol and gasoline have similar laminar flame speeds as they both possess similar combustion duration in SI engines. The same observation at 100% butanol was also quoted by Szwaja and Naber[11]. Wigg *et al.*[12] evaluated the feasibility of neat butanol and neat ethanol and concluded that butanol and gasoline performed in a similar manner in terms of performance of engine but the emissions of UHC in case of butanol are too much nearly two to three times in comparison to gasoline.

CO emissions are equal in ethanol and butanol and lower in comparison to gasoline. Aleiferis *et al.*[13] and Fu *et al.*[14] concluded from the experiments conducted that flame propagation of butanol was rapid than petrol but lesser than ethanol. By above investigational studies, it is observed that butanol is a bio-fuel with enormous potential. The present study evaluates the prospects of utilizing the optimum blend of butanol and gasoline blend in Variable Compression Ratio engine. Ashraf Elfasakhany[16] examined the effect of adding methanol and butanol in gasoline and concluded an adverse effect on engine performance.

Experimental setup

All the experiments were conducted on a multi-fuel (petrol) single cylinder 4-stroke at open ECU mode. The engine for testing includes Variable Compression Ratio connected to eddy current dynamometer. Dedicated software for engine testing purpose (IC engine soft) is used to record the experimental data like various performance parameters. The various important specifications of the experimental setup engine are presented in Table 2.

Experimental procedure

Set of experiments were run on multi-fuel (petrol) single cylinder 4 stroke at open ECU mode. The different blends of butanol with gasoline at different blending ratio were made for analysis and neat petrol was taken as baseline fuel for the purpose of analysis. The experimental procedure was performed on variable compression ratio SI engine without any modification under normal operating conditions. Four different blends were used during the testing which includes three test blends (Butanol5, Butanol10 and Butanol15) namely B5, B10 and B15 and finally gasoline as baseline fuel. Butanol AA represents AA percentage content of butanol (v/v) content in test blend fuel. A separate arrangement was assembled to put the engine on loading by coupling an eddy current dynamometer to the engine. A dynamometer controller was deployed to control dynamometer functions. Same cycles of test runs were conducted on the specific interval of time while varying required compression ratio. The data was noted for 100 continuous cycles for the analysis by considering the effect of continuous cycle variations in the outcomes of performance and emissions. All the experiments and data collection process was performed at a fixed speed of 1500 rpm.

Results and Discussion

The results were taken on a constant speed of 1500 RPM for all the blends as well as for neat baseline fuel.

Performance characteristics

The performance of any engine is illustrated by analyzing the different performance parameters like BSEC (Brake specific energy consumption), BSFC (Brake Specific Fuel Consumption), BTE (Brake Thermal Efficiency) and Exhaust gas temperature. These parameters were analyzed in the experiments at the fixed speed and varying load.

Table 2 — Technical specifications of the experimental setup engine

Characteristics of Engine	Technical Specifications
Model Name	Variable Compression Ratio dual fuel research engine
No. of cylinders	1
Number of strokes	4
Diameter of Cylinder	87.5 mm
Length of Stroke	110 mm
Length of Connecting rod	234 mm
Diameter of orifice	20 mm
Length of dynamometer arm	185 mm
Power	3.5 kW
Speed range	1200 to 1800 RPM
CR range	6:1 to 10:1

Brake specific fuel consumption

The Figure 1 depicted the disparity in Brake Specific Fuel Consumption and BMEP. For all the blends, Brake Specific Fuel Consumption decreased as the load on the engine is increased.The blends of butanol and gasoline have higher Brake Specific Fuel Consumption in comparison to the baseline fuel i.e, gasoline. This is because of the reason that butanol has a lower calorific value in comparison to gasoline and as the blending is done then the relative calorific value of the blend is lower than the gasoline[15].The trend of the Figure 1 clearly states that the swell in Brake Specific Fuel Consumption will depend on the butanol content in the blend.As the content of the butanol is increased then in order to produce the identical power output in an engine supplementary fuel quantity on the basis of mass is required. The other reason is that nearly 20% oxygen (w/w) is contained in butanol which does not put in to the process of heat invention.The Brake Specific Fuel Consumption also decreases with increase in the compression ratio because more amount of time is delivered to the fuel in order to assist the process of combustion[15]. From the above illustration of these figures, it can be concluded that, for the low load condition, the minimum percentage enhancement in Brake Specific Fuel Consumption is 1.94% at B10 butanol blend with CR 10. Similarly, for the high load condition, the minimum percentage enhancement in Brake Specific Fuel Consumption is 16.6% at B5 butanol blend with CR 10 in comparison to petrol.

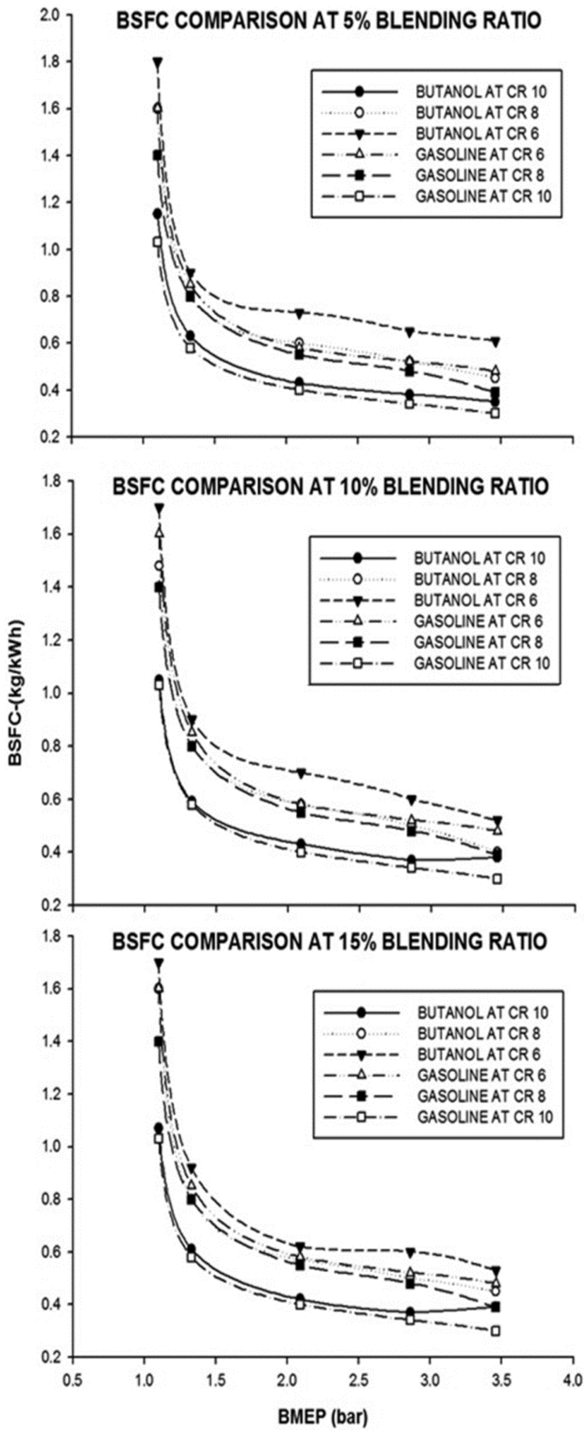

Fig.1 — Brake Specific Fuel Consumption Comparison of butanol at 5%, 10% and 15% Blending ratio with petrol at different compression ratio

Brake thermal efficiency

The effect of butanol addition in brake thermal efficiency in respect to BMEP is presented in the Figure 2. It was pragmatic that as the load enhances the Brake Thermal Efficiency also enhances. Brake Thermal Efficiency of all butanol blends is inferior to gasoline at all loads. The reason of variation of Brake Thermal Efficiency in contrast to gasoline is that butanol has superior enthalpy of vaporization and higher auto ignition temperature in comparison to gasoline. Due to this reason the butanol allows the incorporation of butanol with air, which in turns leads to reduced combustion and tends towards the lower thermal efficiency.The effect of compression ratio is also seen in the Figures that as the compression ratio is increased the Brake Thermal Efficiency is also increased. The Brake Thermal Efficiency is higher at maximum compression ratio and it also tends to increase with respect to increasing load on the engine[17]. The trends of graphs clearly states that for all loading conditions, the brake thermal efficiency will deteriorate. The optimum condition for best efficiency at lower loading condition is at 10% blending. At this condition, the least percentage

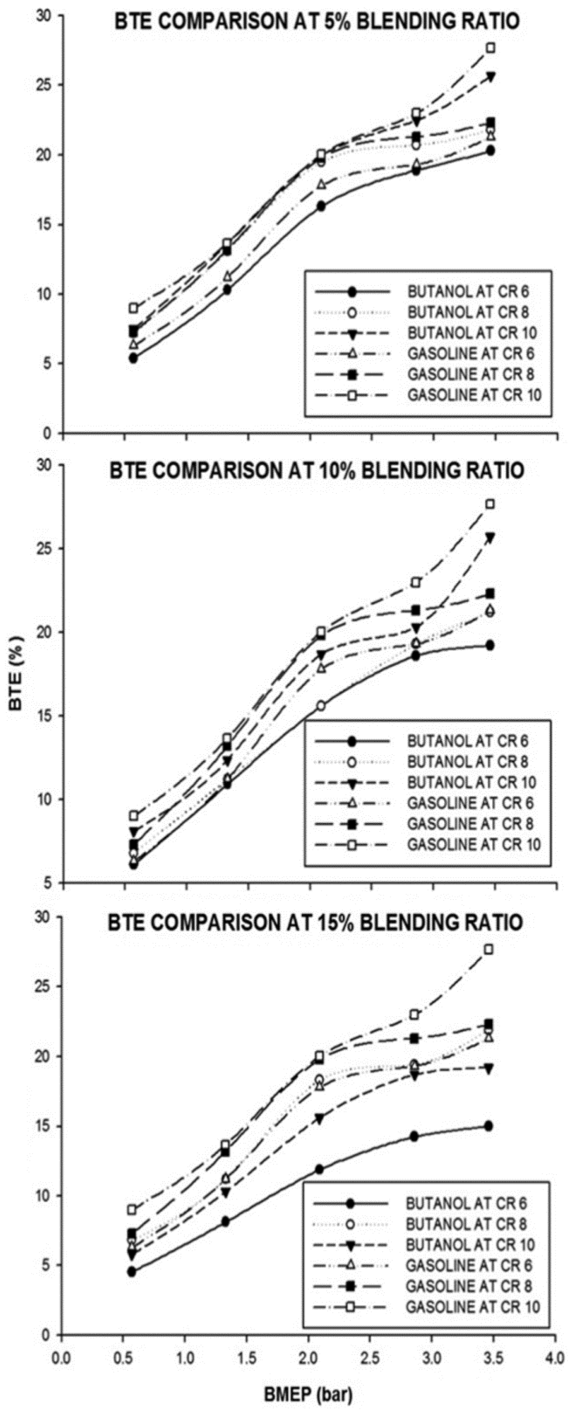

Fig.2 — Brake Thermal Efficiency Comparison of butanol at 5%, 10% and 15% Blending ratio with petrol at different compression ratio

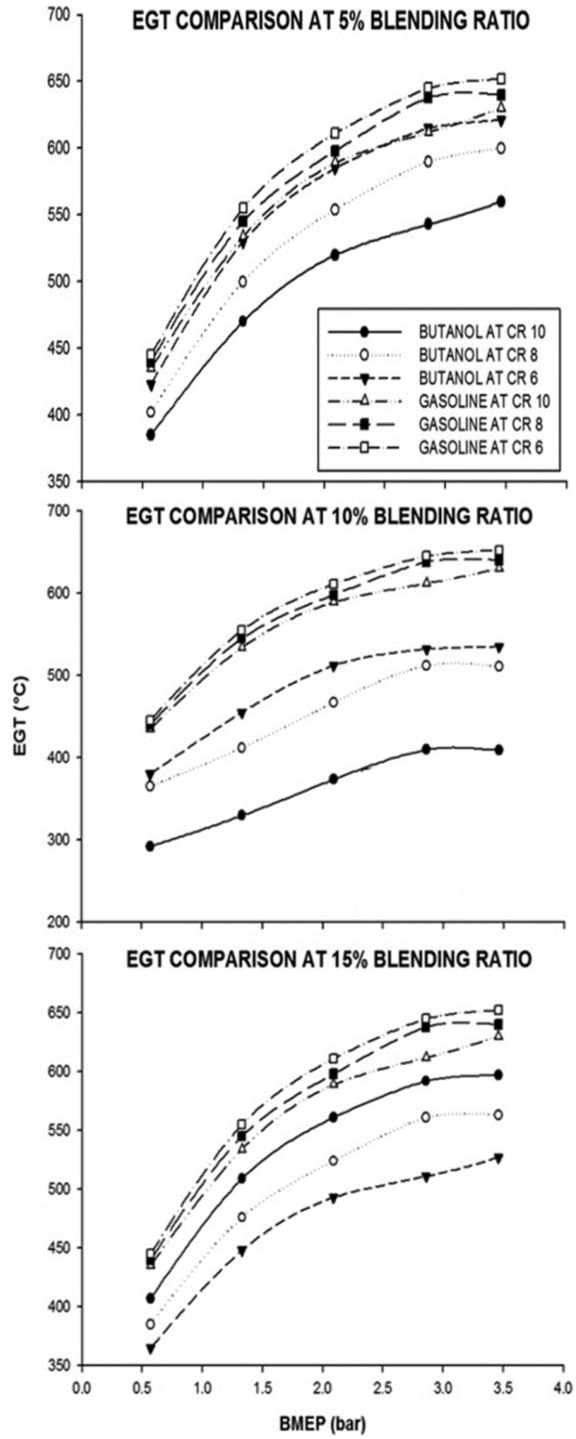

Fig.3 — Exhaust Gas Temperature comparison of butanol at 5%, 10% and 15% Blending ratio with petrol at different compression ratio

reduction in Brake Thermal Efficiency (11.11%) was recorded. This minimum reduction was observed at CR 10. Similarly, in the case of high loading condition, the minimum percentage reduction in Brake Thermal Efficiency was 7.58%. This optimum value was recorded at CR 10 and 10% blending ratio in comparison to petrol.

Exhaust gas temperature

Behaviour of Figure 3 demonstrates that on increasing the load on the engine, the Exhaust Gas

Temperature is also increased. The decline in butanol-fuel blend exhaust gas temperature is seen to be factually inconsequential. Since butanol comprises a superior heat of vaporization (approx 37%) in contrast with petrol fuel, butanol blend vaporization produces elevated temperature declination in the chamber toward the closing stages of admission. In this manner, temperature toward the finish of pressure stroke additionally relatively lesser which exactly prompts and bring down exhaust gas temperature at ending of ignition. The best optimum condition in terms of Exhaust Gas Temperature was 10% blending ratio. At lower loading condition, the maximum percentage reduction in Exhaust Gas Temperature is 48.97% at B10 butanol blend with CR 10. Similarly, for the high load condition, the maximum percentage reduction in Exhaust Gas Temperature is 54.11% at B10 butanol blend with CR 10 in comparison to petrol.

Conclusions

On the basis of the analysis, it was concluded that at every blending ratio,

- The Brake Specific Fuel Consumption of butanol blends is higher than neat petrol at each and every operating parameter. This is due to the fact, that butanol has lower calorific value than petrol. The data found similar properties with 5%, 10% and 15% butanol and gasoline blend as in gasoline.
- Brake thermal efficiency is lesser in contrast to gasoline. The reason of this fact is that butanol has higher enthalpy of vaporization and higher auto ignition temperature in comparison to gasoline.
- Exhaust gas temperature of the gasoline-butanol blend is slightly lower than petrol. The reason behind this effect is that butanol blend vaporization produces elevated temperature declination in the chamber toward the closing stages of admission. In this manner, temperature toward the finish of pressure stroke additionally and relatively lesser which exactly prompts and bring down exhaust gas temperature at ending of ignition.

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