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Methods to Improve the Spray Characteristics of n-Butanol by Visualization of Spray in a Port Injector

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Abstract: Generally, fossil fuels are non-renewable and depleting day by day. The usage of renewable fuels reduces global warming. Alcohols are renewable in nature and used in SI engines due to their good combustion properties like antiknock and flame velocity. Ethanol, methanol, and butanol are commonly used alcohols. Ethanol is widely used in countries, where it is abundant. Butanol is gaining more attention due to its combustion properties being similar to gasoline and its corrosion less behavior when compared to ethanol. Butanol injection in the intake port through port injectors will form a plume, which leads to high emission. The high viscosity of butanol is the reason behind such plume which is the major cause of poor vaporization, less fuel efficiency, and high hydrocarbon emissions. Methods like heating of butanol to high temperatures, increasing the injection pressure and blending of butanol with less viscous fuels like gasoline and ethanol can be accomplished to obtain a better fuel spray. This particular work reveals the visualization of the spray of butanol with different fuel temperatures, injection pressure and the blending of butanol with gasoline and ethanol. Further, it can be a knowledge base for utilizing renewable butanol effectively in automotive engines for achieving low emission and high fuel efficiency.

Keywords: Alternate Fuels; Butanol; Ethanol; Blends; Spray; Plume.

I. INTRODUCTION

Bio-alcohols have become an alternative solution to fossil fuels because of their good emission characteristics and renewable nature [1]- [6]. Various biomass like sugar cane, straws of barley and wheat, corn fiber, grass and agricultural waste are widely used to produce ethanol and butanol [7]-[10]. The higher heat of combustion and lower latent heat of vaporization of butanol makes it more attractive than ethanol [11]-[17]. The values of the combustion properties of butanol are close to that of gasoline, which is beneficial in using it in the existing engines [15],[18],[19]. Port fuel injection has gained attention since the last two decades due to its fast transient response, atomization, targeting and fuel metering [20], [21]. A new combustion technique that gains more attention for its NOx less emission, so-called Homogeneous Charge Compression Ignition (HCCI) relies on port injection technique for its charge preparation [22]-[26]. The cause of higher emissions from butanol is because, its spray forms a plume when it is injected through port injectors [5], [27]. The injection pressure of port fuel injectors is generally 2.5 to 3 bar [28]. It is also one of the reasons for high emissions with n-butanol. The high viscosity of butanol is the reason for the formation of plume which hinders the fuel atomization and evaporation. In port fuel injection engines, the formation of the mixture starts as soon as the liquid fuel is injected on the backside of the intake valve. Size of the droplets, spray velocity, spray pattern, spray penetration, spray angle and targeting are the main factors to define the introduced spray [29]-[31]. These factors are highly influenced by injector design and operating conditions which in turn influence the engine performance [29]. Liquid fuel must evaporate and form a fuel-air combustible mixture to initiate the combustion. Reducing the diameter of hole of port injector leads to better fuel atomization and evaporation [32]. It is due to the increased overall surface area by forming more number of droplets. An increase in injection pressure can also result in a reduction in the droplet's mean diameter and an increase in penetration lengths [33], [34]. It was reported that a better blending of butanol with gasoline or ethanol can also provide good atomization and evaporation [12], [27], [35]. It is the viscosity of butanol, which remains the main barrier for effective spray. The viscosity of butanol can be reduced by increasing the temperature of butanol, increasing the injection pressure and blending the butanol with gasoline or ethanol [29], [36]. All three methods were performed with butanol and the respective sprays were compared with gasoline sprays at similar conditions. An approximate optimistic fuel temperature, injection pressure and blend ratio were suggested to obtain a well-atomized butanol spray similar to that of gasoline in a single hole injector.

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II. EXPERIMENTAL PROCEDURE

A. Experimental Apparatus

Figure 1 shows the experimental apparatus is used for the spray test. The apparatus consists of a fuel pump, single hole port injector, high power LED lamp, regulated power supply (RPS), controller with ATMEGA8L – 8PU processor, digital signal lens reflex (DSLR) camera, pressure gauge, fuel pipes, and adjustable flow control valve. The apparatus specifications are as shown in Table 1.

Table- I: Apparatus Specification

Apparatus	Specification
Fuel pump	12V, 0.6A
Fuel injector	Single hole, 3 bar, 430µm hole diameter
DSLR Camera	18 mega pixels, 35 mm focal length, 3:2 aspect ratio
RPS	32V, 5A

A fuel pump that was used can pressurize the fuel to a maximum of 4 bar injection pressure. A Maruti 800 single hole port injector was used throughout the test. The purpose of the high power LED lamp was to illuminate the fuel spray. RPS that has been used was capable to deliver 32-volt supply. Based on the pump and controller requirements the voltage was set at 12volt each. The DSLR camera was focused to visualize the illuminated fuel spray.

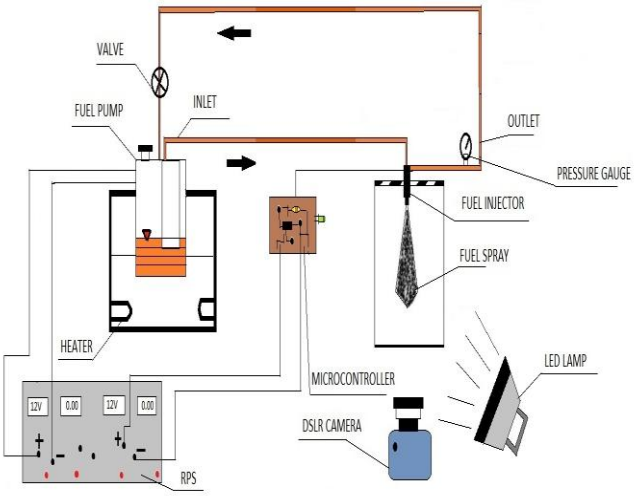


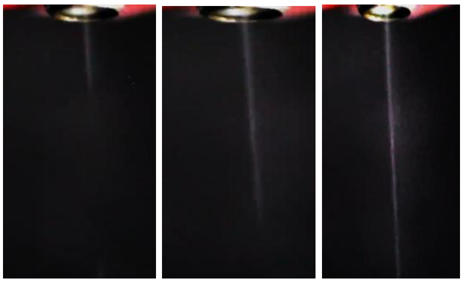
Fig 1. Schematic of Experimental Apparatus

B. Experimental Procedure

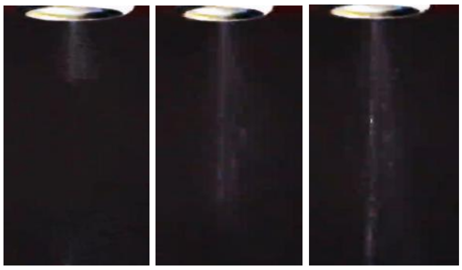
A 12-volt power supply from RPS was given to the controller and fuel pump each. The fuel gets pumped through the pressure lines and reaches the injector. A pulsed spray was achieved through the controller and captured as a video using the DSLR camera. Excess fuel gets back to the fuel tank once again through the fuel return lines. The spray test was performed in four cases. In case 1, butanol was blended with gasoline at 1:1 ratio by mass and the spray images are taken. In case 2, butanol was blended with ethanol at 1:1 ratio by mass and the spray images are taken. In case 3, the temperature of butanol was increased to 40°C and the spray images were obtained for injection pressures, 3 and 4 bar. In case 4, the initial temperature of butanol was increased to 55°C and the spray images were obtained for injection pressures, 3 and 4 bar.

III. RESULT AND DISCUSSION

Initially, the spray test was established without any fuel pretreatment at 3 and 4 bar injection pressure. Figures 2 and 3 show the initial spray images captured at 3 and 4 bar injection pressures of butanol and gasoline without any pretreatment. The spray image of gasoline appeared to be a straight line, whereas for butanol the spray image appeared to be diverging.

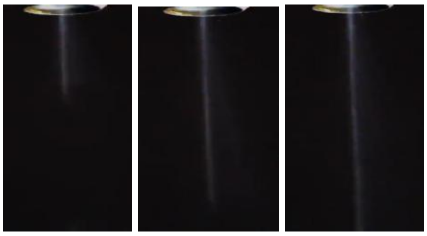


(a) Gasoline



(b) Butanol

Fig 2. Spray image at 3 bar injection pressure



(a) Gasoline

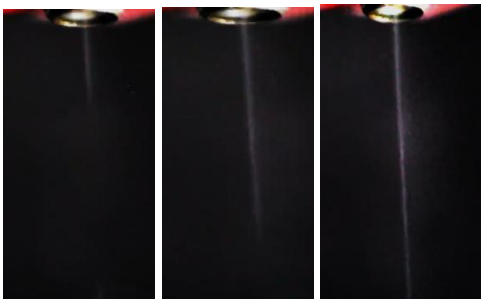
(b) Butanol

Fig 3. Spray image at 4 bar injection pressure

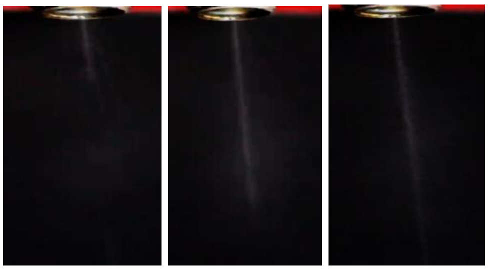
An increase in injection pressure from 3 to 4 bar, it doesn't show much difference in the spray characteristics of butanol. The spray image at both pressures looked very similar. Moreover, a significant difference was observed between the sprays of gasoline and n-butanol.

A. Spray Characteristics of Butanol - Gasoline Blend (50%)

As discussed in the literature the butanol and gasoline were blended by mass in the ratio of 1:1 and the spray test was carried out. Gasoline being a less viscous fuel, it can be blended with butanol for a better spray. Figure 4 shows the spray images of gasoline at 3 bar and spray image of butanol – gasoline (1:1) blend at 3 bar.



(a) Gasoline



(b) Butanol – gasoline (1:1) blend

Fig 4. .Spray image butanol – gasoline blend at 3 bar injection pressure

A spray of butanol – gasoline blend was found to be far better than the spray of butanol at 3 bar (i.e. it is similar to that of gasoline spray). The spray was observed to be with fewer plumes when butanol was blended with gasoline. It can be concluded that, when n-butanol is mixed with gasoline by 1:1 (50% on a mass basis), a better spray can be obtained which could lead to low emission when compared to the use of raw n-butanol (100% n-butanol).

B. Spray Characteristics of Butanol - Ethanol Blend (50%)

From the literatures, butanol was blended with ethanol in the ratio of 1:1 by mass and tested for obtaining better spray characteristics. Ethanol, being less viscous can be blended with butanol for better spray. Figure 5 shows the spray images of gasoline at 3 bar and butanol – ethanol (1:1) blend at 3 bar.

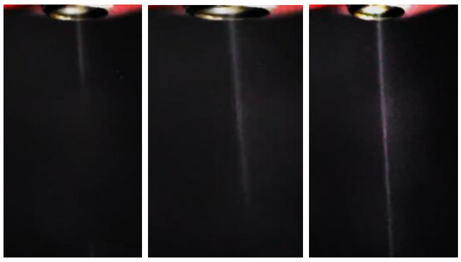
(a) Gasoline

(b) Butanol - Ethanol (1:1) blend

Fig. 5. Spray images butanol – ethanol (1:1) blend at 3 bar injection pressure

C. Spray Characteristics of Butanol at 40°C

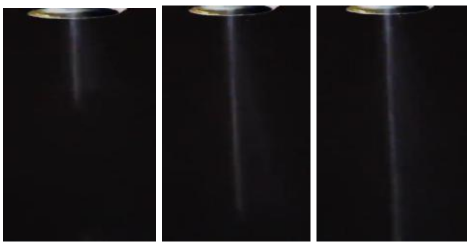
Generally, fuel viscosity decreases with an increase in temperature. This could lead to a better spray of n-butanol. This motivates to conduct the study on the visualization of n-butanol with high fuel temperatures of 40° C. Also, the flashpoint of butanol was 35°C and hence the initial temperature of butanol was increased to 40°C and the spray test was performed at 3 and 4 bar injection pressures. Figure 6 shows the spray images of preheated butanol at an injection pressure of 3 bar. Figure 7 shows the spray images of preheated butanol at an injection pressure of 4 bar.



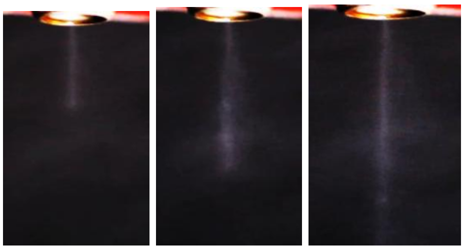
(a) Gasoline

(b) Butanol

Fig. 6. Spray image of butanol at 3 bar injection pressure, 40°C temperature



(a) Gasoline



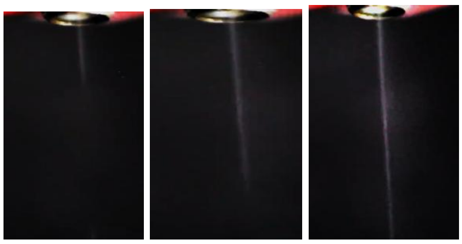
(b) Butanol

Fig. 7. Spray image of butanol at 4bar injection pressure, 40°C temperature

An increase in temperature and pressure had significant influence on the spray. The spray at 4 bar and 40°C was found to be straight with good penetration. Plume was reduced when compared with spray without preheating. Increase in injection pressure from 3 to 4 bar and temperature to 40°C have a significant effect on the butanol spray.

D. Spray Characteristics of Butanol at 55°C

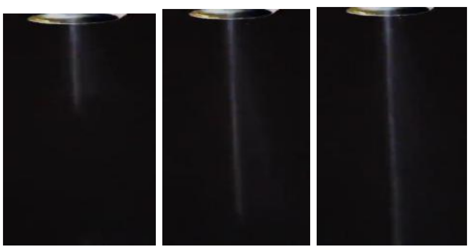
The temperature increase of butanol to 40°C showed a considerable difference in the spray. So the test was performed at 3 and 4 bar injection pressures and a further increase in butanol temperature to 55°C. Figure 8 shows the spray images of preheated butanol at 3 bar injection pressure at 55°C. Figure 9 shows the spray images of preheated butanol at 4 bar injection pressure at 55°C.



(a) Gasoline

(b) Butanol

Fig. 8. Spray image of butanol at 3bar injection pressure, 55°C temperature



(a) Gasoline

(b) Butanol

Fig. 9. Spray image of butanol at 4bar injection pressure, 55°C temperature

Increasing the temperature of n-butanol to 55°C without increasing the injection pressure (i.e. at 3 bar injection pressure) shows similar spray characteristics of gasoline. Increasing the butanol pressure from 3 bar to 4 bar at 55°C doesn't show any significant difference. The spray remained straight with fewer plumes. It can be concluded that at 3 bar injection pressure, elevating the temperature to 55° C is sufficient to improve the spray characteristics of butanol. However, in the earlier case of fuel injection at 40° C, the injection pressure influences the spray when increased from 3 bar to 4 bar. This could be a better option for improving the spray in the earlier case. Thus an overall idea about the spray of n-butanol at different injection pressures, temperatures and blends with gasoline and ethanol arrived from this research work.

IV. CONCLUSION

From the literature, Bio-butanol is gaining more attention due to its combustion properties being similar to gasoline, which leads to the use of it in already existing engines. However, the high viscosity of butanol forms a plume (poor spray) when it is injected, which leads to poor vaporization and high emission. Approaches to enhance the spray characteristics of butanol were studied. The main conclusions are: -

- Preheating of n-butanol to 55° C at an injection pressure of 3 bar has led to its spray similar to that of gasoline.
- Simultaneously, increasing the injection pressure (3 to 4 bar) and fuel temperature (30 to 40°C) has led to a good spray of butanol.
- Increasing the injection pressure alone from 3 bar to 4 bar resulted in no significant improvement in its spray at 55°C temperature.
- Blending of butanol with gasoline and ethanol by 1:1 mass ratio (50% by mass) results into reduction of the viscosity of butanol which has led to good butanol's spray.

On the whole various methods are used to improve the butanol spray in a single hole port injector were studied and reported based on the visualization of butanol spray and the results can have significant effects if used purposely.

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