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Evaporation Rate Analysis of Different Fuel Blends for Low Temperature Combustion Engine Applications

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ABSTRACT: As the global emission norms for automotive engines are becoming more and more stringent because of environmental concerns, an improved understanding about the fundamental processes which plays a role in emission formation is required. The rate at which the fuel evaporates is one such processes which affects the emission formation in a significant manner owing to its role in fuel-air mixing. Low Temperature Combustion (LTC) are emerging as the most promising strategies to simultaneously reduce oxides of nitrogen and particulate matter emissions along with maintaining higher thermal efficiency. LTC strategies demand fuel blends of varying reactivities to have a better control on combustion at varying loads. Understanding evaporation rate of possible fuel blends for LTC strategies is yet to be explored.

This study presents the fuel and evaporation rate characteristics of blends of commercial fuels (Gasoline and Diesel) as well as alternative fuels (Butanol and Ethanol) which are the potential fuel blends for LTC applications. The evaporation rate characteristics of all the fuel blends are carried out by using hanging droplet method. The obtained results show that diesel increases non evaporative part. Along with that multicomponent system behave differently compare to single one's.

KEYWORDS: Evaporation Characteristics, Fuel Blends, Low Temperature Combustion, Alternative Fuels

NOMENCLATURE

D/ Do Diameter/ Initial diameter t
Time (sec)
K Evaporation Constant

I. INTRODUCTION

The rise of civilization is closely related to the improvement of transportation. The internal combustion engines occupy a major role in that [1]. However, in the recent times the exhaust pollutants from the internal combustions are of serious concern owing to their global warming potential and human health problems. The countries all over the world have implemented stringent emissions norms to improve the air quality [2]. The engine out emissions could be reduced by utilizing after-treatment devices which are expensive or by in-cylinder control [1]. Low temperature combustion (LTC) is an in-cylinder emission control strategy which has evolved based on the understanding of emission formation mechanisms. LTC is driven by the fuel chemical kinetics and is fuel flexible. LTC strategies demand fuels with varying reactivities to widen the operating load range which could be achieved by the use of different fuels or by blending fuels of different reactivities [3].

Evaporation is an important mechanism in the internal combustion engines which helps to understand the mixture preparation, distribution and combustion [4]. Studies related to fuel evaporation rates at high pressure and high temperature conditions are well established for both single and multi component fuels such as biodiesel [5]. However, evaporation rate studies for different fuel blends which are of interest for LTC engine applications are scarce.

In this work, analysis of evaporation behaviour along with fuel characteristics is discussed for various commercial (Gasoline, Diesel) and alternative fuels (Ethanol, Butanol) and their blends. The results obtained from this study would provide improved understanding of evaporation rate behaviour of fuel blends utilized for LTC engine applications.

II. EXPERIMENTAL SETUP AND TEST PROCEDURE

The present study involves fuel blends preparation, characterization and their evaporation rate estimation based on experiments.

Fuel Preparation and Characterization

Selected fuels are two commercial fuels (Gasoline and Diesel) and two alternative fuels (Butanol and Ethanol). The selection of fuels is based on the differences in their reactivities. Further, the selection of fuel blends is based on the base fuel evaporation behaviour. In case of diesel tests were performed at 10 and 20% by volume of diesel and in case of butanol, gasoline and ethanol 20, 50 and 80% of volume is tried. Blends are gasolinediesel (GD10, GD20), Butanol Diesel (BD10, BD20), Ethanol diesel (immiscible), Butanol Gasoline (BG20, BG50, BG80), Ethanol Gasoline (EG20, EG50, EG80) and Butanol Ethanol (BE20, BE50, BE80). GD10 represents 10% of diesel with 90% gasoline.

Engine fuel properties, viz. density, viscosity, surface tension are measured according to ASTM standards for the test fuel blends and are presented in Table 1. For fuel density measurement, Oscillatory U-tube method is used and for measuring viscosity rotating drum method is used. Surface Tension is measured with Attension Sigma 700 using Du Nuoy ring method.

TABLE 1: Fuel blends properties with base fuels.

Fuel	Density (g/cm ³)	Viscosity (mm ² /s)	Surf. Tension (mN/m)
Diesel	0.8175	2.999	24.679
Gasoline	0.799	0.43694	22.268
Butanol	0.8107	2.6311	22.283
Ethanol	0.7932	1.1656	20.35
GD10	0.8024	0.4864	22.565
GD20	0.8036	0.5216	22.853
BD10	0.8118	2.8457	22.86
BD20	0.813	2.9115	23.229
BG20	0.8055	2.0103	22.411
BG50	0.798	1.1613	21.802
BG80	0.8025	0.98321	21.84
EG20	0.7938	0.9791	20.774
EG50	0.7953	0.7263	21.093
EG80	0.7957	0.52404	21.608
EB20	0.7958	1.3449	21.209
EB50	0.8014	1.7269	21.903
EB80	0.8075	2.4112	22.145

Evaporation Characterisation

Various established techniques are available in the open literature for studying the single droplet evaporation behaviour. Among those, suspended droplet method is found to be more accurate and provides insight for both qualitative and quantitative nature of droplet evaporation [6]. Earlier similar technique has been used for studying fuel evaporation behaviour for Biodiesel, Diesel and respective blends [7]. To understand the evaporation behaviour of urea water solution for selective catalytic reduction (SCR) applications, similar kind of hanging droplet technique was used [6]. In suspended droplet technique, the presence of a suspender makes the method intrusive. To counter that care has been taken to minimize the effect of the suspender on evaporation behavior of the droplet by using a glass micro fiber [6, 8] of diameter about 25 microns as the suspender. Lower thermal conductivity of glass combined with very low cross sectional area helps in restricting heat conduction through the suspender and keeping it to a minimum. Use of a very fine suspender also leads to droplets retaining their spherical shape during evaporation [6].

The experimental setup contains a glass fiber fixed with clamps, a high speed camera and background light. Tests are performed at ambient conditions while placing droplets at fiber using syringe manually. Images of evaporating droplets were captured using a Photron fast cam mini, a high speed camera at a certain 50 frame speed and are recorded in a computer. The light source used is an LED array. The complete test setup is presented in Fig 3 along with a representative suspended droplet. Captured images are post processed using an in house developed codes written in MATLAB. The diameter of the suspended droplet was retrieved from the image.

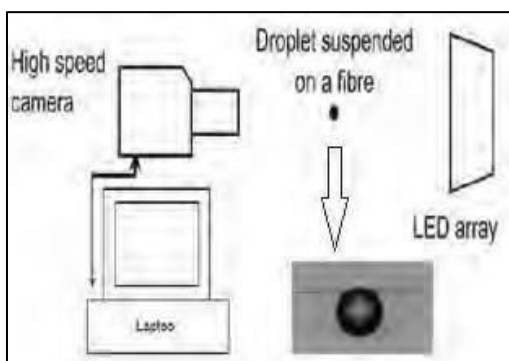


FIGURE 1. Experimental Setup for Evaporation Studies

To evaluate the evaporation rate of test fuel blends, D square (D^2) law is applied as provided in Equation 1 [9]. To get the evaporation rate plots of non-dimensional parameter $(D/D_0)^2$ is plotted with (t/D_0^2) where „t“ is time.

$$D^2(t) = D_0^2 - Kt \quad (1)$$

D is Diameter at time t, D_0 is initial diameter and K is the evaporation constant.

III. RESULTS AND DISCUSSIONS

Results are presented and are discussed next based on the test fuel blends. Evaporation characteristics is represented as normalised diametric variation in form of $(d/d_0)^2$ versus t/d_0^2 which reflects the evaporation behavior and left over fuel.

Gasoline Diesel: Gasoline being a multicomponent system shows decreasing evaporation rate with time but initial evaporation is very fast as compared to diesel which evaporates at a slower rate owing to the presence of heavier components. Both the fuels exhibit some non evaporative behaviour after a time frame. Similar trends are observed with fuel blends as well. Non evaporative volume increases proportionally with increase of diesel proportion and rate of evaporation at initial part is also affected with diesel proportion as shown in Fig. 2.

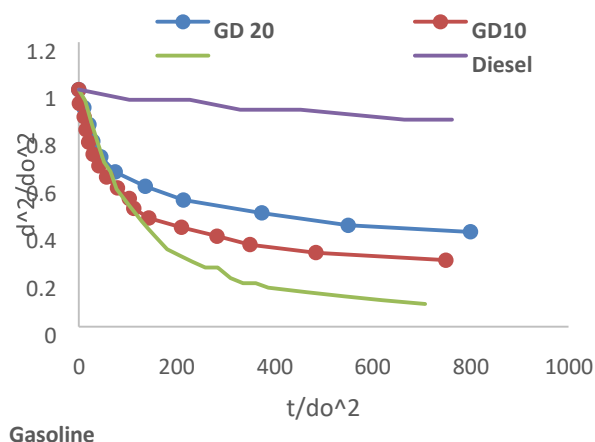


FIGURE 2.Evaporation Behaviour of Gasoline Diesel Blends

Butanol Diesel: In butanol-diesel blends butanol being a single component fuel shows a linear trend with higher evaporation rate as expected. Diesel fuel exhibits slower evaporation behaviour. Fig 3 shows that with an increase in the diesel blend percent the proportion of non evaporative component is increasing but it is not affecting the overall evaporation rate significantly.

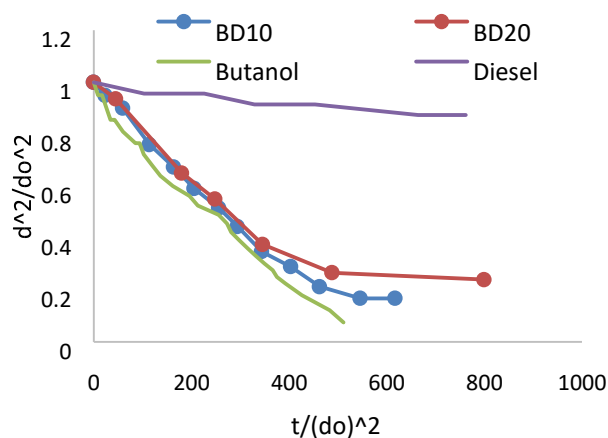


FIGURE 3. Evaporation Behaviour of Butanol Diesel Blends

Butanol Gasoline: In this blend system, butanol is a single component and gasoline is a multicomponent. Butanol being a single component shows a linear evaporation behavior and gasoline shows a decrease in evaporation rate with time. Their respective blends shows similar property as gasoline proportion increases the non evaporative part of system also increases. The evaporation rate of blends with upto 20 percent butanol in gasoline is not much affected as shown in Fig 4.

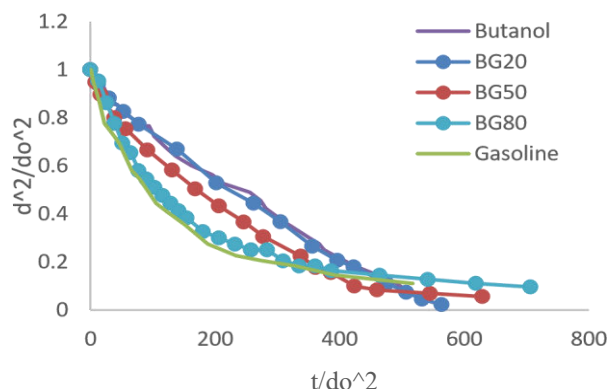


FIGURE 4. Evaporation Behaviour of Butanol Gasoline Blends

Ethanol Gasoline: In this blend system, ethanol is a single component fuel which exhibit a linear evaporation behaviour initially but being hydrophilic it also contains a non evaporative part. Gasoline exhibit the evaporation rate as discussed earlier. Both the fuels have almost similar and a higher evaporation rate so their blends lies in between due to this plots are majorly overlapping as shown in Fig 5.

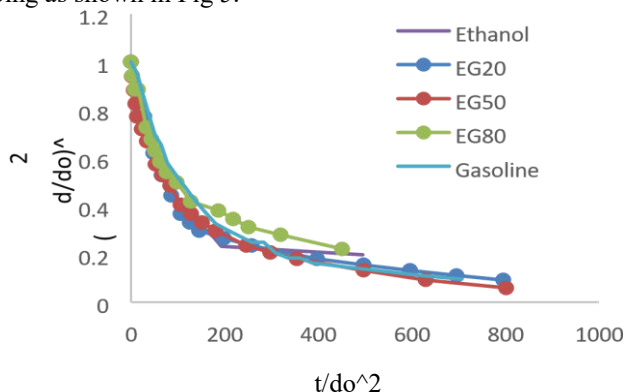


FIGURE 5. Evaporation Behaviour of Ethanol Gasoline Blends

Ethanol Butanol: Ethanol and butanol both are single component fuels whose evaporation rate are discussed earlier. For the blends, the evaporation rate comes in between. Also, it is observed that with an increase in ethanol content, the non evaporative component is reducing. Thus, the hydrophilic nature of ethanol is suppressed in presence other fuel as shown in Fig 6.

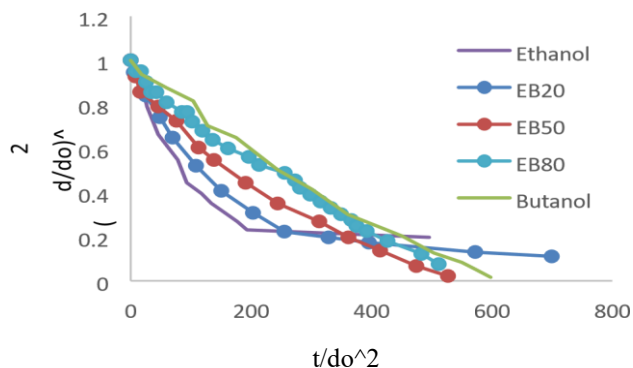


FIGURE 6. Evaporation Behaviour of Ethanol Butanol Blends

V. CONCLUSIONS

In the present work, evaporation rate behavior of potential fuels for LTC engines are studied. The major conclusions drawn from this work are as follows:

- 1- Evaporation behavior of single-single component blends (Ethanol-Butanol) or multi-multi component blends (Gasoline-Diesel) are varying linearly.
- 2- In case of blends of a single component and a multi component fuel, the evaporation rate behavior is not affected much for lower blend level (20%) (Butanol-Diesel, Butanol- Gasoline). This effect is not clear in ethanol gasoline blend due to similar evaporation behavior.
- 3- Addition of diesel increases the non evaporative part for blends (Butanol-Diesel and Gasoline-Diesel).
- 4- Blends helps in accommodating the hydrophilic nature as well (Ethanol-Gasoline, Ethanol- Butanol).
- 5- Lower density, viscosity and surface tension helps in evaporation. It also depends on fuel nature (Multicomponent or single component).

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