Energy Conversion and Management 113 (2016) 209–219

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

# Determining the optimum conditions for modified diesel fuel combustion considering its emission, properties and engine performance

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ARTICLE INFO

*Article history:*
Received 6 November 2015
Accepted 23 January 2016

*Keywords:*
Diesel
n-Butanol
Nano-additive
Air pollutant
Engine performance

ABSTRACT

This essay scrutinizes an experimental study conducted to appraise the influence of using n-Butanol with diesel fuel in 5% and 10% (volume) n-Butanol, 1% nitro methane (NM), injection timing and two Nano-particles (alumina and a type of silica powder) on the engine performance (brake specific fuel consumption and engine power), fuel properties (Cetane number and flash point) and exhaust emissions (soot, $NO_x$ and CO) of an engine with 4-cylinder (with a system of common rail fuel injection), intercooling, cooled exhaust gas recirculation (EGR), and turbocharged. The tests are conducted by varying the engine load (25 and 75 nm) and changing engine speed (1500 and 2200 rpm). Normal Butanol presents better brake specific fuel consumption (BSFC) but this blend doesn't reflect better engine power. All the percentages of n-Butanol in the fuel make Cetane number decrease but adding 1% of nitro methane makes Cetane number increase. For all the n-Butanol, the percentage flash makes the fuel decrease in comparison to pure diesel fuel. The current experimental study demonstrates that adding the n-Butanol and nitro methane to diesel fuel direct into diminishing soot emission. In contrast, this blend raises $NO_x$ and CO emissions. Furthermore, this research indicates that the increase of engine speed dwindle air pollutants and enhances BSFC. It also remarks that power gets increased at low engine speed. However, power gets reducedat high speed. This article represents that the increasing of engine load leads to increasing all of air pollutant, increasing of power and decreasing of brake specific fuel consumption. Both the Cetane number and flash point are independent from engine speed and engine load. The present paper shows that the effect of silica with high percentage of n-Butanol and high injection timing are better than other additives soot emissions which are getting decreased. Moreover, these additives along with low injection timing are more suitable for increasing the brake specific fuel consumption.



## 1. Introduction

Diesel engine is widely used in transportation system and construction machines for the sake of their high fuel efficiency and lastingness [1–4]. Diesel fuel is a fossil base mainly consisting of aliphatic hydrocarbons from $C_8$ to $C_{28}$ with boiling points varying from 130 to 375 °C [2]. Diesel has a high energy moving up the air pollution [5–7]. Alcohols can be used as oxygenated fuel additives with diesel fuel for diesel engine to decline exhaust emissions (air pollutant) and increase the engine performance [8–10]. These high performance materials can be applied as oxygenate additives due to high percentage of oxygen, short molecular chain in comparison to diesel fuel molecular chain and low molecular weight of alcohols contributing to complete fuel combustion and finally reduce emission [11]. Many classes of alcohols with different chemical structures such as ethanol [12–15], methanol [16–18] and n-Butanol [19–21] have been synthesized and investigated to assess their performance as fuel additives.

Among these alcoholic additives, n-Butanol is more remarkable and influential as an optional additive fuel for internal combustion engine [22–24]. N-Butanol is less corrosive and evaporative and it makes more energy per unit mass than the others. Also, n-Butanol has a lower auto-ignition temperature and its properties of n-Butanol are similar to fossil-base fuels. Therefore, n-Butanol can be ignited very easy when used in the diesel engine [22]. Many studies have demonstrated the effect of n-Butanol-diesel fuel on exhaust emissions and engine performance in a limit engine speed and different load [25–27].

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http://dx.doi.org/10.1016/j.enconman.2016.01.058
0196-8904/

**Nomenclature**

| | | | |
|---|---|---|---|
| $b_0, b_1, \ldots, b_n$ | regression coefficients | $X_1, X_2, X_3$ | coded variables |
| *DOF* | degree of freedom | $\bar{X}$ | mean value of variables |
| *F*-value | ratio of variances, computed value | *Y* | response |
| *i* and *j* | subscripts (integer variables) | BSFC | brake specific fuel consumption |
| *n* | number of factors (variables) | CI | Cetane index |
| *P*-value | statistical criterion | $CO_2$ | carbon dioxide |
| CV | coefficient of variation | CO | carbon monoxide |
| *R* | correlation coefficient | HC | hydrocarbon |
| $R^2$ | coefficient of multiple determinations | NM | nitromethane |
| $R^2_{adj}$ | adjusted statistic coefficient | $NO_x$ | oxides of nitrogen |

When n-Butanol is blended with diesel fuel, it creates some advantages in comparison to ethanol and methanol. One of the positive aspects is than the reduction of Cetane number is not as much as methanol and ethanol (the Cetane number of n- Butanol is almost 25). The other advantage is that no- two fuzzy solution is made because the physical and chemical properties of n-Butanol and diesel fuel are close each other in comparison to ethanol and methanol [28,29]. Nitrogen oxide ($NO_x$) and carbon monoxide (CO) emissions are increased by blending of this additive, though [30]. Byungchul et al. [24] investigated the effect of n-Butanol blended with diesel fuel on the decrease of exhaust emissions and the increase of engine performance. They proved that blending of n-Butanol to diesel fuel cause to decrease of soot emissions and increase of $NO_x$, CO and hydrocarbons emission. However, they stated that this mixture can increase the BSFC (brake specific fuel consumption) making the engine power reduce. Sahin et al. [25] concluded an experimental study on the exhaust emission and engine performance by running a diesel-n-Butanol blend. They showed that n-butanol can increase of BSFC, $CO_2$, HC and $NO_x$ but this blend cause to decrease of engine power. Zhang and Balasubramanian [31] studied the effect of n-Butanol with different isomers on diesel conventional. They demonstrate that all of isomers are able to decrease soot emissions. Reduction of soot emissions relies on the percentage of n-Butanol (oxygen percent) in blending with fuel. Rakopoulos et al. [32] analyzed the influence of Butanol-diesel fuel blends on the exhaust emission and performance of engine. They reported that this modified fuel resulting in lower soot emission can enhance both of HC and carbon monoxide emissions and increase brake specific fuel consumption (BSFC) in all cases. Sahin and Orhan [25] reported that by adding of n-Butanol (2, 4 and 6% vol.) to diesel fuel, soot emission is reduced and $NO_x$ and $CO_2$ and HC emissions are increased. However, they also reported that as the engine speed is moved up, all of air pollutant is reduced. Adding Nano-particle is directed to increase engine power for the sake of increasing micro-explosion in the engine. Experimental results figure out that silica is able to increase engine power more than alumnia. Air pollutant and engine power get increased through raising engine load but the increase of engine load decreases of BSFC. Raising the speed engine increases the engine speed and decreases air pollutants, and enhances engine power and BSFC. The increase of injection timing increases $NO_x$ emission and engine power. As a matter of fact, it reduces BSFC, soot emission and CO emission because of improving reaction between fuel and oxygen. Huang et al. [33] to investigate the impact of 20% and 30% butanol blended to diesel fuel on the engine performance and the exhaust emissions. In the experiment, brake thermal efficiency and $NO_x$ emission reduced, but brake specific fuel consumption increase compare to neat diesel fuel.

Previous studies [32,34–36] have demonstrated that the distribution size of any particulate matter (PM) depends on various reasons and different factors like the engine load and speed. This research is going to figure out the influence of n-Butanol, Nano-particle and tertiary additive (nitro methane) blended with diesel fuel on the engine performance, blended fuel properties and soot, $NO_x$ and CO emissions. This study concentrated on two speeds of engine (1500 and 2200 rpm) and two different engine loads (25 and 75% N m). The percentages of n-Butanol practiced in this study are different (5 and 10 wt%). In this study, the Nano-particle is practiced to increase the brake thermal efficiency and engine power along with the use of nitro methane for the increasing Cetane number and homogeneous blends.

## 2. Experimental and methodology

### 2.1. Material

The diesel fuel used in this study is a gas oil providing commercial and ultra-low sulfur (less than 330 ppm). The Butanol practiced in this study contains no sulfur is produced by the fermentation of biomass, especially by wasted wood materials. Physical and chemical properties of diesel fuel and n-Butanol used in this research are given in Table 1. Two different Nano-particles used in this article are of silica and alumina. The Nano-particles are produced in the institute of petroleum industry (RIPI, Iran) with the purity of 93–95%. The average diameter of Nano-particles is 50–75 nm with their length from 12 to 15 micrometers.

### 2.2. Engine and experimental set up

The baseline engine used in this study is a 4-cylinder diesel engine with a system of common rail fuel injection, intercooling, cooled exhaust gas recirculation (EGR), and turbocharged. The in-cylinder pressure is estimated using an air cooled quartz pressure sensor (genre GH13P, AVL). This sensor has a measuring range of 0–250 bar, overload of 300 bar, linearity of ±0.3% for FSO (full scale output) and mounting torque 1.5 N m. Gaseous emissions are analyzed by smoke meter (AVL 415s) with maximum exhaust temperature 600 °C at standard 340 mm sample probe. Moreover

**Table 1**
Physico-chemical properties of diesel and n-butanol.

| Properties | Diesel | n-Butanol |
|---|---|---|
| Molecular weight | 196 | 74 |
| Boiling point (°C) | 190–280 | 118 |
| Density 20 °C (kg/m$^3$) | 840 | 790 |
| Viscosity 20 °C | 2.8 | 3.6 |
| Cetane number | 52 | 25 |
| Oxygen content (wt%) | 0 | 21.6 |
| Latent heat of vaporization (KJ/Kg) | 250 | 585 |
| Molar C/H ratio | 0.51 | 0.4 |