

# **Effects of Temperature and Droplet Size on the Ignition Delay of Diesel and Bio-Diesel Blends**

**\*M. Arsalan Khan<sup>1,2</sup>, Majid Baseer<sup>1</sup>, and Dr. Abdul Shakoor<sup>2</sup>**

<sup>1</sup>Sarhad University of Science and Information Technology, Peshawar, Pakistan

<sup>2</sup>NWFP UET, Peshawar, Pakistan

[arsal678@yahoo.com](mailto:arsal678@yahoo.com)

## **Abstract**

The main motive behind this experimental setup was to find out the effect of temperature and droplet size on ignition delay period of different bio diesel blends. For experimental analysis, the equipment was assembled to carry out different tests for petroleum based Diesel and Bio-Diesel blends. During these tests, the Ignition delay of Diesel, Bio-Diesel and its different blends, in a temperature range of 600 °C to 750 °C and at an atmospheric pressure were studied. In addition fuel droplets of different diameters (750-950 microns) were introduced into the furnace chamber of the experimental set up and Combustion characteristics were measured for the Diesel and Bio-Diesel blends which shows the ignition delay time of diesel and BD blends decreases as the temperature increases. In this investigation, the effect of different combustion variables like the ignition temperature, ignition delay time, droplet diameter in the perspective of various biodiesel blends has been studied, and the effect of these variables on each other have been compared and elaborated in a simultaneous manner with the help of Design expert 3D graphs.

## **Keywords**

Ignition temperature, ignition delay time, droplet diameter, biodiesel blends, and combustion characteristics

## **I. INTRODUCTION**

As the advent of a time when fossil fuel will cease to exist draws near, All the petro heads of the world are tirelessly working on producing a renewable fuel which will not only work as efficiently in an internal combustion engine as the fossil fuels but will be economical as well [1].

Biodiesel fuel blends are one option currently being researched as a pathway to energy diversity and reduced petroleum dependence in the transportation sector. One of the key factors related to the success of biodiesel fuel blends is their compatibility with vehicle components such as fuel systems, combustion parts, and advanced emission control systems [2]. In this regards for diesel engines, Bio-Diesel has been proved to be the best option available yet. All over the world petroleum based diesel is being replaced by the bio diesel blends at an alarmingly (but positively) high rate, the main reason for which is that it can be used in diesel engines without any modifications [3].

Biodiesel, a renewable fuel, is safe, biodegradable, and produces lower levels of most air pollutants than petroleum-based products [1, 4]. And it is the fastest growing alternative fuel in Europe and the United States. Also the ultimate goal is to build a stronger, more self-sufficient and independent community by using a community-based biodiesel production model. A community-based biodiesel distribution program benefits local economies, from the farmers growing the feedstock to local businesses producing and distributing the fuel to the end consumer. The raw materials for the production of biodiesel ranges from oils produced domestically like soybean oil, to other cheaply available sources animal fats, recycled cooking oils, non-edible oils, etc. [5, 6]. In this way, the money stays in the community while reducing the impact on the local environment; heavy petroleum import expenses and increasing energy security issues [7].

The beauty of biodiesel is its eco friendliness and it's potential for reducing greenhouse gases emission and provision of an efficient performance in existing diesel engine [8]. Therefore, it is important to conduct more researches to formulate optimal operation conditions as biodiesel is used as fuel.

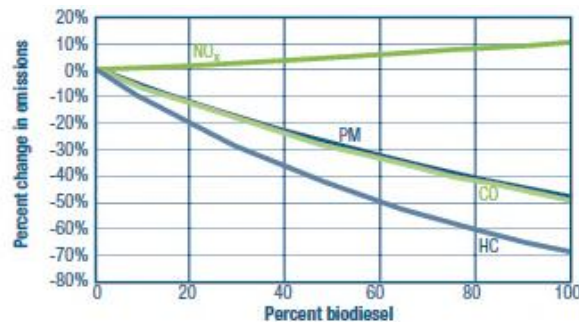


Figure showing the Average emission impacts of biodiesel for heavy-duty highway engines. Source: U.S. EPA [19]

## **II. LITERATURE REVIEW**

### **I. MIXING OF BIODIESEL BLENDS:**

Blending of biodiesel with petroleum based diesel may be accomplished by the following three methods

- Mixing in tanks at manufacturing point.
- Splash mixing in the tanker truck
- In-line mixing at the tanker truck. [9]

#### ***I. Splash mixing:***

This is the most commonly used and also the least accurate method of blending biodiesel. Splash blending is done when a truck tanker which is already having diesel at 8 degree Celsius is pumped with biodiesel at 18 to 20 degree [10].

#### ***II. In line mixing method***

This method involves two storage tanks one containing biodiesel and the other having fossil diesel. Both of the fluids are then passed through a pipe and hose, and mixed in a particular ratio (depending on the type of blend) and then accumulated in a third, tanker [11].

This method is widely used for production of Biodiesel on large scale.

#### ***III. Injection mixing method***

In this method the blending of fuels is done in tanks at manufacturing points prior to the supply to the tanker truck. Valve controls are used to ensure that monitored quantities of diesel and biodiesel components are injected into the mixing tank to get a specific blend of biodiesel and diesel [7].

Blends of biodiesel and conventional fossil-based diesel are produced by mixing biodiesel and petroleum diesel in suitable proportions under appropriate conditions. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix [11, 12]:

- 100% biodiesel is referred to as B100, while
- 20% biodiesel, 80% petro diesel is labeled B20
- 5% biodiesel, 95% petro diesel is labeled B5
- 2% biodiesel, 98% petro diesel is labeled B2

Biodiesel mixing with diesel improves most of the fuel properties and can be used as an alternative fuel for diesel engines. Analysis of the emissions of BD blends showed that its fuel blends reduce the Particulate Material (PM), Hydrocarbon, Carbon Monoxide and Sulphur Oxides. However,

NOX emissions are slightly increased depending on Cetane number [9, 10] and Even though Bio-Diesel fuel has a longer Ignition Delay than diesel but the Ignition Delay decreases for blends and depends on the amount of diesel in the blends [13].

Similarly the experimental Study of the Combustion Characteristics of the spray of Diesel and BD Blends in a Direct Injection Common-Rail Diesel Engine of BD5 and BD20 of Soybean oil led to the facts the fuel injection profiles for diesel and BD blends are very similar to the pilot injection i.e. an increase of the blending ratio results in the decline of peak injection rate [14].

They have lower emissions and high flash point (usually >300F), hence they are safer. They are biodegradable and essentially free from Sulphur and aromatics, making it safer to handle and transport [15, 16]. One of the other advantage of biodiesel include that its physical and chemical properties are very similar to that of petroleum based diesel fuel in terms of operation. Therefore, it can be used in diesel engines without any expensive alterations to engine or fuel system [17]. Also the addition of even 2% biodiesel to diesel helps in significant improvement of lubricity of diesel [18].

As a conclusion to an extensive studies based on the different thermal characteristics of biodiesel it was remarked that there exist three stages of combustion namely the Warm-up followed by liquid phase boiling which is later commenced by the Burn-off of the vaporized fuel [2].

M. Renksizbul et.al after working on Multicomponent droplet evaporation at intermediate Reynolds numbers” concluded that at elevated pressures, the evaporation of relatively heavy hydrocarbon droplets is essentially controlled by liquid phase heating and also the Reynolds number decreases largely due to the deceleration of the droplet, as a droplet radius varies much more slowly [4].

Similarly after conducting Experiments on the evaporation of Multicomponent droplets at varying Reynolds numbers, it was found that the Reynolds number decreases mainly due to the deceleration of the droplets and also at elevated pressures, the evaporation of relatively heavy hydrocarbon droplets is dependent on the liquid phase heating [5].

In addition it was also found that the Effect of fuel blending and injection pressure on single spray tip penetration is slight, and the pilot spray development of biodiesel is shorter compared with the pilot and main injection of diesel fuel. [6]

As Compared to conventional diesel, the application of biodiesel to diesel engines still has several properties that need a lot more improvement such as lower engine power output and higher emissions of nitrogen oxides and its ignition temperature. In this investigation, the effect of different combustion variables like the ignition temperature, ignition delay time, droplet diameter in the perspective of various biodiesel blends has been studied, and the effect of these variables on each other have been compared and elaborated in a simultaneous manner with the help of Design expert 3D graphs.

## **ABOUT THE SOFTWARE**

Design Expert is software, used to help with the designing and interpretation of multi-factor experiments. The software offers a wide range of designs, including factorials, fractional factorials and composite designs. Design-Expert software offers an impressive array of design options and provides the flexibility to handle categorical factors and combine them with mixture and/or process variables. After building design, a run sheet can be generated with experiments laid out in randomized run order having Add, delete or duplicate runs in any design with the handy design editor. Rotatable 3-D color plots make response visualization easy. With the powerful optimization features in Design-Expert, desirability for dozens of responses simultaneously can be maximized.

## **I. EXPERIMENTAL SETUP**

Different experiments were carried out for the study of droplet ignition delay time of suspended fuel droplet in a combustion chamber lined with fire bricks, at varying temperatures and atmospheric pressure. The experimental setup is divided into three different sub systems namely the

- A. Droplet Formation system
- B. Combustion system
- C. Observation and Photographic Recording System.

These Sub systems are briefly discussed here.

*I. Droplet formation system:*

Droplet of fuel is produced with the help of a medical syringe having a very fine needle. Fine droplets of miniature dimensions are produced by applying pressure on plunger of the syringe and the Fine needle gives the mono-disperse droplets of controlled dimension The droplet is then settled on a steel rod tip of extremely small diameter of 500 micron and with a suitable configuration, the droplet is introduced into the combustion chamber. The droplet is ellipsoid close to the shape of sphere and its equivalent diameter is calculated from the cubic root of the square of the minor axis multiplied by the major axis. Thus droplet is not exactly a sphere but an ellipse. Size of droplet is equivalent value determined as the cubic root of the product of the droplet width squared and droplet length

*II. Combustion system:*

For the experiment, a combustion chamber lined with fire bricks was prepared having inner length of 540mm, width of 300mm and having a height of 290 mm. Two windows having dimensions of (140 × 50 mm) were also introduced in the opposite walls of the furnace which were made to record the droplet ignition photographically. One opening on the side wall (50 mm diameter) is made for inserting the fuel droplet into the furnace.

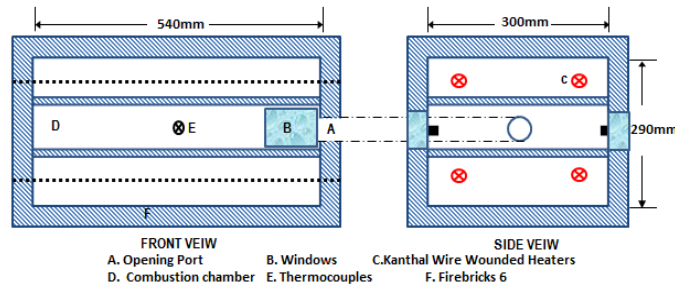


Figure 1 Sectional view of the combustion system

The furnace is heated with the help of four 1.5 KW each, Kanthal wire wound heaters. The technical specifications of the furnace in which the fuel combustion is carried out is given in the table 1. The temperature of the furnace is controlled by varying the current flow in the Kanthal wire wound heaters with the help of variacs. Two 5 mm diameter Chromel-Alumel (K-Type) thermocouples are also used to measure the temperature of the furnace and their average is then utilized for calculations.

**Table 1 Specifications of the Combustion System**

Components	Dimensions/specifications
Furnace Chamber	Length 540 mm
internal dimensions	Width 300mm
Fire Bricks	Insulation Purpose(sand and clay)
Kanthal Wire Wounded Heaters	Capacity of 1.5 KW. Diameter 12 mm
Thermocouple	Chromel – Alumel ( K-Type)
Data acquisition system	Display Temperature Reading in °C
Variacs	Capacity 0-260 V

**Table 2 Comparison of properties Bio Diesel with its blend**

Properties	Diesel	Jatropha Bio-Diesel	After 20% of Blend
Density	0.841	0.862	0.828
Viscosity in stokes (cSt)	4.5	5.0	3.3
Calorific Value	10031	8890	9685
Cetane number	48	52	49
Carbon Residue	-	0.6% w/w	0.7% w/w
Ash Content	-	0.02% w/w	0.01% w/w
Sulphur Content	-	.031% w/w	0.004% w/w
Flash Point	-	184 °C	74 °C

### III. Observation and Photographic Recording System:

All of the combustion process was monitored with the help of a video recorder. As a droplet was introduced into the furnace through the opening, a digital camera in the video mode started recording the progress of the droplet heating and ignition. The ignition time was determined from the digital camera time record.

**Table 3 Physical Parameters**

Parameter	Ambient Condition
Pressure	Atmospheric Pressure
Temperature Variation	600 °C to 750 °C
Size of Droplet	750– 950 micron

The initial size of the droplet was found by photographing the droplet before introduction into the furnace. Considerable effort was expended towards minimizing this non-uniform temperature region relative to the ignition delay, and the present experimental design and procedure were consequences of the best of such efforts. The droplet was suspended on the thin steel rod which was then introduced into the combustion chamber and exposed to a hot air temperature environment under atmospheric conditions. The temperature before the ignition process was controlled and raised by varying the dial on the Variacs. The thermocouples took the temperature recordings which were displayed on the data acquisition system. The time needed for transferring a fuel droplet from glass syringe to the steel rod during the experiment was about 2 to 3 seconds, including the time in which a photo of initial diameter was taken. The experimental setup is shown in the figure 3 Experiments were carried by varying droplet size 750/950 microns under different temperature ranges of the diesel from 600°C to 750°C. The fuels which were used during the experiment are diesel, bio-diesel and bio-diesel blends. Then the droplet ignition was monitored and data was recorded with the digital camera from the window of the combustion chamber.



Figure 3 showing the Assembled System

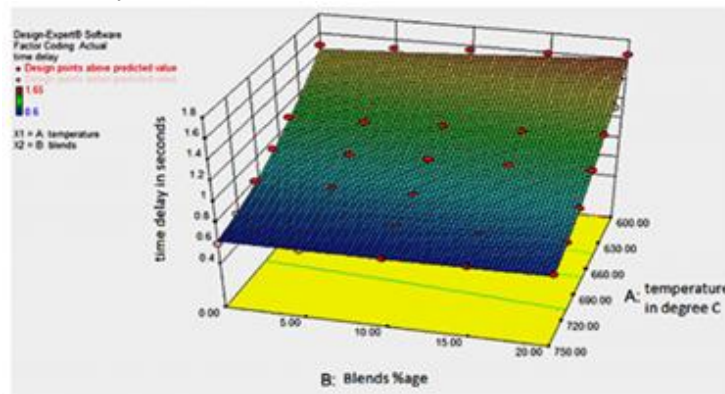
## RESULTS

### *Effects of temperature and blend composition:*

The figure 4 shows that for all of the fuels, the time delay period decreases as the temperature increases; however the difference in ignition delay time is pretty much significant at low temperatures and becomes smaller as the temperature rises.

It is also observed from this figure that ignition delay for blends of diesel and bio-diesel lie between the values for the pure Diesel and pure Bio Diesel. In addition the figure 4 clearly illustrates the time delay response of different bio diesel blends as we vary the values of ignition temperature. At the minimum temperature of 600°C we get the maximum time delay of 1.65 seconds and as the temperature increases

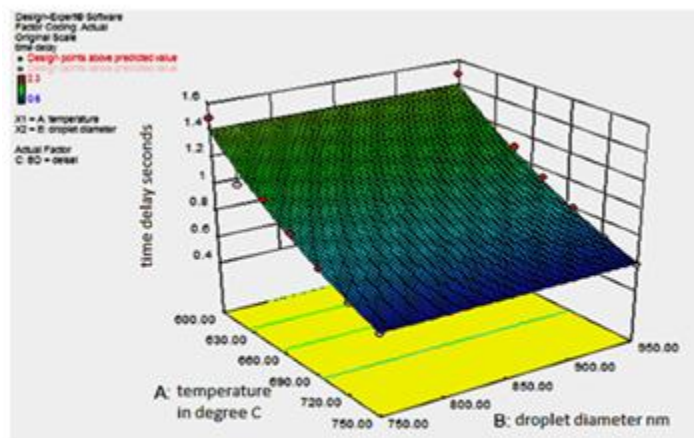
there is a gradual decline in the ignition delay time. The graph also shows that the time delay for pure diesel at low temperatures is less as compared to bio diesel blends. And as the percentage of BD blends increases so does the time delay.



**Figure 4 showing the Effects of temperature and blend composition on time delay**

### **I. Effects of Droplet Diameter Variation:**

The implementation of this setup enabled us to record readings for different blends of bio diesel having specific diameters. Figure 5 shows the effects of variation in droplet diameter for ignition delay with temperature for two different sizes of the droplet and consists of the ignition delay readings each for 750 and 950 microns at varying temperatures. It can be clearly seen from the figure that the effect of droplet diameter is negligibly small. The graph 5 clearly shows that the variation in ignition delay with the change in droplet diameter is not very significant at the given temperature. This trend is observed for both bio-diesel and diesel and remains almost same for all of the reference fuels.



**Figure 5 showing the Effects of Droplet Diameter Variation on time delay**

## **CONCLUSION**

The study of droplet combustion and ignition analysis was mainly concentrated on comparing the ignition behavior of pure Diesel and various blends of Bio-diesel so the conclusions based on this study are stated as under:



- Temperature of the working fluid play keys role in regards of the ignition delay time of bio-diesel blends, so preheating before ignition is of vital significance.
- In regards of the effect of Droplet diameters of reference fuels, it was found that the variation of droplet diameter has a very little effect on the ignition delay time of these fuels at atmospheric pressure, so its effect can be neglected.
- In addition, the ignition delay of pure diesel at the atmospheric pressure is less than that of Bio-diesel blends and this delay tend to increases as the percentage of the blends increases, this will also result in the requirement of an elevated pre-heating temperature of the reference fuels.

## REFERENCES

- [1]. Jinlin Xue Et Al. *“Effect of Biodiesel on Engine Performances and Emissions”* Renewable and Sustainable energy reviews journal 15 1098-1116. (2011)
- [2]. Anthony lam and Andrzej Sobiesiak, *“Biodiesel Droplet Combustion Journal of Kones Powertrain and Transport”* Vol 13, no. 2. Pg.267-274.
- [3]. Ali Reza Valipour *“Experimental Combustion Analysis Of Biodiesel Fuel Spray With Hot Surface Ignition”* Volume 2, issue 1, January 2014 ISSN 2321-6441
- [4]. M.J.Thornton, e.t all. *“Impacts Of Biodiesel Fuel Blends Oil Dilution On Light-Duty Diesel Engine Operation”* Conference paper NREL/cp-540-44833 August 2009
- [5]. M. Renksizbul and M. Bussann *“Multicomponent Droplet Evaporation At Intermediate Reynolds Numbers”*, Heat Mass Transfer.Vol. 36, no. Li, pp.2827-2835, 1993.
- [6]. Chandrasekhar *“Effect Of Biodiesel, Jet Propellant (Jp-8) And Ultraslow Sulphur Diesel Fuel On Auto-Ignition, Combustion, Performance And Emissions In A Single Cylinder Diesel Engine Journal Of Engineering For Gas Turbines And Power”*, Vol. 134 /022801-pp. 1-11 by ASME. February 2012
- [7]. Jayashri Nair, e.t. all *“Study Of Biodiesel Blends And Emission Characteristics Of Biodiesel”* ISSN: 2319 issue 8, August 2013
- [8]. Y.X. Li e.t. all *“Fuel efficiency and exhaust emissions for biodiesel blends in an agricultural tractor”* CANADIAN BIOSYSTEMS ENGINEERING Volume 48 2006
- [9]. Clean cities, a review, U.S. Department of energy, energy efficiency and renewable energy, fact sheet, April 2008. . Viewed on 20th November 2014
- [10]. J.P.Szybist, e.t. all *“Biodiesel Fuel Combustion, Emissions and Emission Control Process”*. Technol. 88 679–691.2007.
- [11]. Peterson, C.L., e.t. all *“Continuous flow biodiesel production”* Applied Engineering in Agriculture 18(1): 5-11. 2002
- [12]. C. H. Wang, e.t. all *“Combustion and Micro Explosion of Freely Falling Multicomponent Droplets”* Combustion and Flame 56: 175-197 (1984) 175,
- [13]. Laurencas Ras Lavičius & Donates Markšaitis *“Research into Three-Component Biodiesel Fuels Combustion Process Using a Single Droplet Technique”* transport, vol. XXII, no 4, pp. 312–315. (2007)
- [14]. Jyotirmoy Barman et al. *“Experimental Investigation Of Bio-Diesel Droplet Ignition”*, International Journal Of Oil, Gas And Coal Technology, Vol.1, No.4, pp.464 – 477. 2008
- [15]. R.K.Malhotra, *“Biodiesel as Blending Component for Diesel Fuel & Its Applications and Benefits”*, Biodiesel Conclave, November 5, 2005.
- [16]. V.A.N.Gerpen, *“Biodiesel Processing and Production, Fuel Process”*. Technol. 86 1097–1107. (2005)
- [17]. K.Tapan Gogoi, T.Shovana, C.Debendra, Baruah, *“Comparative Analysis of Performance and Combustion of Koroch Oil and Jatropha Methyl Ester Blends in a Diesel Engines,”* world renewable energy congress, Sweden, 2011.
- [18]. [www.biodiesel.org/docs/ffs-basics/emissions-fact-sheet.pdf](http://www.biodiesel.org/docs/ffs-basics/emissions-fact-sheet.pdf). Biodiesel emissions. Viewed on 20th November 2015
- [19]. [www.eere.energy.gov/cleancities](http://www.eere.energy.gov/cleancities) prepared by NREL. April 2005 viewed on November 2015.

## **Biography**

**Muhammad Arsalan Khan** is a post graduate student at the Mechanical Engineering department of University of Engineering and Technology, Peshawar, Pakistan and also working as a Lab-engineer and technical assistant at Sarhad University of Science and Information Technology, Peshawar, Pakistan. He earned B.S. in Mechanical Engineering from University of Engineering and Technology, Peshawar, Pakistan, also Masters in Materials engineering from the said university. His research interests include manufacturing processes, engineering materials, failure analysis, renewable energy resources. He is member of ASME, SAE, PEC and SMEP.

**Majid Baseer** is currently a fulltime assistant professor at the Mechanical Engineering department of Sarhad University of Science and Information Technology, Peshawar, Pakistan. Mr. Majid Baseer holds a Bachelor of engineering degree in Mechanical engineering from University of Engineering and Technology, Peshawar, Pakistan, and MS in Engineering Management from UTS, Sydney.

**Dr. Abdul Shakoor** is currently working as an Associate Professor at the Department of Mechanical Engineering of University of Engineering and Technology, Peshawar, Pakistan. He did MS in Manufacturing Engineering from Loughborough University, U.K and also PhD in Materials Composites from the said university. He is the president of University of Engineering and Technology Teachers Association, a syndicate member of the university and other numerous executive bodies.