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# A Study on Property Variations of Biodiesels derived from Indian Origin based Non-Edible Oils by Blending them with Plastic Pyrolysis Oil

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***Abstract: Biodiesels from Indian origin based oils such as Jatropha and Karanja have been experimented in number of ways by different researchers across the world. The literature concludes that these biodiesels under-perform in a compression ignition engine and this can be attributed to their poor physio-chemical properties. Several researchers have tried blending them with diesel and tried to address the issue of under-performance. But, the fact that diesel gets extinct in near future suggests that it is better not to rely on diesel, again. Alongside, waste disposal and non-biodegradability of waste plastic has become a serious threat to humankind. Therefore, an attempt to blend biodiesels with pyrolysis oil derived from waste plastic is made in the present study. The biodiesels considered for the study include jatropha and karanja. It was observed that blending plastic oil to Jatropha and Karanja biodiesels reduced their viscosities to a greater extent and this can help in improved spray characteristics. Plastic oil also improved the calorific value and density of biodiesels significantly, which can reduce the specific fuel consumption and reduce it down to that of diesel. The flash point of the biodiesels decreased by blending them with plastic oil and this seemed to be a disadvantage of dilution of biodiesels with it. However, the study suggests that the option of blending plastic oil over diesel, not only addresses the issue of under-performance of biodiesels but also the issue of non-biodegradability of waste plastic***
***Keywords: Biodiesel, Plastic pyrolysis oil, kinematic viscosity, heating value, density, flash point.***

## I. INTRODUCTION

For the past decades, conventional Fossil fuels like Gasoline and Diesel have accounted for the economical ease of various divisions like transport, commercial enterprises, industrial and domestic sectors etc. Diesel fuel has a number of advantages and applications. But, its high Carbon-Di-Oxide emissions are a starting to be a huge threat to the environment by being one of the major reasons for Global warming. [Baskaran, R., and P. Sathish Kumar. 2015]. Diesel combustion also results in Nitrogen oxide emissions and soot which are harmful to human health. [Ihnin, A. M et al 2014]. These fossil fuels are on the verge of extinction and are being consumed rapidly and the prices of these fuels are increasing rapidly. This accounts as another threat to the humans. According to the studies, oil reserves would be extinct in about 41 years and the gas reserves in nearly 63 years. Due to the high usage of these fossil fuels, there is a huge difference being between the demand and supply of these fuels. These mentioned factors are menacing the mankind about supply of fuels and energy sources for the future.

## II. ALTERNATIVE ENERGY SOURCES

### *A. Biodiesel: An Alternative*

Researchers have done various tests and researches to check if the performance of the CI engine increased when run on a Vegetable oil-Diesel blend but they concluded that the engine performance reduced drastically [Bari S et al 2004]. The vegetable oil's viscosity was observed to be about ten times that of diesel and the penetration which lead to the engine deposits would increase due to poor atomization characteristics [Darnoko D 2000]. However, techniques such as transesterification, Pyrolysis, dilution and micro-emulsification which would help in this aspect. Many experiments have been performed by diluting a vegetable oil with a less viscous diesel fuel [Singh and Singh et al 2010, Ziejewski et al 1986]. A mixture of two or more immiscible liquids, one as a droplet dispersed throughout the other continuous phase liquid. This is called an emulsion. The mixture is classified into different types, such as emulsion, micro-emulsion and Nano-emulsion on the basis of the droplet diameter. A review was conducted by Kiran Raj Bukkarapu on the recent advances in water in oil emulsions and concluded that when we introduce water into Biodiesel or diesel this can reduce the soot and NOx emissions simultaneously [Kiran Raj Bukkarapu et al 2017a]. The most acceptable technique which reduces the viscosity of a vegetable oil is transesterification. This is a process in which the feedstock is made to react with alcohols like ethanol or methanol to separate glycerin while obtaining methyl esters from triglycerides as shown in Figure1 [Hoekman S 2012]. In this process, the end product which is called as Biodiesel which meets the standards required [Saba et al 2016, Amini Niaki 2013]. Biodiesel is unsaturated and saturated mono-alkyl esters of long fatty acids that come from vegetable oils [Amit Sarin 2012]. Biodiesel, which has the closest properties to that of conventional diesel is the final product of the process. Transesterification has been opted in this study as, it is a simple and easy process in which the yield is greater than any other processes used to reduce the viscosity of vegetable oil. In the present study, for transesterification, Methanol is used as it is cheaper than ethanol. A catalyst must be used for successful transesterification as methanol is hardly soluble in oils. A base, an enzyme or any acid can be used as a catalyst. If the FFA value is significantly low (less than 2%), base catalyst is used. Else, the base catalyst would form soap and water by reacting with FFA in a process called “Saponification”. Then, more FFA would be yielded, as the resultant water would react with the triglycerides and affect the transesterification reaction [Leung et al 2010]. Arabian et al [Atabani et al 2012] in their review article have identified almost 350 crops as biodiesel sources. The feedstock for biodiesel can either be an edible vegetable oil such as camelina, canola, coconut, palm, peanut, soy, sunflower or non-edible oils like karanja, jatropha, algae or used cooking oils or yellow grease, fish oil, etc. Therefore, if properly explored, biodiesel can be the future fuel [Amit Sarin 2012].

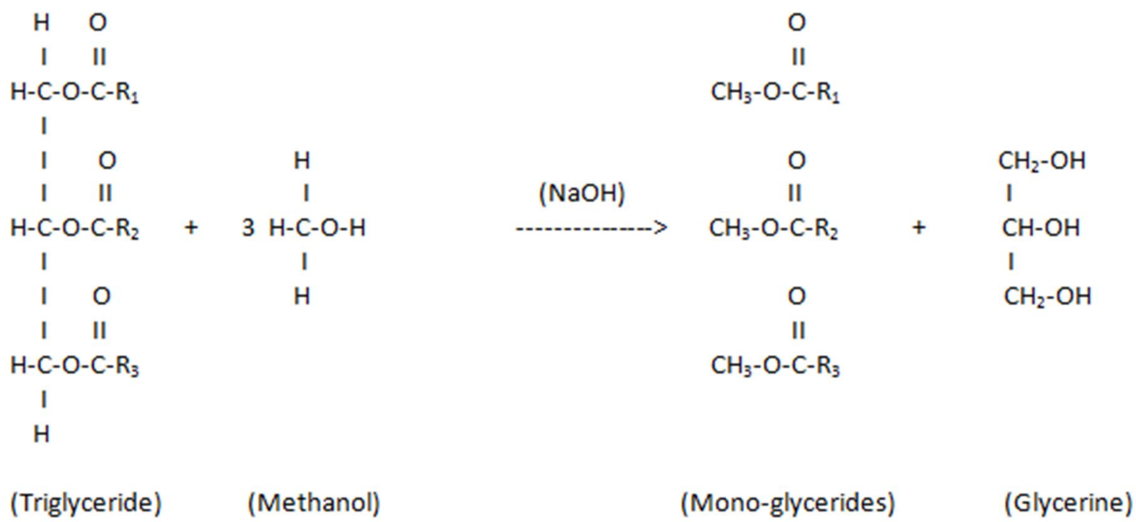


Figure 1 Transesterification reaction

### *B. Biodiesel Properties*

In terms of efficiency and fuel economy, no fuel can replace diesel. But due to its availability and renewability it can substitute diesel. It is more viscous and denser when compared to diesel. It has high specific fuel consumption and less energy content. The flash point of biodiesel is high which makes it safe enough to be transported. But its oxidation stability and cold flow properties are poor. Due to its oxygen bound nature, it helps in reducing the carbon monoxide and hydrocarbon emissions but yields higher NOx emissions. Carraretto C et al [Carraretto et al 2011] report that higher the biodiesel percentage in a blend with diesel, lower will be the power output of the engine. Lower emissions of CO, CO2 and HC were observed by Labeckas G et al in their investigation with rapseed biodiesel in diesel engines [Labeckas, G. and Slavinskas, S. 2006]. Chit Wityi Oo et al studied the performance of a diesel engine using diesel, Jatroptha biodiesel, coconut, soybean and palm biodiesel and reported that the ignition delay of all the biodiesel fuels are shorter than that of diesel while coconut methyl esters exhibit significant shortest ignition delay [Chit Wityi Oo et al 2015]. These results convey that the combustion, emission and performance characteristics depend on the properties of the biodiesels and therefore any improvement in the properties can improve them. It is important to note that not all biodiesels have same properties. The physio-chemical properties of biodiesel depend on the structure and the molecular composition of the feed stock [Fazal M A et al 2011. It was concluded by Allen [Allen CW 1999] that differences in the properties of biodiesels were a reason for the difference in the emissions and performance of a diesel engine run on biodiesel. Kiran Raj Bukkarapu [Kiran Raj Bukkarapu and Anand K 2019a] concluded that, the viscosity of the biodiesel was dependent on degree of unsaturation and methyl oleate concentration. To study the changes in properties, researchers have also tried to blend various biodiesels with conventional diesel. Among individual blends of groundnut, coconut, palm and sunflower biodiesels with conventional diesel, Coconut biodiesel-diesel blends have closest properties to that of a conventional diesel [Kiran Raj Bukkarapu 2017b]. Therefore, a successful alternative to diesel can be made by improving the biodiesel properties which could yield better performance.

### *C. Plastic Pyrolysis: An Alternative*

The plastic production has been increasing for the past few decades by an average of 3 to 4 % every year. Many industries adopted it due its economic factors like durability,workability, corrosion resistive nature and many more [Miskolczi, Bartha, and Angyal 2009]. Plastics are not only non-biodegradable, but also effect the food cycle of animals and humans by undergoing photo-degradation by which it gets converted into plastic dust [Pawar Harshal and Lawankar Shailendra 2013]. Apparently, the total amount of plastic waste disposed in India is only 60% [Zhang et al. 2018]. This shows us how important the management of solid waste is. Converting waste plastic to useful energy can address both the need for an alternate fuel and non-bio-degradability of plastic. As an alternative to diesel in compression ignition engines, plastic pyrolysis oil that is generated from different kinds of municipal wastes by a selective pyrolysis process can be used. This solves the waste management problem. Not only as an alternative fuel, but it can also be used to characterize and for synthesis of additives of lubricants. [Odigure et al. 2015]. In Greek, 'pyro' means fire and 'lysis' means decomposition. The detailed process of pyrolysis is reviewed by Kiran Raj Bukkarapu et al [Kiran Raj Bukkarapu et al 2018b]. Experiments on these lines have been conducted on marine applications of oil produced from waste plastic. The reports show that the engine performance can be improved by blending waste plastic oil to heavy oil used in marine applications [Ioannis S. A and P Tserkezou 2008]. Experiments on plastic oil and B20 algae blend were conducted by Ramesh et al. It was observed by the authors that the brake thermal efficiency of B20 was 15.7% higher than that of conventional diesel fuel [Ramesh et al. 2016]. Therefore, the literature strongly supports the functional suitability of plastic pyrolysis oil in a compression ignition engine and, if properly understood, it can substitute diesel in near future.

### *D. Plastic Pyrolysis Oil: Properties*

The literature clearly reports that the Plastic pyrolysis oil has a higher viscosity, lesser calorific value and almost similar density when compared to diesel. This conveys that the performance of neat plastic oil is not going to be as ideal as in the case of diesel. In their investigation on diesel engine running on waste plastic oil Ioannis Kalargaris, Sai Gu and Guohong Tains observed that the waste plastic pyrolysis oil has lower brake thermal efficiency than that of diesel which can be due to higher aromatic hydrocarbon content of plastic pyrolysis oil for disassociation because they require higher energy . The rate of heat release is higher with plastic pyrolysis oil from waste due to in-cylinder pressures and temperatures being high [Ioannis K, G Tian and Sai Gu 2017]. Hariram V et al. conducted experiments and observed that at low loads the brake- specific fuel consumption is higher for 70% diesel blend and 30% plastic oil attributed by higher aromatic hydrocarbon concentrations in plastic oil. At higher loads, brake-specific fuel consumption was minimal due to high heat release rate and was closer to that of diesel and at higher loads due to high heat release rate [Hariram et al. 2017]. Research was conducted by M. Mani, C. Subash, G. Nagarajan concluded that the concentration of unburnt hydrocarbons is 0.4393 g/kWh for plastic oil and 0.431g/kWh for diesel when rated power was at 25% [Mani, Subash, and Nagarajan 2009]. The unburnt hydrocarbon emissions of the waste plastic pyrolysis oil can be attributed to high aromatic content of waste plastic pyrolysis oil and wall impingement being high due to its dense nature and high viscosity. Brake-specific fuel consumption depends on physio-chemical properties of a fuels like heating valve, kinematic viscosity, density and is inversely proportional to thermal efficiency. Because of lesser heating valve and having a higher fuel requirement at full loads, Brake-specific fuel consumption in case of waste plastic pyrolysis oil is reported to be higher than that of diesel, at rated power. Experiments were carried out by Sanjeev and Dr. Sudhir Kumar on different blends of plastic oil with Jatropha methyl esters and diesel and they concluded that with increase in augmentation in blend percentage, brake-specific fuel consumption increases [Sanjeev and Dr. Sudhir Kumar. 2015]. Therefore, it is well understood that it is better to blend plastic oil with some alternative fuel to improve its properties and there by its performance in a compression ignition engine.

## III. NOVELTY OF THE WORK AND FUTURE SCOPE

All these reports suggest that neat biodiesels under-perform due to certain poor properties and any improvement in their properties can improve their performance. Also, plastic oils are suitable as alternatives to diesel, but with certain disadvantages which can be attributed to their poor properties. Blending biodiesels with diesel is again relying on a fossil fuel and hence it is better to blend them with plastic oil. Apparently, there is no any work in the literature reported on the extent to which biodiesel properties could be improved by blending it with plastic oil. Therefore, this work studies the effect of dilution of biodiesels, derived from non-edible oils, with plastic oil, on their physio-chemical properties. This study can help in understanding the influence of plastic oil and hence can be extended to engine studies once the improvement in biodiesel properties is well understood and established.

## IV. MATERIALS AND METHODOLOGY

The present work is an experimental study of the effects of plastic oil on biodiesels produced from non-edible oils on their properties. The corresponding methodology can be classified into: Production of plastic pyrolysis oil, production of biodiesel and blend characterization.

### *A. Production of Plastic Pyrolysis Oil*

The thermal decomposition of the organic material at high temperatures, but, in the without Oxygen is called Pyrolysis [Nam-Chol O et al 2017, Baskaran R et al 2015]. It is a process in which polymers are converted to monomers. Sizing machinery is fed with plastic. machines such as cutters and crushers. For the ease of handling the feedstock, the material is graded into uniform size. This material is fed to a reactor, in which it is heated in theabsence of Oxygen, for nearly 4 hours, to a temperature of 673K at 1 atmosphere. The obtained products are then condensed to hydrocarbons. These hydrocarbons are separated using fractional distillation. The resultant plastic pyrolysis oil is then filtered twice to get rid of any solid impurities.

### *B. Production of Biodiesel*

Eight non-edible oils have been used in this work and have been transesterified to extract their respective biodiesels. Figure 2 shows the process of transesterification. Before the transesterification process, it is made sure that any solid impurities or moisture content is eliminated. This is the pre-treatment of the feedstock. The presence of these impurities may affect the transesterification reaction in a negative way. So it is made sure that they have been eliminated. We carry out primary filtration to remove the solid particles by using a cloth filter after which secondary filtration is carried out.

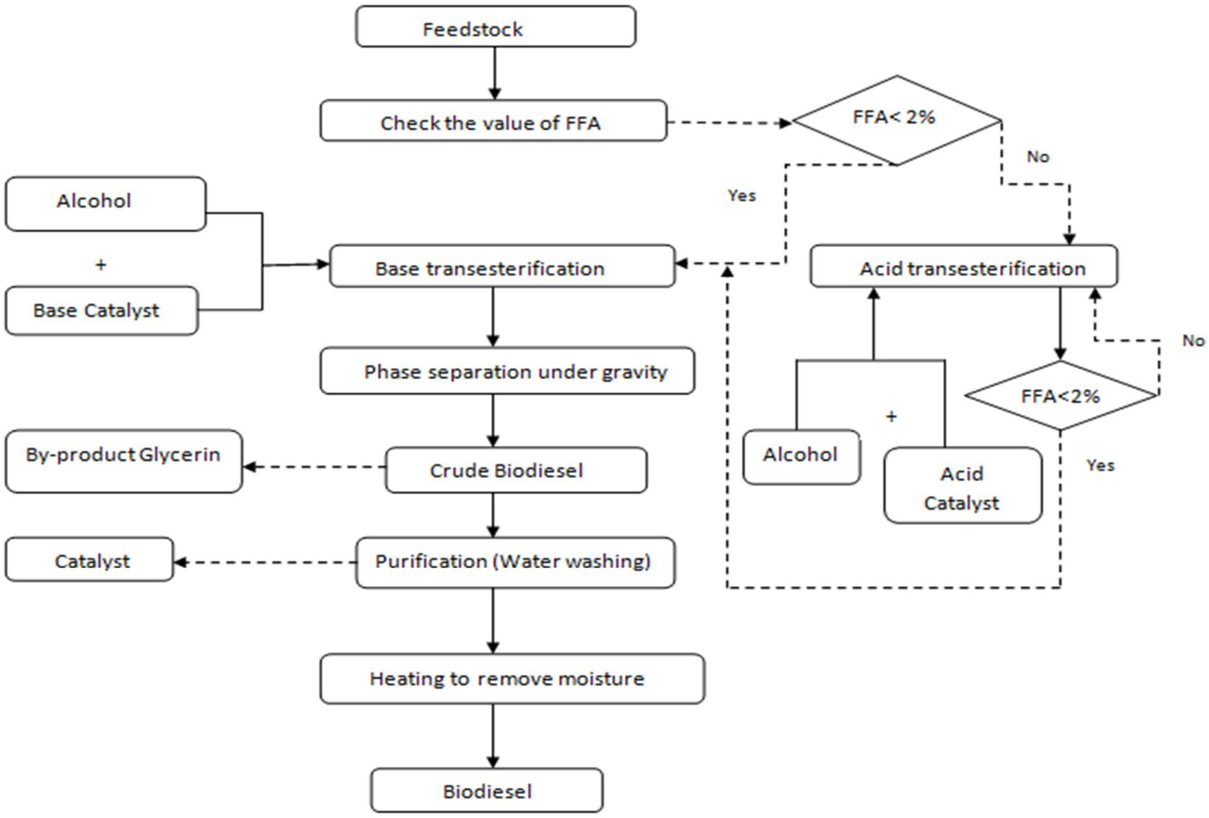


Figure 2 Transesterification process

To complete this process in a smaller duration, the feedstock is heated upto 60`C which reduces its viscosity. Water washing is used in order to eliminate any water soluble impurities. Finally, the feed stock is heated upto 105`C to completely remove the water content. The free fatty acid (FFA) value of all biodiesels lies between 0.1 to 0.3 gKOH/kg of feedstock. Therefore, single base transesterification is conducted. 300ml of methanol (in 1:16 ratio) and 10 grams of KOH (1%) are added to the feedstock which is heated to 60`C and stirred at a speed of 700rpm for 120minutes. The resultant products are allowed to settle in a gravity separator and glycerin is separated from the biodiesel after 8 hours. To get rid of the dissolved excess KOH and methanol, the obtained biodiesel is washed with hot water. Now, to ensure zero water content, the biodiesel is heated to 105`C. For all the oils, the same procedure is used. These biodiesels were prepared at Fuel Testing laboratory in Department of Mechanical Engineering of VFSTR.

### *C. Blend Characterization*

Tire pyrolysis oil prepared is blended with each biodiesel in steps of 10 from 10% to 100%. IS 15607 (2005) prescribes the methods of sampling, testing, and requirements for suitability of a biodiesel as a fuel in diesel engines. Therefore, the physiochemical properties of the prepared biodiesels have to be determined as per the standard test procedure. A Pycnometer of 25 ml was used to determine the density of the samples at 288 K. Ostwald's U-tube glass viscometer was used to determine the kinematic viscosity of the samples at 313K. Both the apparatus were calibrated using distilled water. Gross heating value of the samples were determined using a bomb calorimeter, calibrated using Benzoic acid. Cleveland's open cup apparatus was used to determine the flashpoint of the samples, as specified by ASTM. Though, International standards include properties like pour point and cloud point, the tropical weather conditions in the Indian scenario suggest that they are insignificant. However, to have an understanding of the low temperature flow properties, Cold filter plugging point (CFPP) of the samples was determined as specified by ASTM D6371. The cetane number of the neat tire pyrolysis oil and biodiesels was abstracted from the literature and mixing rule [Bamgboye AI et al 2008] was used in calculating the cetane number of the blends. The uncertainty for all the measurements is between 0.5% and 1.5% for three separate determinations.

## V. RESULTS AND DISCUSSION

Biodiesels produced from non-edible oils such as Jatropha and Karanja oils have been characterized and their properties are tabulated as Table 1. As per 1.9 and 6 cst the viscosity should lie between 1.9 and 6 cst. If EN 14214 is considered, then the viscosity should lie between 3.5 and 5.0 cst and all the biodiesels meet these standards. Same is the case with IS 15607 (2005), according to which the viscosity should lie within 2.5 and 6 cst. Notably, there is no any standard specified for Calorific value either in EN 14214 or in ASTM D6751 or in IS 15607 (2005). The European standards suggest minimum or lowest flash point of 101`C, American standards suggest a minimum of 93`C and the Indian standards suggest a minimum of 120`C, and all the biodiesels meet these standards.

Table 1 Physiochemical properties of the biodiesels prepared from non-edible oils and plastic oil

| **Property** | Kinematic viscosity (cst) at 40`C | Calorific value (MJ/kg) | Density ($gm/cm^3$) at 15`C | Flash point (`C) |
|---|---|---|---|---|
| Jatropha biodiesel | 4.75 | 40.70 | 0.8880 | 152 |
| Karanja biodiesel | 4.20 | 38.90 | 0.8750 | 174 |
| Plastic pyrolysis oil | 3.11 | 44.34 | 0.8280 | 42 |

Almost all the properties of biodiesels such as higher density, higher viscosity, low calorific value, in comparison to diesel, are responsible for poor performance of a diesel engine run on B100. Blending diesel with biodiesels can improve its performance. But. This solution has a limitation of using diesel, a fossil fuel which is about to be extinct. Therefore, blending biodiesels with plastic pyrolysis oil can address this issue to some extent. Table 1 clearly suggests that blending biodiesels with plastic pyrolysis oil which has lower viscosity, lower density, higher calorific value is advantageous. Plastic pyrolysis oil has viscosity lesser than these biodiesels and so blending any biodiesel with plastic oil can improve the atomization in the cylinder and thus the performance. Also, the density of plastic oil is lower than that of biodiesels and thus blending them with plastic pyrolysis oils would reduce the fuel consumption. One of the major concerns with biodiesels over diesel is that they possess lower energy content, indicated in terms of calorific value, consequently will end up with higher specific fuel consumption. Blending biodiesels with plastic pyrolysis oil,

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which has heating value almost similar to diesel, can reduce the specific fuel consumption significantly. The flash point of plastic oil is very less and so biodiesels-plastic oil blends would have poor flash points, consequently weakening their portability and safety. Since plastic oil improves the quality of biodiesels it is better to understand the impact of plastic oil on the properties of biodiesels which would help in improving the performance of a diesel engine. Hence, plastic pyrolysis oil was blended in different volume proportions to jatropha and karanja biodiesels and the properties of the prepared blends were determined. The following section discusses the variations in the properties of biodiesels (derived from non-edible oils) when diluted with plastic pyrolysis oil.

### *A. Effect of Plastic Oil Content on the Viscosity of Biodiesels*

The uncertainty in the measurements of density is 1.5%. With an intention of improving the spray characteristics of jatropha and karanja biodiesels in a diesel engine, they were diluted with plastic oil in different volume ratios. Apparently, for the same blend percentage, karanja biodiesel-plastic oil blends possessed lesser kinematic viscosity when compared to jatropha biodiesel-plastic oil blends. Interestingly, blend with 90% plastic oil in jatropha biodiesel had viscosity (3.25 $mm^2/s$) almost same as that of blend with 90% plastic oil in karanja biodiesel (3.20 $mm^2/s$). This conveys that the plastic oil could bring in a greater change in the poor viscosity of jatropha biodiesel. The maximum reduction in the viscosity of jatropha biodiesel (90% plastic oil blend) is up to 31.5% and that in the case of karanja biodiesel is up to 23.8%. The following relations generated using single variable least square regression analysis in RStudio can be used to predict the viscosity of any blend, given the percentage of plastic oil blended to it.

$$\nu_{J+PO}\ (mm^2/s) = -0.0164x + 4.74 \quad (1)$$

$$\nu_{K+PO}\ (mm^2/s) = -0.011x + 4.19 \quad (2)$$

$\nu_{J+PO}$ represents the kinematic viscosity of jatropha-plastic oil blends at 40°C and $\nu_{K+PO}$ represents the kinematic viscosity of karanja-plastic oil blends at 40°C. The multiplied $R^2$ of equations 1 and 2 are 0.9994 and 0.9983 respectively. The observed viscosities are compared to the predicted viscosities in Figure 3 and Figure 4 respectively for jatropha-plastic oil blends and karanja-plastic oil blends, which ensures the reliability of the models.

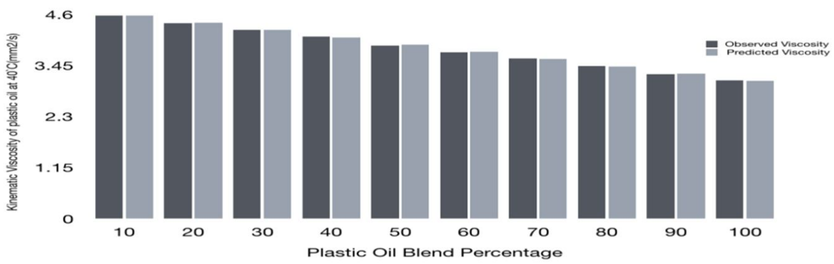


Figure 3 Observed viscosities versus predicted viscosities of jatropha-plastic oil blends

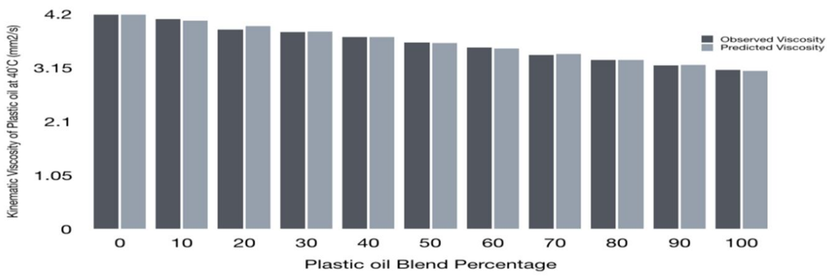


Figure 4 Observed viscosities versus predicted viscosities of karanja-plastic oil blends

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### *B. Effect of Plastic Oil Content on the Calorific Value of Biodiesels*

Apparently, karanja biodiesel has lesser calorific value than that of jatropha biodiesel. However, blending plastic oil to both these biodiesels helped in improving their calorific values significantly. The improvement in calorific value of jatropha was seen from 40.7 MJ/ kg (0% plastic oil) to 44.1 MJ/kg (90%plastic oil). The same for karanja biodiesel is observed to be from 38.9 MJ/kg (0% plastic oil) to 44.1 MJ/kg (90%plastic oil). Though, plastic oil improved the energy content of both the biodiesels, it was more helpful in case of karanja biodiesel. The amount of plastic oil in the blend is related to its calorific value using the following equations 3 and 4, whose multiplied $R^2$ is 0.9944 and 0.9968 for jatropha-plastic oil blends and karanja-plastic oil blends, respectively.

$$CV_{J+PO}\ (MJ/kg) = 0.037x + 40.64 \quad (3)$$

$$CV_{K+PO}\ (MJ/kg) = 0.0559x + 38.87 \quad (4)$$

$CV_{J+PO}$ represents the calorific value of jatropha-plastic oil blends and $CV_{K+PO}$ represents the calorific value of karanja-plastic oil blends. The observed calorific values are compared to the predicted calorific values in Figure 5 and Figure 6 respectively for jatropha-plastic oil blends and karanja-plastic oil blends, which ensures the reliability of the models.

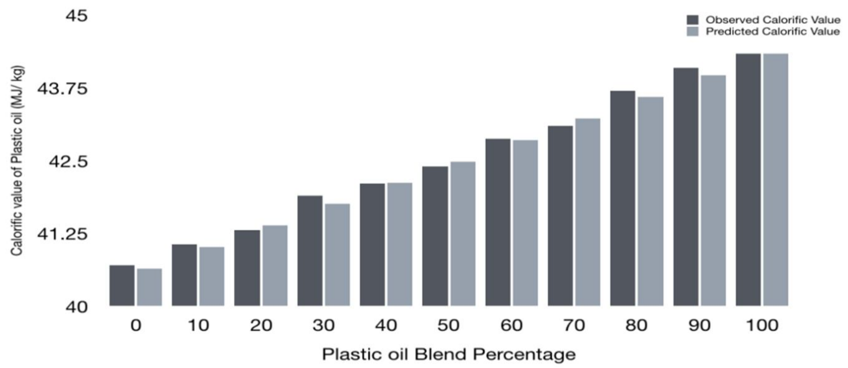


Figure 5 Observed calorific values versus predicted calorific values of jatropha-plastic oil blends

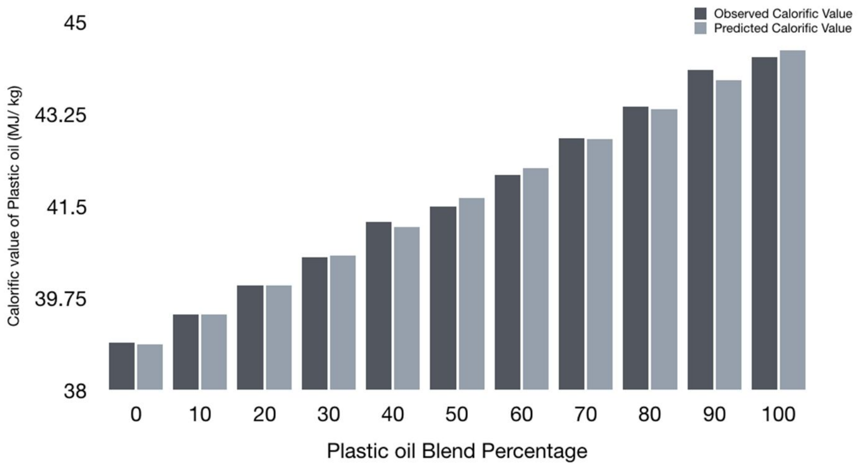


Figure 6 Observed calorific values versus predicted calorific values of karanja-plastic oil blends

### *C. Effect of Plastic Oil Content on the Density of Biodiesels*

For three separate determinations, the uncertainty in density measurement is 0.5%. As it is aimed to reduce the density of the biodiesels, to reduce the fuel consumption, the maximum reduction in density of jatropha biodiesel was found to be by 6.2% and that for karanja biodiesel was found to be by 4.72%. However, not significant variation in the density was observed. Density of the blends is dependant on to the plastic oil content as shown in equations 5 and 6. The predicted density is compared to the observed value in Figure 7 and Figure 8 for jatropha-plastic oil blend and karanja-plastic oil blend, respectively. The multiplied $R^2$ for both the prediction models are 0.9984 and 0.9971 respectively. Note that the density of jatropha-plastic oil blends is represented by $\rho_{J+PO}$ and the same for karanja-plastic oil blends is represented by $\rho_{K+PO}$.

$$\rho_{J+PO} = -0.0006x + 0.8877 \quad (5)$$

$$\rho_{K+PO} = -0.0005x + 0.8755 \quad (6)$$

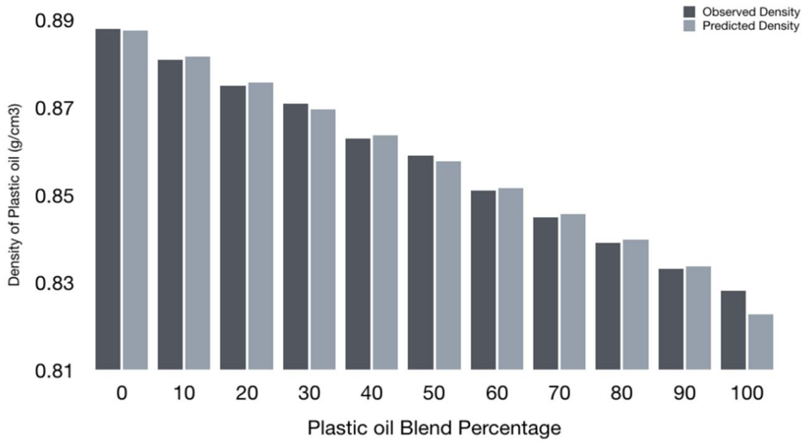


Figure 7 Observed densities versus predicted densities of jatropha-plastic oil blends

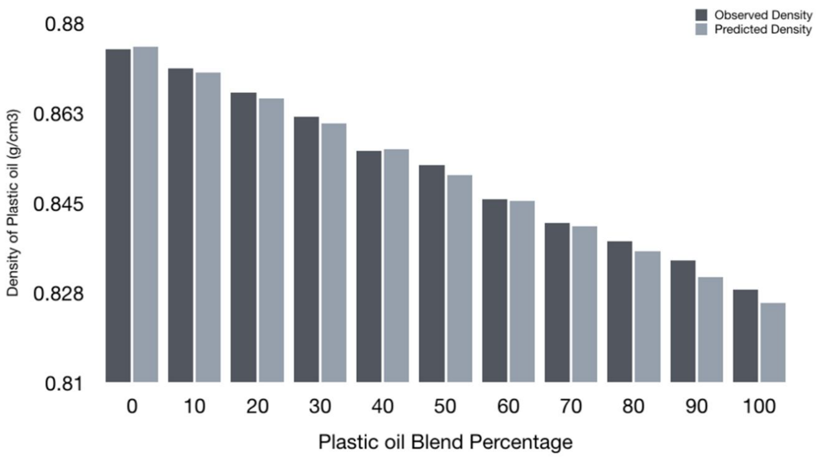


Figure 8 Observed densities versus predicted densities of karanja-plastic oil blends

### *D. Effect of Plastic Oil Content on the Flash Point (FP) of Biodiesels*

The uncertainty in the measurements of flash point is 1%. As mentioned earlier, all the neat biodiesel meet the European, American and Indian standards. The portability of the fuel can be safer with a higher flash point (FP) and so blending it with plastic oil which has poor flash point would worsen the condition. However, blends were prepared and characterized to establish the results. Blending plastic oil with biodiesel decreased its flash point and this makes its portability questionable. Flash point of the blend is related to the plastic oil content (x) as shown in equations 7 and 8 for jatropha-plastic oil and karanja-plastic oil blends respectively.

$$FP_{J+PO} = -1.111x + 152.18 \quad (7)$$

$$FP_{K+PO} = -1.327x + 174.09 \quad (8)$$

The $R^2$ for the equation 7 is 0.9996 and the same for equation 8 is 0.9995. Figure 9 and Figure 10 compare the observed flash point with the predicted flash point for jatropha-plastic oil blends and karanja-plastic oil blends respectively.

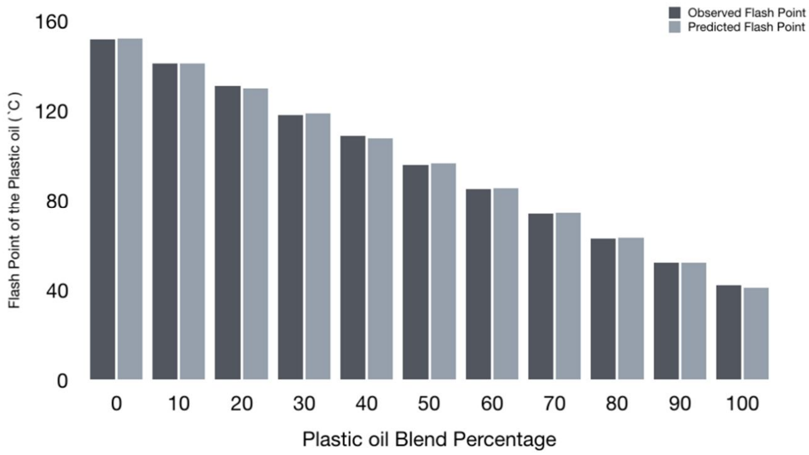


Figure 9 Observed flash points versus predicted flash points of jatropha-plastic oil blends

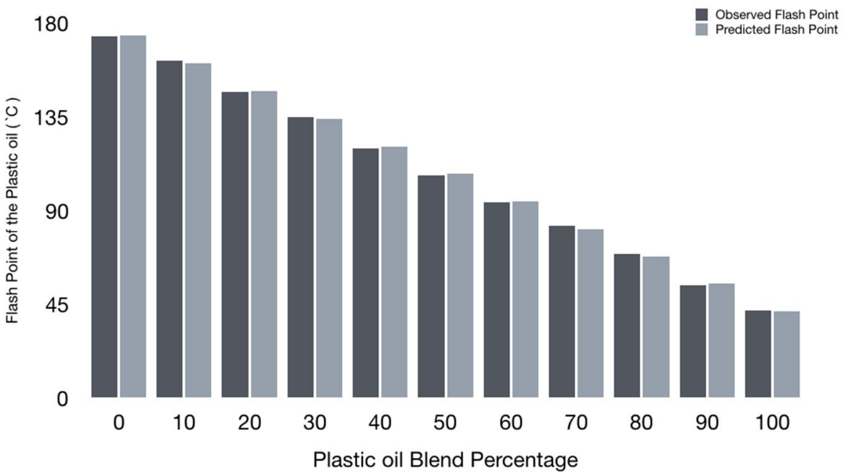


Figure 10 Observed flash points versus predicted flash points of karanja-plastic oil blends

The above discussion clearly suggests that blending plastic pyrolysis oil is advantageous in thr terms of improved spray characteristics and specific fuel consumption at the expense of impaired flash point. However, the same analysis can be extended to other physio-chemical properties like cold filter plugging point, pour point, , cloud point , cetane number etc. to get a complete understanding of how favorable plastic oil is to the combustion of biodiesels in a compression ignition engine.

## VI. CONCLUSIONS

The following conclusions have been made from the present study.

*A.* Blending plastic oil to jatropha and karanja biodiesels reduced their viscosities to a greater extent and this can help in improved spray characteristics.

*B.* Plastic oil also improved the calorific value and density of biodiesels significantly, which can reduce the specific fuel consumption and reduce it down close to that of diesel.

*C.* The flash point of the biodiesels decreased by blending them with plastic oil and this seemed to be a disadvantage of dilution of biodiesels with it.

However, diluting biodiesels with plastic oil can help in addressing one of the major threats to human survival, such as non-biodegradability of waste plastic. Alongside, it can also address the issue of poor performance of biodiesels in a CI engine.

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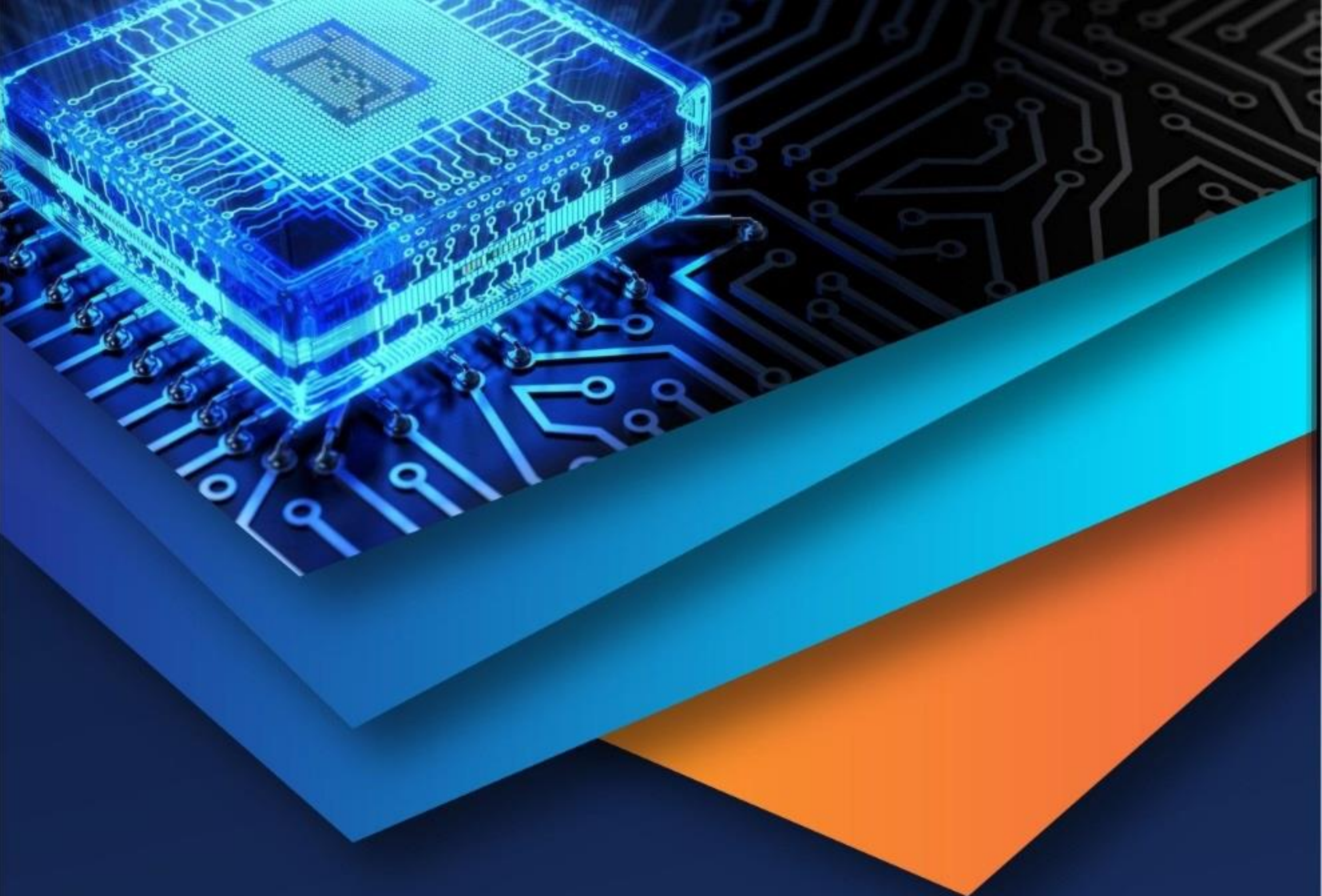

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