Title	The evaluation of viscosity and density of blends of Cyn-diesel pyrolysis fuel with conventional diesel fuel in relation to compliance with fuel specifications EN 590:2009
Authors(s)	Murphy, Fionnuala, McDonnell, Kevin, Butler, Eoin, Devlin, Ger
Publication date	2012-01
Publication information	Murphy, Fionnuala, Kevin McDonnell, Eoin Butler, and Ger Devlin. "The Evaluation of Viscosity and Density of Blends of Cyn-Diesel Pyrolysis Fuel with Conventional Diesel Fuel in Relation to Compliance with Fuel Specifications EN 590:2009" 91, no. 1 (January, 2012).
Publisher	Elsevier
Item record/more information	http://hdl.handle.net/10197/5656
Publisher's statement	This is the author's version of a work that was accepted for publication in Fuel. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in Fuel (VOL 91, ISSUE1, (2012)) DOI:10.1016/j.fuel.2011.06.032 Elsevier Ltd. Elsevier B.V. Elsevier Inc.
Publisher's version (DOI)	10.1016/j.fuel.2011.06.032

The evaluation of viscosity and density of blends of Cyn-diesel pyrolysis fuel with conventional diesel fuel in relation to compliance with fuel specifications EN 590:2009.

Fionnuala Murphy, K. McDonnell and G Devlin.

Biosystems Engineering Department, University College Dublin, Belfield, Dublin 4, Ireland.

Email of corresponding author: fionnualanmurphy@gmail.com
Tel +353 1 716 7418. Fax +353 1 716 7415.

Abstract

The production of synthetic fuels from alternative sources has increased in recent years as a cleaner, more sustainable source of transport fuel is now required. In response to European renewable energy targets, Ireland has committed, through the Biofuels Obligation Scheme of 2008, to producing 3% of transport fuels from biofuels by 2010 and 10% by 2020. In order to be suitable for sale in Europe, diesel fuels and biodiesels must meet certain European fuel specifications outlined in the EN 590:2004 and EN 14214:2009 standards. The aim of this project is to prepare blends of varying proportions of synthetic diesel fuel (Cyn-diesel), produced from the pyrolysis of plastic, versus regular fossil diesel. The viscosity (mm^2/s) and density (kg/m^3) of these blends as well as of the regular diesel fuel were analysed in relation to compliance with the European fuel standard EN 590.

Key Words

Alternative fuels

Waste-to-energy

EU biofuel targets

Fuel properties

Viscosity

Density

Please cite as - Murphy F, McDonnell K, Butler E, Devlin G. The evaluation of viscosity and density of blends of Cyn-diesel pyrolysis fuel with conventional diesel fuel in relation to compliance with fuel specifications EN 590:2009. Fuel. 2012:112-8.

1 Introduction

1.1 Biofuel policy

1.1.1 European biofuel policy

The European Council released a new Directive in 2009 on the promotion and use of energy from renewable sources. This directive amends and repeals both Directive 2001/77/EC of the European Parliament and of the European Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market and Directive 2003/30/EC of the European Parliament and of the European Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels in transport [1]. The directive confirms the European Community's commitment to the previous mandatory targets of a 20% share of energy from renewable sources in overall Community energy consumption by 2020 and a mandatory 10% minimum target of transport fuelled by renewables by 2020 [1].

1.1.2 Irish biofuel policy

As a response to the above mentioned European biofuels targets, Ireland developed a Biofuels Obligation Scheme (BOS) in order to meet the required targets. The BOS will ensure that a certain percentage of the transport fuel used in the state by 2010 consists of biofuels. The penetration level of the BOS is to be 3% (by volume) in 2010. This figure will move to 6% in 2012 if certain criteria are met. Going beyond 2010 it is the Government's intention to progressively increase the level of the obligation in a manner consistent with the pace of developments within the rest of the EU to ensure the delivery of the 2020 10% target [2].

Both European and Irish biofuel policies fail to incorporate alternative fuels other than biodiesel at present. It is important that these policies are updated to allow the contribution of other alternative fuels, such as synthetic diesel, to the European and national renewable energy targets.

1.2 EN 590:2009 fuel standards

Fuels are required to meet certain fuel specifications to ensure adequate performance in spark and compression combustion engines. When these specifications are met, alternative diesels can be used in the most modern engines without any modification while maintaining the engines durability and reliability. The EN 590:2009 standard, developed by the European Committee for Standardization (CEN), specifies property limits which marketable fuels must conform to. The standard also specifies test methods for marketed and delivered automotive diesel fuel [3].

When tested using the standard test methods indicated in Table 1, marketable automotive diesel fuel properties must be within the limits specified in these tables.

Table 1 Generally applicable requirements and test methods EN 590:2009

Property	Unit	Limits		Test Method
		Minimum	Maximum	
Density at 15°C	kg /m^3	820.0	845.0	EN 3675, EN 12185
Kinematic Viscosity at 40°C	mm^2/s	2.00	4.50	EN 3104

1.3 The Cynar Process

The Cynar Process is a chemical recycling process which converts waste plastics into synthetic fuel. The system technology was developed by Cynar Plc. The system can directly process a wide range of unsorted and unwashed plastics including commercial and industrial packaging as well as heavily contaminated agricultural wastes. [4]. The system consists of stock in-feed system, pyrolysis gasification chamber, contactor, condensers, centrifuge, oil recovery line, off-gas cleaning, and adulterant removal. A Cynar plant can produce up to 9500 litres of high-grade synthetic fuel (Cyn-diesel) from 10 tonnes of waste plastics (polyethylene, polypropylene and polystyrene), with systems ranging from 10 to 20 tonnes per day. The Cynar Process yields a hydrocarbon distillate comprising straight and branched chain aliphatics, cyclic aliphatics and aromatic hydrocarbons. The resulting mixture is essentially equivalent to regular diesel [5].

1.4 Fuel Properties

1.4.1 Viscosity

Viscosity is defined in the International Standard EN 3104:1996 as "the resistance to flow of a fluid under gravity" [6]. Viscosity is a key fuel property as it influences the atomization of a fuel upon injection into the combustion chamber and eventually the formation of soot and engine deposits [7]. In a diesel engine, the liquid fuel is sprayed into compressed air, and atomized into small drops near to the nozzle exit. The liquid fuel, usually, forms a cone-shaped spray at the nozzle exit and its viscosity affects on the atomization quality, size of fuel drop and penetration [8].

1.4.2 Density

Density is defined by the International Standard EN 3993:1996 as: "mass of the liquid divided by its volume at 15 °C or 20 °C, reported in units of mass and volume, together with the standard reference temperature; for example, kilograms per cubic metre at 15 °C for practical purposes, the apparent mass in air corrected for air buoyancy may be taken to represent the mass" [9]. Knowledge of density gives a broad indication of fuel type. For fuels of a known type, it serves as a general inspection check for the presence of contaminants. It also influences the performance of pumps in fuel systems [10].

1.5 Fuel blending

In light of the EU requirements relating to biofuels outlined above, blending of alternative diesel fuels with regular diesel has taken on added importance. Blending allows the adjustment of fuel properties in line with EU standards while achieving the targets outlined in the EU Directive on the promotion and use of energy from renewable sources. The majority of research has been carried out on blending several types of biodiesel [11-13], with conventional diesel. Fewer studies have dealt with alternative fuels from other feedstocks. These feedstocks include straight vegetable oil [14], waste polystyrene [15], and biomass [16]. Few studies examine the effect of blending of fuels derived from plastic with diesel.

The fuel properties of alternative fuels differ from conventional diesel and can have an important effect on engine performance. Therefore, an understanding of the fuel properties of alternative diesels, diesel fuels and their blends is important before using such blends in a diesel engine [8]. As the use of alternative diesels becomes more widespread, engine manufacturers have expressed concern about the differing properties of alternative fuels. It has been reported that the addition of biofuels to petrodiesel fuels results in the enhancement of the properties related to the injection and lubrication of the fuel in the engines [12].

The blending of alternative diesel fuels at differing levels with conventional diesel can have a significant effect on blend fuel properties such as viscosity and density properties. Research has been carried out on the properties of alternative fuels and blends with petroleum diesel [8, 11, 13-15, 17-19].

1.5.1 Blending – Viscosity

Several studies have been carried out examining how blending biodiesel with regular diesel affects the fuel blends' viscosity [8, 11, 14]. Tat and Van Gerpen [11] studied the kinematic viscosity of blends of biodiesel with commercially available diesel fuels. The results indicated that the viscosity of the straight biodiesel and biodiesel-diesel blends are higher than regular diesel, while the viscosity of the blends increases with increasing biodiesel content [11]. Alptekin and Canakci [8] examined two commercially available diesel fuels and blends of six different vegetable oils (sunflower, canola, soybean, cottonseed, corn oils and waste palm oil) with these diesel fuels. According to the results, the viscosities of the blends increased with the increase of biodiesel concentration in the fuel blend, however, the viscosity does not change mostly for the blends up to 20% biodiesel [8]. Abollé et al. [14] examined the variation of viscosity of a number of blends of straight vegetable oil (SVO) with diesel oil. It was found that blends containing up to 30% SVO have viscosities lower than 4.5 mm^2/s and therefore conform to EN 590 standards for diesel.

Pramanik [13] found that viscosity of blends of jatropha oil with diesel increased with increasing volumes of jatropha oil in the blends, while the viscosity is reduced by heating. This trend can be seen in Figure 1. Among the various blends, the blends containing up to 30% jatropha oil have viscosity values close to that of diesel while blends containing 40% or more jatropha oil have higher viscosities than diesel. The viscosity of the blends containing 30% oil became close to that of diesel in the temperature ranges of only 35–40 °C. The corresponding temperatures were found to be and 54 °C and 55–60 °C for 40% and 50% blends and even higher for 60% and 70% blends at 60–65 °C and 70–75 °C[13].

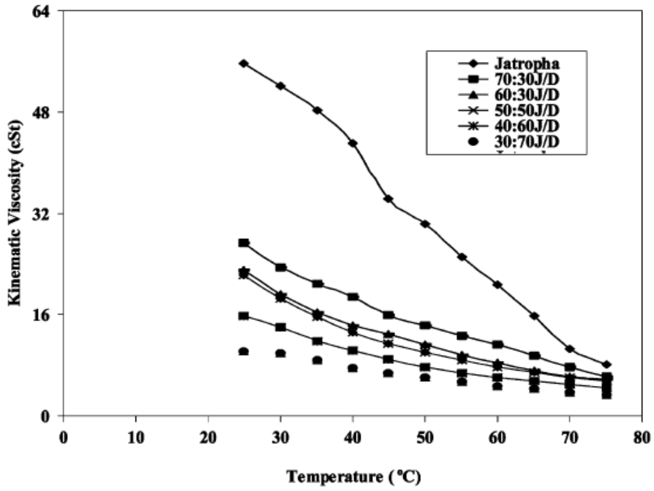

Figure 1: Effect of temperature on the viscosity of jatropha oil and various blend [13].

Kuzhiyil and Kong [15] used biodiesel as a recycling agent in which polystyrene (PS) packing peanuts were dissolved in different concentrations as a means to recover energy from waste plastics. Results indicated that the optimal polystyrene concentration that could be used without difficulties in fuel flow and injection was 5% by weight and 10% is the feasible limit beyond which the fuel mixture became too viscous for proper fuel pump operation. Higher concentrations caused poor fuel flow through the injection system and higher emissions. However, PS concentration of 2% by weight (viscosity of 6.36 mm^2/s) was the only blend to come close to conforming to the ASTM D 445 standard (1.9–6.0 mm^2/s) [15].

The effects of different gas-to-liquid (GTL) volume fractions on GTL-diesel blends' properties were examined in a paper by Wuet al. [16]. The study determined the viscosity of the blends keeps relatively constant when the GTL volume ratio is below 50%, yet it increases when the ratio goes beyond 50%. This result can be seen in Figure 2 [16].

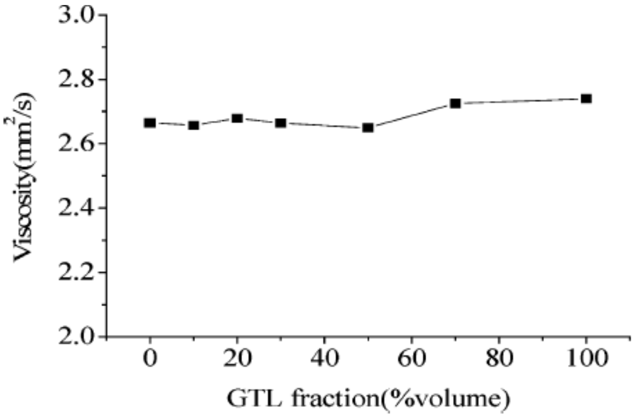

Figure 2: Effect of GTL fraction on viscosity of GTL-diesel blends [16]

1.5.2 Blending – Density

Several studies have been carried out examining how blending biodiesel with regular diesel affects the fuel blends' density. Altepkin and Canakci [8] examined the densities of blends of biodiesel derived from six different vegetable oils (sunflower, canola, soybean, cottonseed, corn oils and waste palm oil) with two commercially available diesel fuels. They found that the densities of diesel fuels are lower than those of biodiesels, and the density of the blends approach those of the diesel fuels as the biodiesel concentration decreases in the blends. The density of the biodiesel-diesel blends increases with the increasing volume fraction of biodiesel in the blends [8]. Abollé et al. [17] carried out a study on the density of blends straight vegetable oils (SVO) with diesel fuel. The densities of SVOs vary from 0.9 to 0.93 kg/l, whereas the density of conventional diesel varies from 0.81 to 0.87 kg/l. It was found that density increases as concentration of palm oil in the blends increases [17].

Wu et al. [16] examined the effects of different GTL volume fractions on GTL-diesel blends' properties. The study determined that the densities of the GTL blends decreased gradually with increasing volume fraction of GTL. This result can be seen in Figure 3. This is due to the fact that the density of GTL is lower than that of diesel fuel by 7.2% [16].

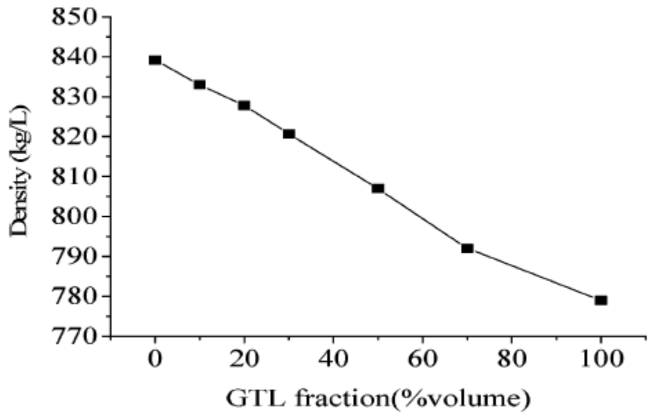

Figure 3: Effect of GTL fraction on density of GTL-diesel blends [16]

2 Materials and Methods

Samples of Cyn-diesel were obtained from Cynar Plc in Portlaoise. This Cyn-diesel was produced by the pyrolysis of waste plastics as described in the section on pyrolysis above. Regular road diesel was also obtained for preparing blends with the Cyn-diesel.

Cyn-diesel was blended with regular diesel in ratios of 10%, 20%, 30%, 40% and 50% Cyn-diesel by volume. Samples of pure diesel and Cyn-diesel were also used for analysis.

The EN 590 standard specifies test methods and procedures which should be followed in the testing of fuel properties in relation to compliance with EN 590. The standard governing the measurement of viscosity is EN 3104:1996 - 'Petroleum products - Transparent and opaque liquids - Determination of kinematic viscosity and calculation of dynamic viscosity'. This method requires the use of a u-tube viscometer [6]. The standard governing the measurement of density is EN 3675:1996 – 'Crude petroleum and liquid petroleum - Laboratory determination of density or relative density - Hydrometer method'. This method requires the use of a hydrometer [9]. An alternative test method for density is EN 12185:1996 – 'Methods of test for petroleum and its products - Crude petroleum and petroleum products - determination of density - oscillating u-tube method'. This method requires the use of an oscillating u-tube.

2.1 Determination of kinematic viscosity

The dynamic viscosity, in centipoise (cP), of each fuel sample was measured using a rotational viscometer. The conversion of the obtained dynamic viscosity to the required kinematic viscosity is outlined.

Viscometer

The dynamic viscosities of the fuel samples were determined using a Brookfield DV-II+ Programmable viscometer. The viscometer measures dynamic viscosity in units of centipoise (cP). The ULA spindle (code 00) was used.

The water bath temperature was set at 40 °C for testing the fuel samples as this is the temperature specified in the EN 590 fuel standards.

Before testing the fuel samples, the viscometer was calibrated using a sample standard. Viscosity was measured for each of the 7 different blends.

2.1.1 Calculation of kinematic viscosity

The dynamic viscosity (μ) measured by the procedures above is expressed in centipoise (cP).
Kinematic viscosity (ν) is the ratio of dynamic viscosity to density. Kinematic viscosity can be obtained by dividing the dynamic viscosity of a fluid with the fluid's density (ρ) as represented by the following equation:

$$\nu = \mu / \rho$$

Where

ν = kinematic viscosity

μ = dynamic viscosity

ρ = density

The following steps were followed to convert to kinematic viscosity:

1. The units of the measured dynamic viscosity were converted from cP to Ns/m^2 following the relationship: 100 cP = 1 Ns/m^2.
2. The units of the measured density at 40°C were converted from kg/m^3 to Ns^2/m^4 following the relationship: 1 kg/m^3 = 1 Ns^2/m^4.
3. The equation above was evaluated, giving kinematic viscosity in m^2/s.
4. Kinematic viscosity is required in mm^2/s according to the EN 590 standard. This is obtained by multiplying m^2/s by 10^{-6}.
5. As such, kinematic viscosity in mm^2/s was calculated using the measured dynamic viscosity and density [19].

2.2 Determination of Density

The densities of the samples were measure using a Densito 30PX portable density meter by Mettler Toledo.

The Densito meter measures density using the oscillating tube method. Density was measured in g/cm^3 at 15 °C (the temperature specified in the EN 590 fuel standards) and 40 °C (required in the calculation of kinematic viscosity). The Densito meter has a density range of 0 -2 g/cm^3, a density resolution of 0.0001 g/cm^3 and a density accuracy of ±0.001 g/cm^3.

Density was measured at 15 °C and 40 °C for each of the seven different blends. The density meter was calibrated using a sample standard prior to the implementation of the experimental procedure. As such, the density meter was producing precise results with an accuracy of ±0.001 g/cm^3.

3 Results

3.1 Viscosity

The results of the experimental procedure carried out with the Brookfield viscometer are outlined in Table 2. The viscosity measurements shown are dynamic viscosity. In order to compare these results to the EN 590 standard, it was necessary to convert to kinematic viscosity. The steps outlined in Section 2.11 were followed to convert dynamic viscosity in cP to kinematic viscosity in mm^2/s.

Table 2 Viscometer results – dynamic viscosity

Dynamic Viscosity (cP)							
	Rep 1	**Rep 2**	**Rep 3**	**Rep 4**	**Mean Dynamic Viscosity (cP)**	**Standard Deviation**	**Standard Error**
Diesel	2.48	2.48	2.49	2.48	2.48	0.01	0.003
10% Cyn-diesel	2.44	2.43	2.44	2.43	2.44	0.01	0.003
20% Cyn-diesel	2.4	2.39	2.39	2.39	2.39	0.00	0.002
30% Cyn-diesel	2.33	2.34	2.34	2.33	2.34	0.01	0.003
40% Cyn-diesel	2.28	2.28	2.29	2.27	2.28	0.01	0.004
50% Cyn-diesel	2.24	2.23	2.24	2.23	2.24	0.01	0.003
100% Cyn-diesel	1.83	1.83	1.86	1.86	1.85	0.02	0.009

Table 3 Viscometer results – kinematic viscosity

Kinematic Viscosity (mm²/s)							
	Rep 1	Rep 2	Rep 3	Rep 4	Mean Kinematic Viscosity (mm²/s)	Standard Deviation	Standard Error
Diesel	2.96	2.96	2.97	2.96	2.96	0.01	0.003
10% Cyn-diesel	2.93	2.93	2.92	2.91	2.92	0.01	0.006
20% Cyn-diesel	2.89	2.88	2.87	2.87	2.88	0.01	0.005
30% Cyn-diesel	2.82	2.83	2.82	2.81	2.82	0.01	0.005
40% Cyn-diesel	2.78	2.78	2.77	2.75	2.77	0.01	0.007
50% Cyn-diesel	2.74	2.74	2.72	2.71	2.73	0.01	0.006
100% Cyn-diesel	2.30	2.30	2.33	2.33	2.31	0.02	0.009

The final kinematic viscosity results obtained from the experimental procedure (Table 3) can be compared to the EN 590 viscosity requirements outlined in Table 1. The EN 590 standards for kinematic viscosity specify that the fuel must have a viscosity within the range of 2.00–4.50 mm^2/s. By comparing the mean kinematic viscosity of each of the blends with this requirement, it can be seen that all of the blends are within this range. As such, each of the 7 blends is in compliance with EN 590 requirements in terms of kinematic viscosity.

3.2 Density

The results of the experimental procedure carried out with the Densito 30PX portable density meter are given in Table 4. The density readings are shown in g/m^3. In order to compare these results to the EN 590 standard, it was necessary to convert to the units of density to kg/m^3.

The density of the blends in kg/m^3 can be seen in Table 4. The EN 3675 standard for the measurement of density states that the final result is to be reported to the nearest 0.1 kg/m^3.

Table 4 Density results at 15°C in kg/m^3

Density at 15°C (kg/m³)							
	Rep 1	Rep 2	Rep 3	Rep 4	Mean Density (kg/m³)	Standard Deviation	Standard Error
Diesel	838.6	838	838.5	836.3	837.9	1.07	0.53
10% Cyn-diesel	833.5	834.1	834	833.8	833.9	0.26	0.13
20% Cyn-diesel	830.3	830.3	830.2	830.3	830.3	0.05	0.02
30% Cyn-diesel	825.7	825.7	825.5	825.7	825.7	0.10	0.05
40% Cyn-diesel	821.3	821.5	821.2	821.9	821.5	0.31	0.15
50% Cyn-diesel	817.1	817	817.1	817.3	817.1	0.13	0.06
100% Cyn-diesel	796.2	796.3	795.9	793.2	795.4	1.48	0.74

The EN 590 standards for density specify that the fuel must have a density within the range of 8.20–8.45 kg/m^3. Comparing the mean density of each of the blends with this requirement, it is clear that blends up to, and including, 40% Cyn-diesel content are within this range. Blends containing 50% and 100% Cyn-diesel lie below the required density range. As such, blends up to, and including 40% Cyn-diesel content are in compliance with EN 590 requirements in terms of density. The blends containing 50% and 100% Cyn-diesel are not in compliance with EN 590 standards, therefore, it is probable that blends containing upwards of 50% will also not be in compliance.

3.3 Statistical analysis

3.3.1 T-test for significance

The t-test for significance, carried out using SAS, was used to determine whether the observed differences in responses (i.e. values of viscosity, and density) are due to the treatments (i.e. differing blend ratios of Cyn-diesel versus regular fossil diesel) or simply random variation. The purpose of significance testing is to ensure that the experimenter does not try to interpret random variation. The output of interest from the t-test is the P value. If the P value is small it may be used to reject the null hypothesis (i.e. that the observed difference between means is due to chance) as not credible. Ultimately, if the P value is small (<0.05), it can be said with a reasonable amount of confidence that the observed effects were due to treatment effects [20].

The output (P) from the t-test for significance for the dynamic viscosity results from the viscometer is less than 0.0001. Similarly, the t-test for significance for the kinematic viscosity results which were computed using the dynamic viscosity results from the viscometer shows that $P < 0.0001$. Furthermore, the P value from the t-test for significance for the density results from the Densito density meter is again less than 0.0001, confirming that blending of Cyn-diesel with regular diesel in differing ratios has a highly significant effect on the observed differences in density. These results confirm that blending of Cyn-diesel with regular diesel in differing ratios has a highly significant effect on the observed differences in viscosity and density.

3.3.2 Regression analysis

Regression analysis can be used to determine the contributory effect of one variable upon another - in the case of this project, the effect of increasing Cyn-diesel concentration in the fuel blend on selected fuel properties (viscosity and density). The regression analysis is utilised to estimate the quantitative effect of the causal variables upon the variable that they influence [20]. In regression, the R^2 value is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1.0 indicates that the regression line perfectly fits the data. The R^2 value is calculated by expressing the regression (model) sum of squares statistic as a percentage of the total sum of squares.

The regression analysis was carried out using SAS statistical analysis software.

Table 5 gives the output from the regression analysis applied to the dynamic viscosity, kinematic viscosity and density results. In each case, the regression analysis gives an R^2 close to 1. This high R^2 value indicates that a linear relationship approximates the correlation between the measured parameter of the fuel blend and the percentage Cyn-diesel content very well. An equation can be obtained from the regression analysis which can be used to predict the variation of y (parameter) according to the change in x (Cyn-diesel content).

The P_synd parameter in table 5, gives the slope of the line. This parameter indicates that for each percentage increase in Cyn-diesel in the fuel blend, the dynamic viscosity decreases by 0.006 cP. Similarly, both kinematic viscosity and density of the fuel blend decreases with increasing the Cyn-diesel content.

Table 5 Regression analysis output

Parameter	R^2	P-synd	Equation
Dynamic viscosity	0.98	-0.006 cP	y = -0.006x + 2.51
Kinematic viscosity	0.97	-0.006 mm^2/s	y = -0.006x + 3
Density	0.99	-0.43 kg/m^3	y = -0.43x + 838.22

Figure 4, graphs the dynamic viscosity versus Cyn-diesel content of the fuel blends. The linear regression line is imposed in the data. As evident from the graph, a linear relationship is a good fit for the observed data.

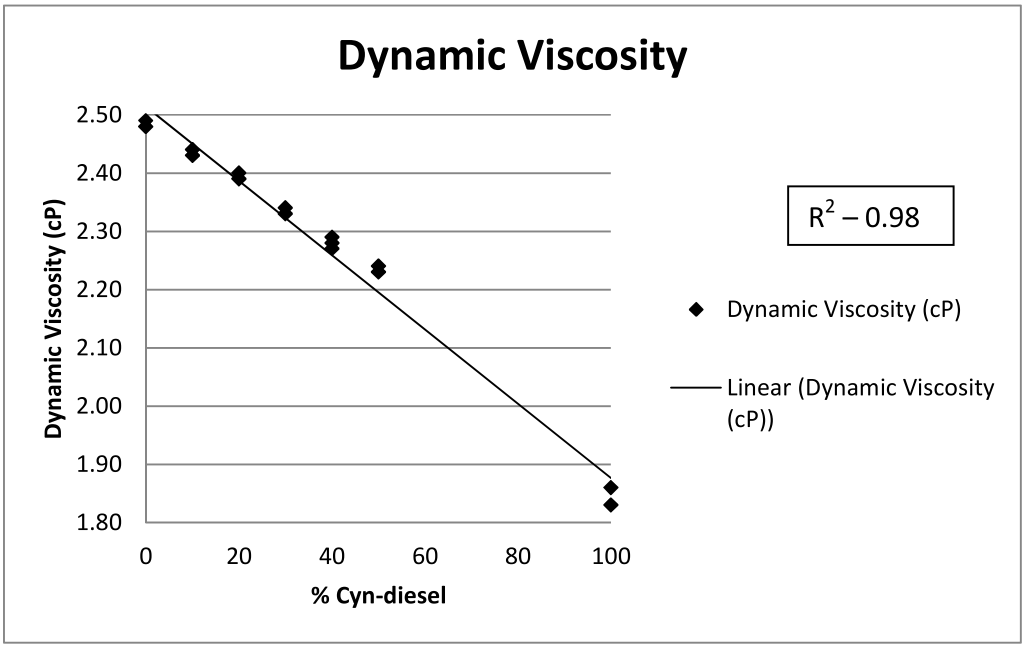

Figure 4: Dynamic viscosity (cP) from the viscometer versus Cyn-diesel content (%).

Figure 5 shows the linear regression line fitted to the kinematic viscosity versus Cyn-diesel content data. The graph shows that the linear relationship is a good fit for the observed data.

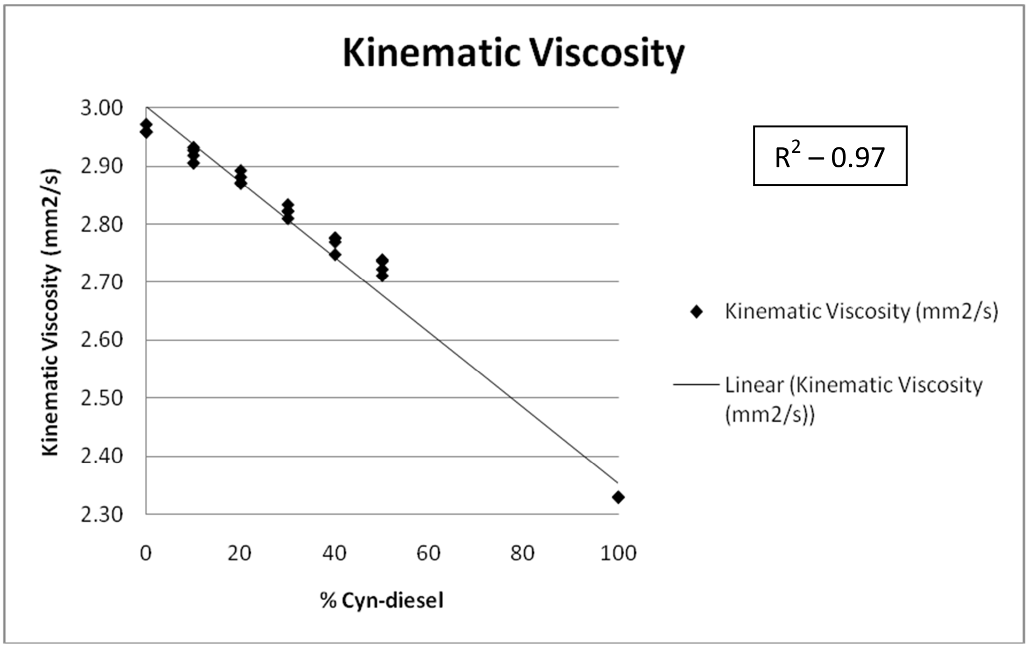

Figure 5: Kinematic viscosity (mm^2/s) from the viscometer versus Cyn-diesel content (%).

Figure 6 shows that the regression line is a good fit for the relationship between the density of the fuel blend and the Cyn-diesel content of the blend.

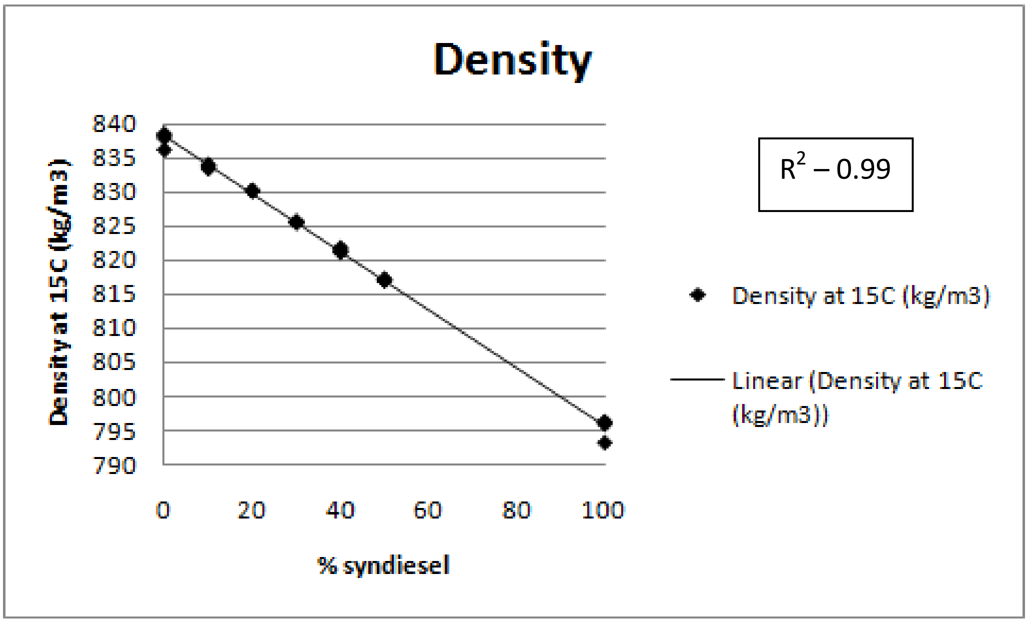

Figure 6: Density (kg/m^3) versus Cyn-diesel content (%).

4 Discussion

The statistical analysis of the experimental results confirms that the blending of Cyn-diesel with regular diesel has a highly significant ($P< 0.0001$) effect on each of the fuel blends' properties examined. As such, it is clear that the Cyn-diesel used in this study can be blended with regular diesel to ensure conformance with EN 590 specifications for the properties investigated.

The main aim of this project was to analyse certain properties of blends of Cyn-diesel versus regular road diesel fuel in relation to compliance with EN 590 standards. The results from the experimental procedure allow the evaluation of the fuel blend properties in relation to compliance with the standards required in EN 590. As it can be seen in the results section, the comparison of the properties of the fuel blends to the EN 590 standards results in a number of trends. Firstly, in relation to kinematic viscosity, all of the fuel blends are in compliance with EN 590 specifications. However, only blends of up to and including 40% Cyn-diesel are in compliance with EN 590 specifications for density. This analysis shows that a blend of 40% Cyn-diesel is in compliance with all of the EN 590 specifications examined, and as such could be placed on the European fuel market.

The t-test for significance highlights that blending has a highly significant ($P < 0.0001$) effect on kinematic viscosity. The regression analysis shows that for each percentage increase in Cyn-diesel in the fuel blend, the kinematic viscosity decreases by 0.006 mm^2/s. Thus, by increasing the Cyn-diesel content of the fuel blend the kinematic viscosity of the blend is decreased.

Similarly, the statistical analysis shows that blending has a highly significant ($P < 0.0001$) effect on the density of the fuel blend. The regression analysis shows that for each percentage increase in Cyn-diesel in the fuel blend, the density decreases by 0.43 kg/m^3. Thus, by increasing the Cyn-diesel content of the fuel blend the density of the blend is decreased.

The review of the literature pertaining to the properties of fuel blends highlights the effectiveness of blending various alternative fuels with regular diesel fuel in altering the resulting fuel blends' properties. However, there is a gap in the literature in assessing the properties of blends of synthetic diesel fuel derived from waste plastics with regular diesel. It is hoped that this project will provide a relevant assessment of the kinematic viscosity, density, cold filter plugging and flash point of Cyn-diesel blends with regular diesel. It is hoped this work will complement existing research into the properties of alternative fuels and blends of these fuels with regular diesel.

5 Conclusion

Several key findings have emerged as a result of this work.

Firstly, it can be confirmed that blending of Cyn-diesel with regular diesel has a highly significant effect on the properties of the resulting fuel blend. The results show that by increasing the Cyn-diesel content of the blend, the kinematic viscosity and density of the blend decrease.

Secondly, the evaluation of compliance of the fuel blends in relation to EN 590 specifications has shown differing results. The kinematic viscosity of all of the fuel blends are in compliance with EN 590 specifications. However, only blends of up to, and including, 40% Cyn-diesel are in compliance with EN 590 specifications for density. This analysis shows that a blend of 40% Cyn-diesel is in compliance with all of the EN 590 specifications examined, and as such could be placed on the European fuel market (provided that the blend meets the requirements for the other properties in the EN 590 specification). This finding highlights the potential for Cyn-diesel blends to be incorporated into the European and national renewable energy targets.

The next step would be to carry out a full characterisation of the fuel blends in relation to the other properties in the EN 590 specification. This would enable the evaluation of blends of Cyn-diesel with conventional diesel fuel in relation to compliance with the full range of properties included in the EN 590 fuel specification.

Role of the funding source

This research was funded under Science Foundation Ireland's Charles Energy Parsons Award 06/CP/E001www.sfi.ie.

6 References

[1] EC. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC; European Commision 2009.

[2] Department of Communications, Energy and Natural Resources, Public Consultation on the Biofuels Obligation Scheme; 2008.

[3] CEN. EN 590:2009 - Automotive fuels — Diesel — Requirements and test methods, B.S. Organisation; 2009.

[4] Ondrey G. Europe to get new wave of plastic-to-diesel plants. Chem Eng 2006; 113(5): 1.

[5] Scheirs J. Overview of Commercial Pyrolysis Processes for Waste Plastics. In: Scheirs J, Kaminsky W, editors. Feedstock Recycling and Pyrolysis of Waste Plastics: Converting Waste Plastics into Diesel and Other Fuels: John Wiley & Sons; 2006 p. 383-431.

[6] CEN. EN 3104:1996 - Petroleum products - Transparent and opaque liquids - Determination of kinematic viscosity and calculation of dynamic viscosity, B.S. Organisation. 1996.

[7] Rashid U, Anwar F, Knothe G. Evaluation of biodiesel obtained from cottonseed oil. Fuel Process Technol 2009; 90(9): 1157-63.

[8] Alptekin E, Canakci M. Determination of the density and the viscosities of biodiesel-diesel fuel blends. Renew Energ 2008; 33(12): 2623-30.

[9] CEN. EN 3675:1996 - Crude petroleum and liquid petroleum - Laboratory determination of density or relative density - Hydrometer method, B.S. Organisation. 1996.

[10] Goodyear EM. Hydrocarbon fuels - production properties and performance of liquids and gases. London: Macmillan; 1975.

[11] Tat M, Van Gerpen J. The kinematic viscosity of biodiesel and its blends with diesel fuel. J Am Oil Chem Soc 1999; 76(12): 1511-3.

[12] Sharma BK et al. Oxidation and low temperature properties of biofuels obtained from pyrolysis and alcoholysis of soybean oil and their blends with petroleum diesel. Fuel Process Technol 2009; 90(10): 1265-71.

[13] Pramanik K. Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. Renew Energ 2003; 28(2): 239-48.

[14] Abollé A, Kouakou L, Planche H. The viscosity of diesel oil and mixtures with straight vegetable oils: Palm, cabbage palm, cotton, groundnut, copra and sunflower. Biomass Bioenerg 2009; 33(9): 1116-21.

[15] Kuzhiyil N, Kong S-C. Energy Recovery from Waste Plastics by Using Blends of Biodiesel and Polystyrene in Diesel Engines. Energ Fuel 2009; 23(6): 3246-53.

[16] Wu T, et al. Physical and Chemical Properties of GTL Diesel Fuel Blends and Their Effects on Performance and Emissions of a Multicylinder DI Compression Ignition Engine. Energ Fuel 2007; 21(4): 1908-14.

[17] Abollé A, Loukou K, Henri P. The density and cloud point of diesel oil mixtures with the straight vegetable oils (SVO): Palm, cabbage palm, cotton, groundnut, copra and sunflower. Biomass Bioenerg 2009; 33(12): 1653-9.

[18] Luján JM, et al. Comparative analysis of a DI diesel engine fuelled with biodiesel blends during the European MVEG-A cycle: Preliminary study (I). Biomass Bioenerg 2009; 33(6-7): 941-7.

[19] Benard ICJ. Handbook of Fluid Flowmetering. 1st ed. Surrey: The Trade & Technical Press; 1987.

[20] Connolly, J. Postgraduate Research Methods for the Life Sciences. Department of Statisitcs, University College Dublin; 2007.