

Combustion and Emission Characteristics of Straight Vegetable Oils and Diesel Fuel Blends

Omar F. Bashir, Fawwaz I. Khalili, Bassam A. Sweileh*

Chemistry Department, Faculty of Science, The University of Jordan, Amman 11942, Jordan.

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Abstract

An experimental investigation was carried out to evaluate the performance and emission characteristics of vegetable oils blends with diesel oil as an alternative fuel. Virgin and waste frying vegetable oils of sunflower, corn, soybean and palm oils were collected and characterized with GC-FID. Nine blends of various vegetable oils and diesel were prepared. The important chemical and physical properties of the blends (including kinematic viscosity, heat of combustion, exhaust emissions (SO_x and NO_x), flash point, pour point, cloud point, sulfur content, density and specific gravity) were compared to those of diesel oil. Generally, there is no significant difference between the use of waste or virgin vegetable oils blends with diesel oil. Among the various blends, those containing up to 30% vegetable oils have viscosity, pour point, cloud point and density values close to those of diesel oil. These blends have approximately 95% of the heat of combustion, but have the advantages of higher flash point and lower emissions compared to those of diesel oil. Blends of 30% vegetable oils have comparable performance and emissions characteristics to those of diesel oil fuel and found to be good substitute for diesel.

Keywords: Diesel oil; Vegetable oils; Waste frying oil; Sunflower oil; Soybean oil; Corn oil; Palm oil; Combustion; Exhaust Emission.

Introduction

Diesel oil, a petroleum fuel derivative, plays a vital role in industrial development, transportation, agriculture and many other basic human applications. Because of the limited fuel resources, excessive use with rapidly increasing prices of petroleum oils, increasing environmental concerns and the effect of greenhouse gases, a new situation has developed for engineers and researchers to look for alternative fuels. Biodiesel derived from vegetable oils or animal fats can be one of the important alternative fuels; it is an environment friendly liquid fuel similar to diesel oil in combustion characteristics.^[1-2] Biodiesel has several advantages: it reduces or eliminates SO_x, NO_x, CO emissions, polyaromatic hydrocarbons, smokes, particulate matter, noises and unburned hydrocarbons in exhaust emissions. It has been indicated that biomass used as energy source can reduce CO₂ greenhouse effect, SO₂, and

* Corresponding author: e-mail: sweilehb@ju.edu.jo

NOx atmospheric pollution due to its neutral carbon and lower sulfur and nitrogen contents.^[3] Biodiesel has also been reported to improve the antiwear properties and fuel cetane number.^[4-6]

The first use of straight vegetable oils (SVO's) as a biodiesel fuel for diesel engines is almost as old as diesel engine itself, when the inventor "Rudolph Diesel" used peanut oil to fuel his engine in 1900. Vegetable oils have cohesive energy density, cetane number, heat of vaporization and stoichiometric air/fuel ratio comparable to those of diesel oil fuel. In addition, they are biodegradable, non-toxic, have minimal sulfur content, negligible aromatic content with higher flash point.^[4-5,7-10] Furthermore, contribution of biodiesel to greenhouse effect is insignificant.^[4,11,12] Recently, systematic efforts have been made by several researchers to use vegetable oils like sunflower,^[13] soybean,^[14] rapeseed,^[15] palm,^[8,16] jatropha,^[16-18] coconut,^[19] rubber seed,^[20] jojoba,^[21] and peanut,^[6] oils as substitute fuels for diesel.

The major problem associated with using SVO's as substitute fuels is their high kinematic viscosity (30–200 cSt) compared to diesel oil (1.9–4.1 cSt) at the same temperature. This may lead to several problems including poor atomization of the fuel, problems in pumping, incomplete combustion and others.^[4,18,22-23] Therefore, reducing the viscosity of vegetable oils is of prime importance to make them suitable as a fuel. Several approaches have been proposed to reduce the viscosity of vegetable oils such as blending (dilution with other fuels), thermal cracking (pyrolysis), micro-emulsion, and transesterification.

Alternative fuels should be environmentally friendly, of low cost and fulfill the energy security needs without degrading the operational performance of an engine. It is quietly known that the transesterification process is the most suitable method of converting vegetable oils to an engine fuel. However, the transesterification process has extra processing costs involving chemical and heat inputs processes.^[4] The transesterification technique will be viable if carried out on a large scale, it may be an attractive proposition in small scale areas of the developing countries; using heated or blended vegetable oils as petroleum fuel substitutes is an attractive alternative

Blends of vegetable oils with diesel have given promising results to researchers.^[1,11,13,22,24] In addition to the environmental advantages of substituting vegetable oil for diesel, this substitution can also help to reduce another growing environmental problem in Jordan and around the world, the irresponsible disposal of waste frying oils (WFO) from household and industrial sources.^[23,25-28] WFO is regularly poured down the drain, adding extra burden for waste water treatment, plants, energy loss and the human health.^[29-30] Many investigations have been carried out to evaluate the durability, performance and emission characteristics of engines fueled with WFO's blends.^[2-4,10,19-21,23,31] These evaluations show that, the performance of engines fuelled by these oils blends is comparable to their performance when fuelled by pure petroleum diesel.^[6,10,21,23,31] Large amounts of vegetable oils are imported and exported

daily around the world for various uses with a total costs valued by millions of Euros. Unfortunately, the WFO's are not utilized in a proper way. Therefore, fuel alternatives such as WFO's will save millions of Euros, as well as improving the environment by reducing the unfriendly gases emissions and pollution by waste oil.

In this work, we report on the use of sunflower oil, corn oil, soybean oil, palm oil and their direct blends with diesel oil as biofuel mixtures. Therefore the vegetables oils were used without any chemical pretreatment or modification prior to blending with diesel oil. The objective of this work is to evaluate the performance and emission characteristics of using virgin and WFO's of sunflower, corn, soybean and palm oils and their diesel blends (100, 90, 80, 70, 60, 50, 40, 20 and 0%, diesel) as alternative diesel fuel.

Experimental

The experiments of performance and emission characteristics were conducted on sunflower oil, corn oil, soybean oil, palm oil and their direct blends with diesel oil. The vegetable oils were collected from different sources; the virgin vegetable oils were obtained from the local markets and the WFO's were obtained from local domestic consumers (i.e., restaurants). The collected oils were filtered through cotton pieces inserted into a glass filtration column to remove solid impurities. The collected vegetable oils were characterized with gas chromatography (with FID detector) (Instrument Supplier: SHIMADZU; Model: 2010) for their fatty acids composition according to CODEX standards for the determination of vegetable oil types. Biofuel mixtures were prepared by blending different volume ratios of vegetable oils with diesel oil (obtained from the Jordanian refinery company Al-Zarqa – Jordan) with a total volume of 250 mL using a magnetic stirrer. Each blend solution was stirred for 15 minutes at 1000 rpm to get the homogeneous stable mixture under normal temperature and pressure condition. The important chemical and physical properties of these blends were tested experimentally according to the ASTM and compared to those of diesel oil. The density and specific gravity of the different blends were measured using a capillary stoppered pycnometer. The kinematic viscosity was measured with a kinematic viscometer by measuring the efflux time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer at 40 °C according to ASTM D 445-06. The kinematic viscosity was calculated by multiplying the viscometer constant with time in seconds. The heat of combustion was measured with a Bomb Calorimeter (Instrument Supplier: Petrotest; Model: KV600) and the flash point was measured with Pensky Martens closed cup apparatus (Instrument Supplier: Herzog; Model: 327). A Karl Fischer titrator (Instrument Supplier: Metrohm; Model: 652) was used for water content determination. Cloud and pour point apparatus (Supplier: Coesfeld; Model: Capp IV) was used to measure pour and cloud points of the different blends. X-ray fluorescence (Instrument Supplier: HORIBA; Model: SLFA-

2100/2800) was used to measure the sulfur content of fuels blends. The titration method was used to measure the total acid concentration as (H_2SO_4 and HNO_3) of the exhaust emissions sulfur dioxide (SO_2) and nitrogen oxides (NO_x) according to ASTM D 240. The various fuel blends properties characterized analytically together with the corresponding standard methods (ASTM) and the equipment used are summarized in Table 1.

Table 1: Blends properties, the corresponding ASTM method and the equipment used

| Serial | Property | ASTM Method | Equipment | Serial | Property | ASTM Method | Equipment |
|--------|-----------------------------|-------------|--|--------|--|-------------|--|
| 1 | Specific gravity | IP 190/93 | capillary stoppered pycnometer | 5 | Flash point ($^{\circ}C$) | D 93 | Pensky Martens closed cup apparatus (Herzog; Model: 327) |
| 2 | Heat of combustion (MJ/kg) | D 240 | Bomb Calorimeter (Petrotest; Model: KV600) | 6 | Water content (%) | D 6304 | Karl Fischer titrator (Metrohm; Model: 652) |
| 3 | Pour point ($^{\circ}C$) | D 97 | Pour point apparatus (Coesfeld; Model: Capp IV) | 7 | Kinematic viscosity (cSt at 40 $^{\circ}C$) | D 445 | kinematic viscometer |
| 4 | Cloud point ($^{\circ}C$) | D 2500 | Cloud point apparatus (Coesfeld; Model: Capp IV) | 8 | Sulfur Content (%) | D 4294 | X-ray fluorescence (HORIBA; Model: SLFA-2100/2800) |

Results and Discussion

The fatty acid compositions of the collected vegetable oils were characterized by gas chromatography (with FID detector) according to CODEX standards, the experimental results obtained are summarized in Table 2. The fuel characteristics of these oils and diesel are compared in Table 3. Different blends of Sunflower oil, Corn oil, Soybean oil, and Palm oil (0, 10, 20, 30, 40, 50, 60, 80 and 100%, v/v blends) with diesel oil were prepared at 250 rpm for 20 minutes. All of the characteristics mixtures that follow in the subsequent tables have been obtained by experimental analysis conducted in the laboratory.

Table 2: Characterization of fatty acid composition of vegetable oil types.

| Vegetable oil | Fatty Acid Composition ^a | | | | | | | | | | | | |
|----------------------------|-------------------------------------|-----------|--------|--------|--------|---------|-----------|-----------|----------|---------|---------|---------|--------|
| | 14:0 | 16:0 | 16:1 | 17:0 | 17:1 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 20:1 | 22:0 | 24:0 |
| Sunflower oil ⁰ | ND-0.2 | 5.0-7.6 | ND-0.3 | ND-0.2 | ND-0.1 | 2.7-6.5 | 14.0-39.4 | 48.3-74.0 | ND-0.3 | 0.1-0.5 | ND-0.3 | 0.3-1.5 | ND-0.5 |
| Sunflower oil ¹ | 0.06 | 6.28 | 0.11 | 0.04 | 0.02 | 3.51 | 25.81 | 62.55 | 0.10 | 0.30 | 0.22 | 0.72 | 0.28 |
| Sunflower oil ² | 0.09 | 7.57 | 0.05 | 0.06 | 0.05 | 4.56 | 34.90 | 50.91 | 0.02 | 0.36 | 0.23 | 0.83 | 0.37 |
| Corn oil ⁰ | ND-0.3 | 8.6-16.5 | ND-0.5 | ND-0.1 | ND-0.1 | ND-3.3 | 20.0-42.2 | 34.0-65.6 | ND-2.0 | 0.3-1.0 | 0.2-0.6 | ND-0.5 | ND-0.5 |
| Corn oil ¹ | 0.03 | 10.69 | 0.12 | 0.07 | 0.02 | 1.89 | 29.26 | 55.91 | 0.96 | 0.44 | 0.26 | 0.17 | 0.18 |
| Corn oil ² | 0.07 | 12.15 | 0.23 | 0.09 | 0.04 | 2.17 | 30.43 | 53.15 | 0.64 | 0.44 | 0.26 | 0.16 | 0.18 |
| Soybean oil ⁰ | ND-0.2 | 8.0-13.5 | ND-0.2 | ND-0.1 | ND-0.1 | 2.0-5.4 | 17.0-30.0 | 48.0-59.0 | 4.5-11.0 | 0.1-0.6 | ND-0.5 | ND-0.7 | ND-0.5 |
| Soybean oil ¹ | 0.08 | 10.65 | 0.09 | 0.10 | 0.04 | 4.38 | 22.33 | 54.51 | 6.65 | 0.38 | 0.20 | 0.44 | 0.16 |
| Soybean oil ² | 0.12 | 11.17 | ND | 0.10 | 0.05 | 4.58 | 24.21 | 54.04 | 4.79 | 0.35 | 0.05 | 0.41 | 0.13 |
| Palm oil ⁰ | 0.5-1.5 | 38.0-43.5 | ND-0.6 | ND-0.2 | ND-0.1 | 3.5-5.0 | 39.8-46.0 | 10.0-13.5 | ND-0.6 | ND-0.6 | ND-0.4 | ND-0.2 | ND |
| Palm oil ¹ | 0.83 | 38.30 | 0.20 | 0.09 | 0.03 | 4.27 | 43.76 | 11.68 | 0.24 | 0.38 | 0.15 | 0.07 | ND |
| Palm oil ² | 0.88 | 38.66 | 0.47 | 0.09 | 0.03 | 4.20 | 41.67 | 13.15 | 0.44 | 0.34 | ND | 0.07 | ND |

^a (XX:Y): No. of carbon atoms: Number of double bonds

⁰: CODEX Fatty acid composition standard for named vegetable oil

¹: Virgin vegetable oil

²: WFO

ND: Not Detected

Table 3: Fuel characteristics of vegetable and diesel oils.

| Fuel | Properties | | | | | | | |
|----------------------------|------------------|----------------------------|-----------------|------------------|------------------|-------------------|------------------------------------|--------------------|
| | Specific gravity | Heat of combustion (MJ/kg) | Pour point (°C) | Cloud point (°C) | Flash point (°C) | Water content (%) | Kinematic viscosity (cSt at 40 °C) | Sulfur Content (%) |
| ASTM method | IP 190/93 | D 240 | D 97 | D 2500 | D 93 | D 6304 | D 445 | D 4294 |
| Sunflower oil ¹ | 0.9212 | 38.862 | -12 | -7 | 201 | 0.03 | 32.00 | 0.0213 |
| Sunflower oil ² | 0.9211 | 39.306 | -9 | -6 | 243 | 0.02 | 35.81 | 0.0234 |
| Corn oil ¹ | 0.9200 | 39.218 | -12 | -7 | 178 | 0.04 | 32.69 | 0.0215 |
| Corn oil ² | 0.9220 | 38.640 | -9 | -6 | 183 | 0.04 | 33.56 | 0.0203 |
| Soybean oil ¹ | 0.9233 | 39.138 | -12 | -5 | 163 | 0.03 | 31.45 | 0.0193 |
| Soybean oil ² | 0.9266 | 39.138 | -6 | -4 | 163 | 0.04 | 36.81 | 0.0211 |
| Palm oil ¹ | 0.9151 | 39.235 | +9 | +20 | 203 | 0.02 | 40.55 | 0.0216 |
| Palm oil ² | 0.9153 | 39.641 | +6 | +20 | 231 | 0.05 | 39.45 | 0.0263 |
| Diesel | 0.8369 | 45.448 | -9 | +4 | 66 | 0.01 | 3.111 | 0.9850 |

¹: Virgin vegetable oil

²: WFO

Effect of dilution on the density and viscosity of biodiesels

Diesel oil has a kinematic viscosity of 3.111 cSt, and a specific gravity of 0.8369, while vegetable oils have higher range of kinematic viscosities (from 30.000 to 40.000 cSt) and specific gravity values of about 0.92. The specific gravity of the diesel was similar to those of the vegetable oils, so that it would be expected that they would mix quickly in all proportions, and indeed stable mixtures were obtained in all cases. However, significant reduction in viscosity and specific gravity were observed by dilution of vegetable oils with diesel oil as described in Tables 4-7. There is an insignificant difference in viscosity of the WFO's and the virgin vegetable oils in the whole range of blends, where the kinematic viscosities of the WFO's blends were slightly higher than those of virgin vegetable oils blends due to the polymerization of the fried oil that may occur through the heating-up stages of the frying process. The change in kinematic viscosity per 10% increase in vegetable oil percentage increased with increasing vegetable oil percentage, so that the increase for small vegetable oil percentages was less than what would be expected. The specific gravity did increase linearly with vegetable oil percentage. This increase in kinematic viscosities vary with the particular vegetable oil used, thus the kinematic viscosities of soybean oil, corn oil and sunflower oil blends were slightly lower than those of palm oil blends for blends up to 50% vegetable oil and much lower above this blending ratio. It may be concluded that up to 30% vegetable oil, virgin or WFO, exhibited similar kinematic viscosities almost within the limits specified for biodiesel (1.9–6.0 cSt at 40° C) according to ASTM D 6751, and clearly may be substituted for diesel without marked changes in density or viscosity.

Table 4: Viscosity and specific gravity trends of sunflower/diesel blends.

| % of Sunflower oil (v/v) | % of Diesel fuel (v/v) | Specific gravity ¹ | Specific gravity ² | Specific gravity Reduction % | | Kinematic Viscosity ¹ (cSt at 40 °C) | Kinematic Viscosity ² (cSt at 40 °C) | Viscosity Reduction % | | Observations |
|--------------------------|------------------------|-------------------------------|-------------------------------|------------------------------|-------|---|---|-----------------------|-------|----------------|
| | | | | 1 | 2 | | | 1 | 2 | |
| 100 | 0 | 0.9212 | 0.9211 | 00.00 | 00.00 | 32 | 35.81 | 00.00 | 00.00 | Stable mixture |
| 80 | 20 | 0.9043 | 0.9052 | 1.83 | 1.73 | 20.33 | 22.33 | 36.47 | 37.64 | Stable mixture |
| 60 | 40 | 0.8866 | 0.8882 | 3.76 | 3.57 | 12.35 | 13.58 | 61.41 | 62.08 | Stable mixture |
| 50 | 50 | 0.8780 | 0.8798 | 4.69 | 4.48 | 9.963 | 10.63 | 68.87 | 70.32 | Stable mixture |
| 40 | 60 | 0.8692 | 0.8714 | 5.64 | 5.40 | 7.981 | 8.345 | 75.06 | 76.70 | Stable mixture |
| 30 | 70 | 0.8606 | 0.8633 | 6.58 | 6.28 | 6.229 | 6.490 | 80.53 | 81.88 | Stable mixture |
| 20 | 80 | 0.8526 | 0.8540 | 7.45 | 7.28 | 4.963 | 5.051 | 84.49 | 85.90 | Stable mixture |
| 10 | 90 | 0.8434 | 0.8452 | 8.45 | 8.24 | 3.945 | 3.982 | 87.67 | 88.88 | Stable mixture |
| 0 | 100 | 0.8369 | | - | | 3.111 | | - | | Stable mixture |

¹: Virgin sunflower oil

²: WF sunflower oil

Table 5: Viscosity and specific gravity trends of corn/diesel blends.

| % of corn oil (v/v) | % of Diesel fuel (v/v) | Specific gravity ¹ | Specific gravity ² | Specific gravity Reduction % | | Kinematic Viscosity ¹ (cSt at 40 °C) | Kinematic Viscosity ² (cSt at 40 °C) | Viscosity Reduction % | | Observations |
|---------------------|------------------------|-------------------------------|-------------------------------|------------------------------|-------|---|---|-----------------------|-------|----------------|
| | | | | 1 | 2 | | | 1 | 2 | |
| 100 | 0 | 0.9200 | 0.9220 | 00.00 | 00.00 | 32.69 | 33.56 | 00.00 | 00.00 | Stable mixture |
| 80 | 20 | 0.9057 | 0.9047 | 1.55 | 1.88 | 20.47 | 20.83 | 37.38 | 37.93 | Stable mixture |
| 60 | 40 | 0.8891 | 0.8879 | 3.36 | 3.70 | 12.85 | 13.04 | 60.69 | 61.14 | Stable mixture |
| 50 | 50 | 0.8802 | 0.8786 | 4.33 | 4.71 | 10.03 | 10.34 | 69.32 | 69.19 | Stable mixture |
| 40 | 60 | 0.8719 | 0.8702 | 5.23 | 5.62 | 7.956 | 8.068 | 75.66 | 75.96 | Stable mixture |
| 30 | 70 | 0.8638 | 0.8615 | 6.11 | 6.56 | 6.305 | 6.434 | 80.71 | 80.83 | Stable mixture |
| 20 | 80 | 0.8558 | 0.8526 | 6.98 | 7.53 | 4.972 | 5.025 | 84.79 | 85.03 | Stable mixture |
| 10 | 90 | 0.8459 | 0.8434 | 8.05 | 8.52 | 4.005 | 3.921 | 87.75 | 88.32 | Stable mixture |

¹: Virgin corn oil

²: WF corn oil

Table 6: Viscosity and specific gravity trends of soybean/diesel blends.

| % of Soybean oil (v/v) | % of Diesel fuel (v/v) | Specific gravity ¹ | Specific gravity ² | Specific gravity Reduction % | | Kinematic Viscosity ¹ (cSt at 40 °C) | Kinematic Viscosity ² (cSt at 40 °C) | Viscosity Reduction % | | Observations |
|------------------------|------------------------|-------------------------------|-------------------------------|------------------------------|-------|---|---|-----------------------|-------|----------------|
| | | | | 1 | 2 | | | 1 | 2 | |
| 100 | 0 | 0.9233 | 0.9266 | 00.00 | 00.00 | 31.45 | 36.81 | 00.00 | 00.00 | Stable mixture |
| 80 | 20 | 0.9082 | 0.9072 | 1.64 | 2.09 | 19.95 | 19.61 | 36.57 | 46.73 | Stable mixture |
| 60 | 40 | 0.8914 | 0.8883 | 3.45 | 4.13 | 12.56 | 13.03 | 60.06 | 64.60 | Stable mixture |
| 50 | 50 | 0.8831 | 0.8805 | 4.35 | 4.98 | 9.970 | 10.25 | 68.30 | 72.15 | Stable mixture |
| 40 | 60 | 0.8750 | 0.8718 | 5.23 | 5.91 | 7.957 | 8.137 | 74.70 | 77.89 | Stable mixture |
| 30 | 70 | 0.8650 | 0.8632 | 6.31 | 6.84 | 6.183 | 6.507 | 80.34 | 82.32 | Stable mixture |
| 20 | 80 | 0.8568 | 0.8540 | 7.20 | 7.84 | 4.960 | 5.060 | 84.23 | 86.25 | Stable mixture |
| 10 | 90 | 0.8481 | 0.8463 | 8.14 | 8.67 | 3.987 | 4.063 | 87.32 | 88.96 | Stable mixture |

¹: Virgin soybean oil

²: WF soybean oil

Table 7: Viscosity and specific gravity trends of palm/diesel blends.

| % of Palm oil (v/v) | % of Diesel fuel (v/v) | Specific gravity ¹ | Specific gravity ² | Specific gravity Reduction % | | Kinematic Viscosity ¹ (cSt at 40 °C) | Kinematic Viscosity ² (cSt at 40 °C) | Viscosity Reduction % | | Observations |
|---------------------|------------------------|-------------------------------|-------------------------------|------------------------------|-------|---|---|-----------------------|-------|----------------|
| | | | | 1 | 2 | | | 1 | 2 | |
| 100 | 0 | 0.9151 | 0.9153 | 00.00 | 00.00 | 40.55 | 39.45 | 00.00 | 00.00 | Stable mixture |
| 80 | 20 | 0.8996 | 0.9022 | 1.69 | 1.43 | 24.30 | 23.30 | 40.07 | 40.94 | Stable mixture |
| 60 | 40 | 0.8841 | 0.8890 | 3.39 | 2.87 | 14.47 | 14.44 | 64.32 | 63.40 | Stable mixture |
| 50 | 50 | 0.8761 | 0.8811 | 4.26 | 3.74 | 11.13 | 11.11 | 72.55 | 71.84 | Stable mixture |
| 40 | 60 | 0.8690 | 0.8735 | 5.04 | 4.57 | 8.614 | 8.498 | 78.76 | 78.46 | Stable mixture |
| 30 | 70 | 0.8603 | 0.8656 | 5.99 | 5.43 | 6.712 | 6.649 | 83.45 | 83.15 | Stable mixture |
| 20 | 80 | 0.8534 | 0.8575 | 6.74 | 6.31 | 5.281 | 5.226 | 86.98 | 86.75 | Stable mixture |
| 10 | 90 | 0.8449 | 0.8496 | 7.67 | 7.18 | 4.055 | 4.046 | 90.00 | 89.74 | Stable mixture |

¹: Virgin palm oil

²: WF palm oil

Effect of dilution on the flash, pour and cloud points of biodiesels

Figure 1 shows that all vegetable oils and their blends meet the specified ASTM D 975 limits for the flash point. The pour point of sunflower, corn and soybean oils blends up to 100% vegetable oil exhibited values close to that of diesel oil (Figure 2). The pour point values of blends up to 30% of palm oil were found to be close to that of diesel oil due to the greater saturation characteristic of palmitic acid. Figure 3 shows that blends up to 40% of vegetable oil exhibited cloud points close to that of diesel oil. However, blends up to 100% of sunflower, corn and soybean oils exhibited better characteristic cloud point than that of diesel oil fuel, and blends up to 30% of palm oil exhibited cloud point values close to that of diesel oil.

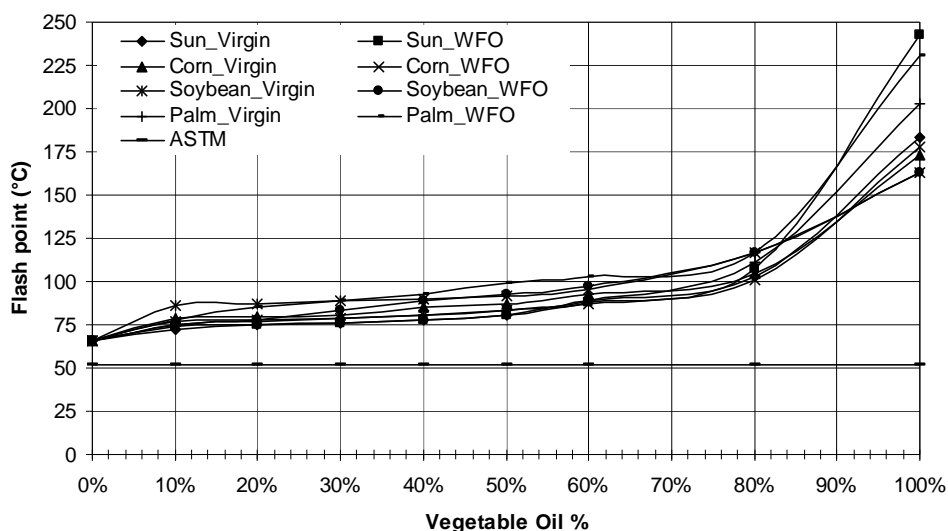


Figure1: Flash point for diesel and different blends of vegetable oils.

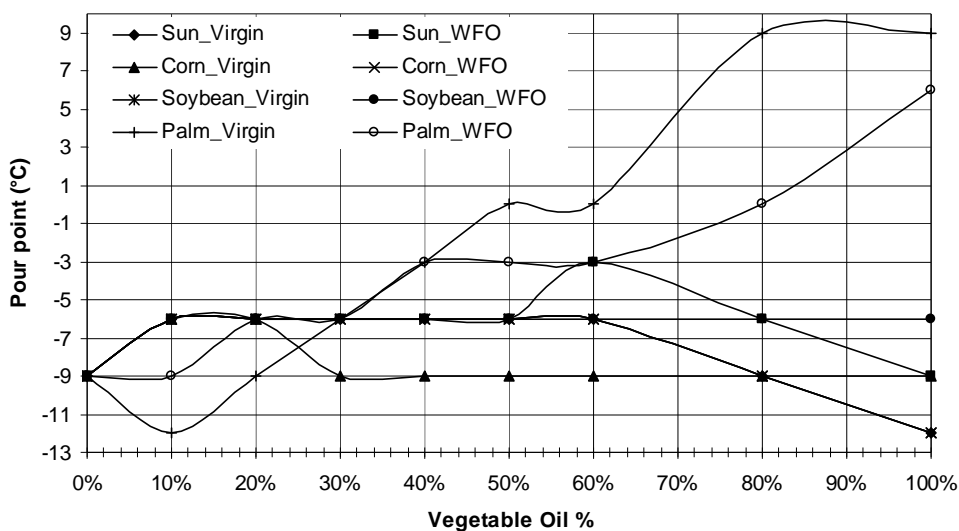


Figure 2: Pour point for diesel and different blends of vegetable oils.

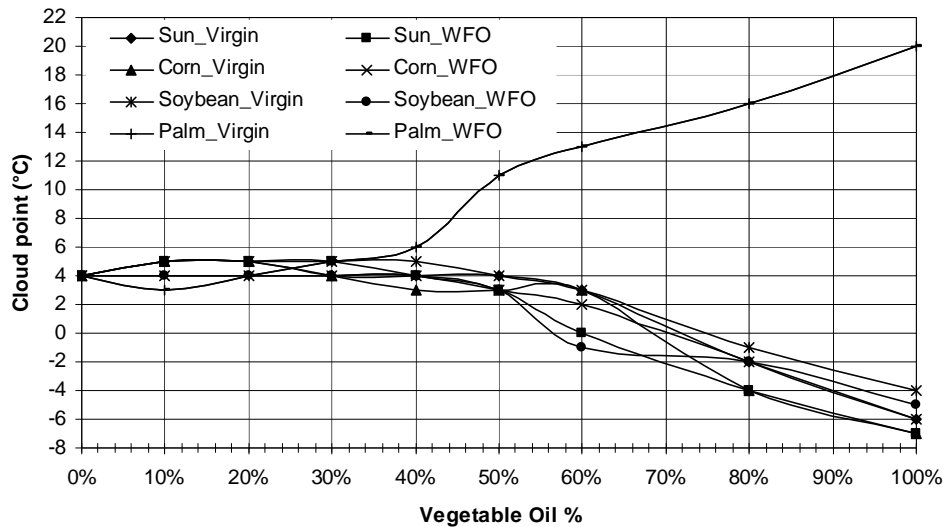


Figure 3: Cloud point for diesel and different blends of vegetable oils.

Effect of dilution on the combustion efficiency of biodiesels

The presence of oxygen in the structure of a fuel improves its combustion properties and emissions but reduces the heat of combustion. Vegetable oils contain more oxygen which means they have lower heats of combustion than that of diesel; therefore decreasing the proportion of vegetable oils in blends increases the heats of combustion of the blends as shown in Figure 4. Vegetable oil blends up to 40% exhibited heats of combustion close to that of diesel oil, since the lower heats of combustion of vegetable oils lead to an increase in the volumetric fuel consumption in order to maintain similar energy input to the engine.

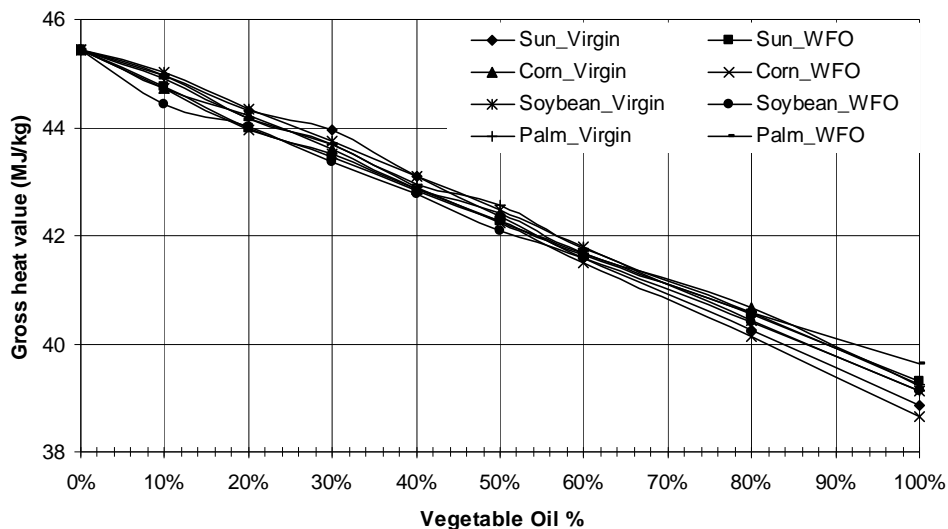


Figure 4: Gross heat value for diesel and different blends of vegetable oils.

Effect of dilution on the exhaust emission gases of biodiesels

Figures 5 and 6 indicate the evolved SO_2 and NO_x expressed as mass percent HNO_3 . According to ASTM D240 procedure, the exhaust of combustion in oxygen includes gaseous CO_2 , NO_x , SO_2 , and water (vapor). Diesel is the major source of sulfur and nitrogen contents that affect adversely the engine durability and the environment as well. Diesel oil has higher proportions of sulfur content (about 1.0 %) as described in Table 3 and as it can be deduced from Figures 5 and 6 that, the exhaust emissions of SO_2 and NO_x decreased dramatically with increasing vegetable oil percentage.

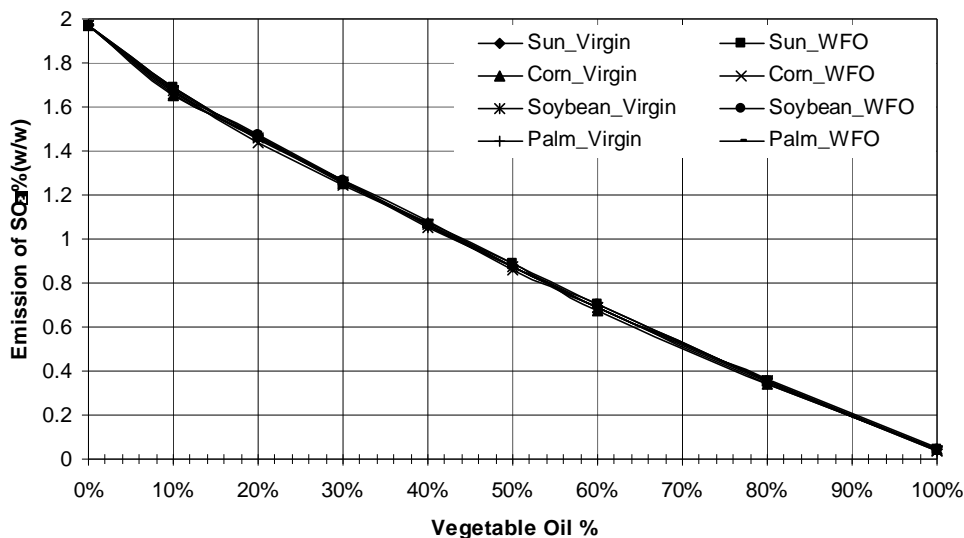


Figure 5: Emission of SO_2 for diesel and different blends of vegetable oils.

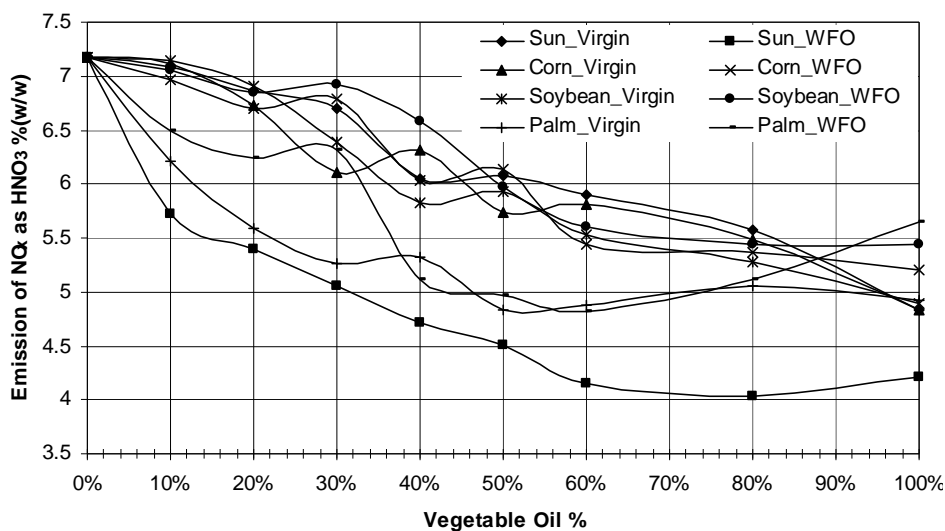


Figure 6: Emission of NO_x for diesel and different blends of vegetable oils.

Conclusions

The experimental investigations have focused on the filtration, preparation, characterization and the evaluation of chemical and physical properties of virgin and WFO's of sunflower, corn, soybean and palm oils which were collected from different sources. The biodiesel was prepared by direct blending of vegetable oil with diesel oil in nine different ratios. The performance and emission characteristics of the various blends were evaluated and compared with diesel oil in order to specify the most efficient type of vegetable oil and its best blending ratio according to ASTM limits. The experimental results of this study lead to the following conclusions:

1. Significant reduction in viscosity and density were observed by dilution of vegetable oils with diesel oil. Among the various blends, those containing up to 30% vegetable oil practically have viscosity and density values close to those of diesel oil fuel and within the required specifications. However, flash points of vegetable oils blends were higher than that of diesel oil.
2. Vegetable oils blends of sunflower, corn and soybean oils exhibit similar cloud and pour points to those of diesel oil at up to 30% ratios while those blends of palm oil above this ratio exhibit higher cloud and pour points. Higher cloud and pour points reflect unsuitability of vegetable oils as a fuel in cold climatic conditions.
3. Vegetable oil has approximately 90% of the heat of combustion of that of diesel oil, but blends with up to 30% vegetable oil were close to having heats of combustion of approximately 95% of that of diesel oil.
4. Diesel oil contains 0.985% by mass sulfur which is 20 times the ASTM limits of sulfur. However, significant reduction in sulfur and exhaust SO₂ emission was observed by dilution of diesel oil with varying proportions of vegetable oils.
5. SO₂ and NO_x exhaust emissions of 30% vegetable oil blends were lower than those of refined diesel fuel; therefore, they are actually preferable to diesel with regard to environmental pollution.
6. The results showed that the performance and emission characteristics of vegetable oil and their blends qualify them to be potentially good substitute fuel for diesel oil.

Thus blends with up to 30% vegetable oil, virgin or waste, are a promising alternative fuel to diesel. However, additional investigations should be carried out on the effects on engines of long-term usage of vegetable oil blends.

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