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Compatibility of Ethanol-Diesel Blends for Use as Engine Fuel

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Abstract:

The studies were conducted to assess the suitability and effectiveness of different surfactants in stabilizing ethanol-diesel blends and the fuel properties of formulated fuels. Sixty four micro-emulsions of different proofs of ethanol and diesel were prepared by using ethyl acetate, 1-octanol and soy biodiesel as surfactants. Eleven stable microemulsions, three from each surfactant group and two based on past review were selected for study of fuel properties like relative density, kinematic viscosity, dynamic viscosity, cloud and pour point, cold filter plugging point, flash and fire point, aniline point, diesel index, cetane number, gross heat of combustion, carbon residue, Reid vapour pressure and copper strip corrosion test. The percentage and degree proof of ethanol were found to have a greater effect on fuel properties of formulated fuels. Fuels properties of microemulsions 180^o[1:0.11:0.15] diesel: ethanol:1-octanol and 200^o[1:0.053:0.35] diesel: ethanol: biodiesel respectively replacing 20.7 and 28.75 %some formulated fuels were found close to that of diesel can be taken for engine performance to access their suitability as engine fuel.

Keywords: Biodiesel, microemulsions, ethanol proof, surfactant

1. Introduction

The world is presently facing twin crisis of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction of underground oil resources. The present energy scenario has stimulated active research interest in non-petroleum, renewable, and non-polluting fuels. The enormous growth of world population, increased economic development, and standard of living in industrial nations has led to an intricate situation in the field of energy supply and demand. World oil production is currently at about 4000 MMT (million metric tonne) and is expected to reach 5200 MMT by 2030. By 2030, India would need three to four times as much as energy as we currently use, if our economy is to grow at 8 to 9% a year. We import nearly 80% of our oil requirement which was 133 MMT in 2008-09. By 2030, we may need from 350 MMT to 500 MMT of oil a year, depending on our growth rate and the policies we follow. Our domestic production of crude is expected to be around 35 MMT. India's import of 300 MMT to 450 MMT will constitute 6 to 9% of global production, up from less than 3% today (Chaudhary, 2011).

Scientists around the world have explored several alternative energy resources, which have the potential to quench the ever-increasing energy thirst of today's population. Various biofuel energy resources explored include biomass, biogas, primary alcohols, vegetable oils, biodiesel, etc. These alternative energy resources are largely environment-friendly but they need to be evaluated on case to case basis for their advantages, disadvantages and specific applications. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties closer to conventional fuels. Among the various alternative fuel options ethanol has been singled out to be the most promising and prospective solution to the energy crisis of India because of large cellulosic biomass and sugarcane availability for its production. According to estimate, 600 MMT of agricultural waste in India can produce cellulosic ethanol equivalent to 80,000 MW of power, which is 60% of India's installed capacity and create 30 million new jobs. As CI (Compression ignition) engines play an important role in developing economics which often are dependent on agriculture, ethanol diesel blends become more relevant (Pantar and Corkwell, 2004). The efforts made by some of the leading institutions in the country have shown that there is an advantage of using ethanol-diesel blends leading to 10 % to 15 % increase in power due to improved air utilization, efficiency and lesser pollution in certain range. The ethanol-diesel emulsion referred to as W/O (water/oil) type emulsion improves combustion properties and water permissiveness. This water serves as a heat sink and lowers the combustion temperature thus leading to reduced NO_x and soot emissions. 41% reduction in particulate matter and 5% NO_x emission with 15% ethanol--diesel blends are reported (Ahmed, 2001). Net savings of 20% CO₂ emissions (46.7MMTy⁻¹ CO₂ equivalent) was achieved in Brazil due to ethanol and bagasse substitution from fossil fuel (Carvalho, 1998). Therefore, blending of ethanol even in small

quantity could give beneficial results. In view of the above, the present study was focussed on the stabilization of ethanol diesel blends (e-diesel) by different surfactants and to compare characteristic fuel properties of formulated fuels with high speed diesel (HSD) for fuel compatibility.

2. Materials and Methods

2.1. Micromulsified Fuels

Eleven microemulsified fuels were selected for study of fuel properties. Out of these eleven microemulsified fuels, nine microemulsions were selected from the preliminary experiments carried out on the temperature stability of sixty four emulsions prepared initially by using ethyl acetate, 1-octanol and soy biodiesel as surfactants (Fig 1, Fig 2 & Fig.3). The remaining two were based on past experimental studies (Fernando and Hanna, 2004) with the same proportion as suggested by them. The eleven microemulsions selected for study of fuel properties are shown in Table 1.



Figure 1: Diesel: Ethanol: EthylAcetate Microemulsions



Figure 2: Diesel: Ethanol: 1-Octanol Microemulsions



Figure 3: Diesel: Ethanol: Biodiesel Microemulsions

2.2. Fuel Properties

The fuel properties of diesel and micro emulsions of diesel: ethanol: ethyl acetate, diesel: ethanol: 1-octanol and diesel: ethanol: biodiesel were determined as per the standard procedures as follows:

2.1.1. Relative Density

The relative density of the selected fuels at 15^oC was determined as per IS: 1448 [P: 32]: 1992. The relative density was calculated as follows:

$$\text{Relative density} = \rho_f / \rho_w \quad \dots\dots\dots 2.1$$

Where,

- ρ_w = Density of water at 15°C (0.9904 g/cc)
- ρ_f = Density of fuel at 15°C, g/cc

The gravity of a fuel usually expressed in degrees API, a scale devised by the American Petroleum Institute (API), was also calculated as

$$\text{API degrees} = (141.5 / \text{Relative density of fuel at 15°C}) - 131.5 \quad \dots 2.2$$

2.1.2. Kinematic Viscosity

The kinematic viscosity of the fuels at 38°C was determined using a Redwood Viscometer No. 1 of Toshniwal make. The working of the apparatus is based on the principle of measuring the time of gravity flow in seconds of a fixed volume (50 ml) of liquid through a specified hole in an agate piece as per IP 70 / 62 issued by Institute of Petroleum, London. Kinematic viscosity in centistokes was calculated from time units by using the empirical relation as given below (Nakra & Chaudhary, 1985).

$$\nu = At - B/t \quad \dots 2.3$$

where,

- ν = Kinematic viscosity, cSt
- t = Time of efflux, s (or degrees for Engler viscometer)
- A and B are constants applicable to the type of the viscometer

2.1.3. Dynamic Viscosity

A Rotational Viscometer of EXPERT R series of Fungilab, SA make was used for measurement of dynamic viscosity of selected fuel samples. The LCP L type spindle suitable for low viscosity liquid was used for measuring the viscosity of the fuels. The dynamic viscosity (cP) was directly noted from the display of Rotational Viscometer.

2.1.4. Flash and Fire Point

The flash and fire point of the fuel samples was determined as per IS: 1448 [P: 32]: 1992 by the use of Pensky Martin Flash Point (closed) apparatus.

2.1.5. Cloud and Pour Point

Cloud and Pour point is the measure which indicates that the fuel is sufficiently fluid to be pumped or transferred. The cloud and pour point of fuel samples was determined as per IS: 1448 [P: 10]: 1970 using the Cloud and Pour point apparatus.

2.1.6. Cold Filter Plugging Point

Cold Filter Plugging Point (CFPP) is defined as the highest temperature at which the fuel when cooled under the prescribed conditions will not flow through the filter or requires more than 60 seconds for 20 ml to pass through or fails to return completely to the test jar. The CFPP of the fuel samples was determined as per: IS: 1448 [P: 110]: 1981 with Cold Filter Plugging Point Apparatus which uses a vacuum to draw a sample of the fuel through a 45 micron screen within a given time. The point at which the sample fails to go through the screen in 60 seconds is the CFPP.

2.1.7. Heat of Combustion

The gross heat of combustion of fuel samples was determined as per IS: 1448 [P: 6]: 1984 with the help of a Toshniwal Microprocessor Bomb Calorimeter.

The gross heat of combustion of the fuel samples was calculated using the equation given below:

$$H_c = W_c \Delta T / M_s \quad \dots 2.4$$

where, H_c = Heat of combustion of the fuel sample, (Cal / g); W_c = Water equivalent of the calorimeter (2283.32 Cal / °C); ΔT = Rise in temperature, (°C); M_s = Mass of sample burnt, (g)

2.1.8. Aniline Point

Aniline point (AP) is an important characteristic of petroleum fractions that indicates the degree of aromaticity of hydrocarbon mixtures. Aniline point is defined as the lowest temperature at which equal volumes of aniline and the sample become completely soluble. The aniline point of fuel samples was determined as per IS: 1448 [P: 3]: 2007 by using Aniline point apparatus.

2.1.9. Diesel Index

The diesel index is an indication of ignition quality of fuel. Higher the diesel index, better the ignition quality of fuel. The diesel index was determined by calculation from the specific gravity and aniline point of the sample as per IP 21/53 (Issued by institute of Petroleum London)

$$\text{Diesel index} = GA/100 \quad \dots (2.5)$$

Where,

- G is the API gravity
- A is the aniline point (°F)

From diesel index, Cetane number (CN) was calculated by an empirical relationship (Haldar *et.al* 2009)

$$\bullet \quad \text{CN} = 0.72 \times \text{Diesel Index} + 10 \quad \dots\dots(2.6)$$

2.1.10. Carbon Residue

Carbon residue was determined for different fuels by using a carbon residue apparatus. The measurement was made in accordance with the ASTM D189-IP 13 of Institute of Petroleum, London. This procedure determines the amount of carbon residue left after evaporation and pyrolysis of an oil.

The percentage of carbon residue on the original sample was calculated using the equation as given below:

$$\bullet \quad \text{Cr} = (\text{W}_c/\text{W}_s) \times 100 \quad \dots\dots 2.7$$

where, C_r =Carbon residue, (%); W_c = Weigh of carbon residue, (g); W_s =Weight of the sample, (g)

2.1.11. Reid Vapour Pressure

This was intended to measure the vapor pressure of microemulsified fuel samples to get inference about their volatility characteristics in comparison with the diesel. The Reid vapor pressure measurement of all the fuel samples was done in accordance with *IS 1448 [P: 39] :1967*.

2.1.12. Copper Strip Corrosion Test

The use of alternate fuels may pose a problem to the engine material especially when the fuel sample contains water or any oxygenate. Copper strip corrosion test is intended to measure the corrosiveness of copper caused by fuel sample. The corrosiveness to copper was determined as per *IS 1448 [P: 15] :2004* by using Copper corrosion testing apparatus which is based on the principle that a polished copper strip is immersed in a given quantity of sample fuel and at a standard temperature and for a time characteristic of the material being tested. At the end of this period the copper strip is removed, washed and compared with the copper strip corrosion standards.

3. Results and Discussion

The results regarding the fuel properties of formulated fuels are presented in Table 2. The main results observed are presented as below:

3.1. Relative Density

The microemulsions having lower proof of ethanol were found to have higher relative density due to higher water content in the proof. The relative density was also found to change inversely with the percentage of ethanol in the blend. The relative density of microemulsions prepared by using either ethyl acetate or biodiesel as surfactant was slightly higher than that of diesel which is because of the reason of higher density of ethylacetate and biodiesel as compared to diesel. In general the density of all the fuel types was found to vary from -0.89 to +2.41 percent different than diesel. The observations on API gravity show that microemulsions containing higher proofs of ethanol have higher API gravity compared to the microemulsions prepared from ethanol of lower proofs. The API gravity of all the selected fuel types was found to vary from -10.29 to +3.4 in comparison to diesel.

3.2. Kinematic Viscosity

The Kinematic viscosity of 180⁰ [1:0.25:1.54] diesel: ethanol: biodiesel microemulsion was found to higher than that of diesel. This is mainly because of the reason of presence of large percentage of biodiesel which has higher density than that of diesel. The kinematic viscosity of 180⁰[1:0.11:0.15] diesel: ethanol: 1-octanol and 190⁰[1:0.11:0.62] diesel: ethanol: biodiesel microemulsions was found only 2.4 percent lesser than that of diesel. The observed values reveal that kinematic viscosity of all the microemulsions except 180⁰ [1:0.25:1.54] diesel: ethanol: biodiesel microemulsion was lesser by 2.4 to 38.4 percent than that of diesel.

3.3. Dynamic Viscosity

In general it was found that as the percentage of ethanol in blend increases, the dynamic viscosity decreases. This is because of low viscosity of ethanol as compared to diesel. The dynamic viscosity of diesel: ethanol: biodiesel microemulsions was found 5.9 to 22.7 percent higher than that of diesel because of the reason of greater density and viscosity of biodiesel as compared to petrodiesel.

3.4. Flash and Fire point

The flash point of 190⁰[1:0.25:0.45] and 185⁰[1:0.11:0.33] diesel: ethanol: ethylacetate microemulsions was low because of the presence of ethyl acetate in higher quantity which significantly leads to reduction of flash and fire point. Among all the selected fuel types, the flash and fire point of 200⁰[1:0.053:0.01] diesel: ethanol: 1-octanol microemulsion was found higher because of the reason of lowest diesel replacement and higher flash point of 1-octanol. The flash and fire point of all the microemulsions was found less as compared to diesel due to low flash and fire point of various ethanol proofs.

3.5. Cloud and Pour Point

The cloud point was found to increase slightly with ethanol concentration which is in accordance with previous results (Jimenez *et.al*, 2011) The pour point was found to decrease with ethanol concentration and increase with biodiesel concentration confirming the

findings of Kwanchareon *et al.*(2005). The reason is that ethanol has a very low pour point and biodiesel normally has a pour point higher than conventional diesel. But all of the blends had diesel as a major component, and therefore, the pour points of the fuel blends were found to be not much different from conventional diesel.

3.6. Cold Filter Plugging Point

The cold filter plugging point of different fuel types revealed that fuel types prepared with biodiesel were having low CPFF than other fuel types. This is because of the reason that as the temperature decreases saturated fatty acid methyl esters (FAME) within biodiesel solidify and form crystals that plug or restrict flow through fuel lines and filters. From the data, it was also observed that increase in ethanol percentage leads to improvement in the cold weather property of fuel.

3.7. Heat of Combustion

It was observed that the microemulsions of anhydrous ethanol have gross heat of combustion close to the diesel fuel. The gross heat of combustion of microemulsions was found to be lesser than diesel by amount varying from 2.07 to 11.7 percent. Further, the observed values indicate that as the proof level of ethanol in the microemulsions decrease, there was a decrease in the gross heat of combustion. The trend is in confirmation with the findings of Maurya, 2004.

3.8. Aniline Point, Diesel Index and Cetane Number (CN)

It was found that as the percentage of ethanol increases, the diesel index decreases which is because of the reason of lower cetane rating of ethanol. The cetane number of 200⁰[1:0.053:0.01] diesel: ethanol: ethylacetate and 200⁰[1:0.053:0.0052] diesel: ethanol:1-octanol emulsions was found very close to that of diesel. This is because of the reason of very less diesel replacement in these two fuel types.

3.9. Carbon Residue

The carbon residue of all the selected fuels except 180⁰[1:0.25:1.54], 200⁰[1:0.053:0.35] and 200⁰[1:0.053:0.26] diesel: ethanol: biodiesel microemulsions was less as compared to baseline fuel. The carbon residue of diesel: ethanol: ethylacetate microemulsions was found 12.63 to 42.11 percent lesser than diesel while the carbon residue for diesel: ethanol: 1-octanol emulsions was found 10.53 to 63.16 percent lesser than that of diesel. The carbon residue of 200⁰[1:0.053:0.26] diesel: ethanol: biodiesel microemulsions was found 13.7% higher than diesel. This was probably because of higher carbon residue content of biodiesel as compared to diesel.

3.10. Reid Vapour Pressure

The vapour pressure of ethyl acetate emulsified ethanol-diesel blends was found higher among the three surfactant groups. This was because of the reason of higher volatility and lower boiling point of ethyl acetate. The vapour pressure of all the microemulsified fuels was higher than that of diesel because of the presence of ethanol.

3.11. Copper Strip Corrosion Test

The corrosion level of all the fuels was within the ASTM limit which has set the maximum limit of 3a. The 1b level of corrosion representing slightly tarnish nature, observed in 180⁰[1:0.11:0.15], 175⁰[1:0.25:0.27] diesel: ethanol:1-octanol emulsions and 180⁰[1:0.25:1.54] diesel: ethanol: biodiesel microemulsion was because of the reason of greater percentage of ethanol and lower proof of ethanol present in them. In case of 180⁰[1:0.25:1.54] diesel: ethanol: biodiesel microemulsion presence of greater amount of biodiesel may also be the contributing factor.

4. Conclusions

- The fuel properties of formulated fuels were found to be greatly affected by the percentage and degree proof of ethanol.
- The fuel properties of microemulsified fuels 180⁰[1:0.11:0.15] diesel: ethanol:1-octanol and 200⁰[1:0.053:0.35] diesel: ethanol: biodiesel respectively replacing 20.7 and 28.75 % diesel were found close to that of Diesel.
- These microemulsified fuels can be evaluated further for engine performance to access their compatibility for being use as engine fuel in the existing CI engine

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ANNEXURE

Blend	Fuel type(v/v)	Diesel replacement (%)
Diesel: Ethanol: Ethyl Acetate Microemulsions	200 ⁰ [1:0.053:0.01]	5.94
	190 ⁰ [1:0.25:0.45]	41.18
	185 ⁰ [1:0.11:0.33]	30.77
Diesel: Ethanol: 1-Octanol Microemulsions	200 ⁰ [1:0.053:0.0052]	5.47
	180 ⁰ [1:0.11:0.15]	20.70
	175 ⁰ [1:0.25:0.27]	34.43
Diesel: Ethanol: Biodiesel Microemulsions	200 ⁰ [1:0.053:0.14]	21.81
	190 ⁰ [1:0.11:0.62]	42.86
	180 ⁰ [1:0.25:1.54]	64.21
Diesel: Ethanol: Biodiesel Microemulsions (Review Based)	200 ⁰ [1:0.053:0.35]	28.75
	200 ⁰ [1:0.053:0.26]	24

Table 1: Microemulsified Fuels Selected For Comparison of Fuel Properties

S.No	Fuel Types	Relative density	API Gravity	Kinematic Viscosity (cSt)	Dynamic Viscosity (cp)	Flash Point (°C)	Fire Point (°C)	Cloud Point (°C)	Pour Point (°C)	Cold filter plugging point (°C)	Gross heat of combustion (MJ/kg)	Aniline point (°C)	Diesel Index	Cetane Number	Carbon residue (%)	Reid vapour pressure (kPa)	Corrosion level
1	Diesel	0.8302	38.94	3.28	2.55	60	64	-1	-6	-5	50.02	75.0	65.03	56.82	0.19	0.6	1a
Diesel: Ethanol: Ethyl Acetate Microemulsions																	
2	200 ⁰ [1:0.053:0.01]	0.8242	40.18	3.07	2.39	38	42	2	-4	-11	47.18	69.0	62.76	55.19	0.17	4.31	1a
3	190 ⁰ [1:0.25:0.45]	0.8349	37.98	2.02	1.42	21	24	1	-5	-10	46.79	55.0	49.76	45.82	0.13	3.01	1a
4	185 ⁰ [1:0.11:0.33]	0.8363	37.70	2.07	1.37	19	23	-1	-4	-13	45.86	58.0	51.42	47.02	0.11	2.12	1a
Diesel: Ethanol: 1-Octanol Microemulsions																	
5	200 ⁰ [1:0.053:0.0052]	0.8228	40.47	3.06	2.51	48	52	-2	-7	-11	47.60	69.0	63.22	55.52	0.17	2.17	1a
6	180 ⁰ [1:0.11:0.15]	0.8241	40.20	3.2	2.36	34.5	39	2	-4	-10	46.19	59.0	55.56	50.00	0.13	2.80	1b
7	175 ⁰ [1:0.25:0.27]	0.8235	40.33	2.97	2.22	33	37	1	-3	-8	44.17	53.0	51.38	46.99	0.07	2.58	1b
Diesel: Ethanol: Biodiesel Microemulsions																	
8	200 ⁰ [1:0.053:0.14]	0.8349	37.98	3.07	2.7	32	37	2	-3	-6	47.29	60.11	53.25	48.34	0.19	2.10	1a
9	190 ⁰ [1:0.11:0.62]	0.8416	36.63	3.2	2.87	31.5	35	-1	-4	-5	47.17	54.61	47.73	44.37	0.15	1.96	1a
10	180 ⁰ [1:0.25:1.54]	0.8502	34.93	3.48	3.13	29.5	34	1	-4	-5	46.62	57.88	47.58	44.26	0.21	1.93	1b
Diesel: Ethanol: Biodiesel Microemulsions (Review based)																	
11	200 ⁰ [1:0.053:0.35]	0.8401	36.93	3.05	2.74	36.5	40.5	1	-4	-3	48.09	51.0	45.72	42.92	0.22	2.08	1a
12	200 ⁰ [1:0.053:0.26]	0.8382	37.31	3.04	2.7	35.5	40	2	-5	-4	49.00	54.0	48.21	44.71	0.20	2.12	1a

Table 2: Characteristic Fuel Properties of Formulated Fuels