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Fuel Properties of Some Stable Alcohol–Diesel Microemulsions for Their Use in Compression Ignition Engines

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This experimental study was carried out to determine the feasibility of utilization of alcohol–diesel microemulsions as diesel fuel in compression ignition (CI) engines. The fuel properties of 12 ethanol–ethyl acetate–diesel microemulsions designated as 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, 190°-20/29/51, 180°-10/35/55, 180°-15/39/46, 180°-20/40/40, 170°-10/43/47, 170°-15/45/40, and 170°-20/50/30 have been determined in accordance with the Bureau of Indian Standards (BIS) and Institute of Petroleum (IP). When compared to diesel, the microemulsion prepared from 200° and 190° proof ethanol were found to have relative density variations from −0.78% to 0.87% and kinematic viscosity and gross heat of combustion variations from 9.8% to 17.7% lower and 2.5% to 21.5% lower than that of the diesel. The flash points, fire points, and pour points of the microemulsions were found in the range of 8.3 to 16.7 °C, 11.5 to 20.5 °C, and 6.7 to –2.3 °C, respectively. The performance of a 3.73 kW diesel engine on microemulsion fuels of 200° and 190° proof ethanol with respect to brake power, brake specific fuel consumption, brake thermal efficiency, and emission of CO, UBHC, and NO_x revealed that these fuels have almost similar power-producing capability with reduced exhaust emission. Thus, the stable microemulsions of 200° and 190° proof ethanol were found to be compatible with the diesel and can be used as an alternative to diesel in CI engines. The use of the above microemulsions replaced 19–49% of the diesel in low brake horse power (bhp) constant speed CI engines.

Introduction

In view of the present energy crisis resulting from reduced availability, nonstop increase in global prices of petroleum fuels, and stiff global regulations for environmental ambient air quality, various alternate fuels are being explored across the world. The use of biodiesel, blends of various vegetable oils with diesel, blends of alcohol with diesel, and its microemulsions are some options that are already being tried out. The fuels of bio origin like ethanol blended with diesel can reduce the thrust over underground-based carbon resources. Among various biofuels, ethanol is an attractive alternative because it is a renewable bio-based resource and oxygenated, thereby providing the potential to reduce particulate emissions in compression ignition engines.[1] Ethanol can be utilized in CI engines by the technique of fumigation in which modification of the existing engine is compulsory. Another method of using ethanol in diesel engines is to modify the fuel instead of modifying the engine, which can be done by simple blending of ethanol with diesel fuel. In this technique, the amount of diesel substitution is dependent on the concentration of ethanol. However, earlier studies have shown that the maximum possible substitution of diesel with ethanol is around 15% under a wide range of engine operatibility (particularly at low-temperature conditions). The amount of diesel replacement in the form of blend is limited with the occurrence of phase separation (immiscibility of ethanol with diesel) in the blend. To overcome the problem of phase separation while preparing the blended fuel by using lower proof of ethanol or higher amount of diesel substitution, microemulsification is the best technique, as it increases water tolerance capacity of the blend. The amount of diesel substitution can be increased to a great extent by the preparation of alcohol–diesel microemulsion using suitable emulsifier. 15% anhydrous ethanol and 85% diesel fuel blends on volume basis have the problem of phase separation when the ambient temperature is down to 0 °C. However, to avoid such a phase separation, 3% ethyl acetate is recommended.[2] The amount of emulsifier mixed in diesel–alcohol blend depends on solvent ability of emulsifier and the amount of water present in ethanol used for the preparation of microemulsion. Commercially available ethanol of 180°–160° proofs (10–20% water content) cannot be blended directly in diesel due to their distinct phase separation from diesel. The engine adjusted to ignite such fuel will produce less power, if ethanol separates from diesel.[3] Microemulsions of diesel–alcohol can be formed by using surfactants like ethyl acetate, 1-butanol, etc. Stable microemulsions formed by using appropriate surfactants such as ethyl acetate and 1-butanol reduces sufficiently the interfacial tension between the dispersed and continuous phase in a blend using aqueous ethanol and

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Table 1. Stable Selected Alcohol–Diesel Microemulsions

Sl no.	microemulsion type	ethanol proof (deg)	water content (%)	ethanol (%)	ethyl acetate (%)	diesel (%)	diesel replacement (%)
1	200°-10/9/81			10.00	9.00	81.00	19.00
2	200°-15/9.5/75.5	200	nil	15.00	9.50	75.50	24.50
3	200°-20/10/70			20.00	10.00	70.00	30.00
4	190°-10/22/68			10.00	22.00	68.00	32.00
5	190°-15/25/60	190	5	15.00	25.00	60.00	40.00
6	190°-20/29/51			20.00	29.00	51.00	49.00
7	180°-10/35/55			10.00	35.00	55.00	45.00
8	180°-15/39/46	180	10	15.00	39.00	46.00	54.00
9	180°-20/40/40			20.00	40.00	40.00	60.00
10	170°-10/43/47			10.00	43.00	47.00	53.00
11	170°-15/45/40	170	15	15.00	45.00	40.00	60.00
12	170°-20/50/30			20.00	50.00	30.00	70.00

increases the miscibility of blend (without phase separation).[4,5] Microemulsions of ethanol with diesel made using surfactants are well accepted practice in Sweden. Ethanol with ignition improvers is an established bus fuel in Sweden.[6]

In order to increase substitution of diesel by ethanol, it is very essential to find out a stable microemulsion. In view of the above facts, the present experimental study has been carried out to determine the suitability of alcohol–diesel microemulsions prepared using 200°, 190°, 180°, and 170° proof ethanol and ethyl acetate surfactant. The stable microemulsions are prepared using different proof of ethanol characterized as 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, 190°-20/29/51, 180°-10/35/55, 180°-15/39/46, 180°-20/40/40, 170°-10/43/47, 170°-15/45/40, and 170°-20/50/30 (v/v) by addition of ethanol–ethyl acetate–diesel, respectively, as shown in Table 1. In order to determine the compatibility of the above microemulsions with diesel, their relative density, kinematic viscosity, gross heat of combustion, flash point, cloud point, and pour point have been compared with that of diesel.

Experimental Description

Initially blends of ethanol (different proofs) with diesel were prepared by splash blending. These blends were kept at room temperature (20–25 °C) for 24 h. After 24 h these microemulsions were checked against possible phase separation. In case of phase separation, the minimum amount of ethyl acetate emulsifier was added further in order to form miscible emulsion. The above procedure was repeated until a stable microemulsion formed at room temperature. These microemulsions were then tested for their stability against phase separation under varying range of temperature from 5 to 45 °C. The relative density at 15 °C was determined using a 50 mL pycnometer.[7] A Redwood viscometer No. 1 was used for the measurement of kinematic viscosity at 38 °C. The gross heat of combustion was determined using an isothermal bomb calorimeter.[8] A closed cup Pensky Martens flash and fire point apparatus was used to measure the flash and fire points of the fuels. The cloud and pour points were determined using the cloud and pour point apparatus.[9]

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Table 2. Observations on Stability of Ethanol–Ethyl Acetate–Diesel Microemulsions at Different Temperature

		temperature[a] (°C)					
Sl no.	microemulsion type	5	10	15	25	35	45
1	200°-10/9/81	S	S	S	S	S	S
2	200°-15/9.5/75.5	S	S	S	S	S	S
3	200°-20/10/70	S	S	S	S	S	S
4	190°-10/22/68	US	S	S	S	S	S
5	190°-15/25/60	S	S	S	S	S	S
6	190°-20/29/51	S	S	S	S	S	S
7	180°-10/35/55	S	S	S	S	S	S
8	180°-15/39/46	S	S	S	S	S	S
9	180°-20/40/40	US	S	S	S	S	S
10	170°-10/43/47	S	S	S	S	S	S
11	170°-15/45/40	US	US	S	S	S	S
12	170°-20/50/30	S	S	S	S	S	S

[a] Note: S represents stable at the temperature and US represents unstable at the temperature.

In order to compare the performance of compatible microemulsions, these were tested on 3.73 kW CI engine (rated power at rated engine speed of 1500 rpm). The brake power, fuel consumption, brake specific fuel consumption, brake thermal efficiency, emissions of carbon monoxide, unburnt hydrocarbon, and nitrogen oxides of these microemulsions were compared with that of diesel fuel. The tests were performed in accordance with BIS specification of diesel engine testing.[10] The above experiments were conducted three times, and the mean value of each is reported.

Results and Discussion

The microemulsions that were prepared by using anhydrous ethanol and ethanol of 190°, 180°, and 170° proof were kept at 5, 10, 15, 25, 35, and 45 °C for 24 h to observe the possible phase separation occurring between diesel and ethanol. The stability of microemulsions was analyzed by visual observation. When the microemulsion became unstable, it showed a clear phase separation of alcohol and diesel in two layers. The stability of microemulsions at different temperatures is shown in Table 2. It is evident from the table that most of the prepared microemulsions were stable at 5–45 °C. The microemulsions designated as 190°-10/22/68 and 180°-20/40/40 were found unstable at 5 °C. However, it was observed that they became stable above 5 °C. Similarly, the microemulsion designated as 170°-15/45/40 was found unstable up to 10 °C. The rest of the microemulsions were found to be at 5–45 °C. At low temperatures of 5 °C the stability of microemulsions made from anhydrous ethanol was found to be better than that of aqueous ethanol microemulsions. It is also evident that in order to have

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Table 3. Observed Fuel Properties of Prepared and Selected Alcohol–Diesel Microemulsions

fuel types	fuel properties							
	relative density	API gravity	kinematic viscosity (Redwood seconds)	gross heat of combustion (MJ/kg)	flash point (°C)	fire point (°C)	cloud point (°C)	pour point (°C)
diesel	0.8444	36.8	33.4	46.85	60.0	66.7	1.5	−7.5
ethyl acetate	0.9060	24.6	24.9	23.47	−0.5	5.0		
ethanol proofs								
ethanol 200°	0.7920	47.1	27.6	30.73	16.7	21.5		
ethanol 190°	0.8110	42.9	27.9	29.33	18.2	23.8		
ethanol 180°	0.8260	39.7	27.9	26.51	20.2	25.3		
ethanol 170°	0.8420	36.6	28.2	26.11	20.8	26.7		
ethanol–ethyl acetate–diesel microemulsions								
200° −10/9/81	0.8430	36.3	30.1	45.70	14.7	20.5	−2.3	
200° −15/9.5/75.50	0.8400	36.9	29.5	43.05	15.0	20.3	−2.8	
200° −20/10/70	0.8370	37.6	29.3	42.24	15.0	19.7	−4.0	
190° −10/22/68	0.8500	35.0	28.1	41.84	14.2	19.5	−2.2	−5.3
190° −15/25/60	0.8510	34.7	27.9	38.93	13.9	19.8	−1.2	−5.3
190° −20/29/51	0.8510	34.7	27.5	36.80	12.8	19.3	−0.7	−4.7
180° −10/35/55	0.8600	33.0	27.4	37.62	12.3	17.0	0.0	−5.8
180° −15/39/46	0.8610	32.8	27.3	35.99	11.5	16.3	1.0	−0.6
180° −20/40/40	0.8620	32.7	26.8	33.51	11.0	15.5	1.4	−3.2
170° −10/43/47	0.8660	31.9	26.7	34.73	9.5	14.2	3.2	−2.0
170° −15/45/40	0.8670	31.6	26.0	32.88	8.2	12.5	4.0	−0.8
170° −20/50/30	0.8700	31.1	25.9	30.47	8.3	11.5	6.7	−0.2

stable microemulsions with higher percentage of aqueous ethanol a higher proportion of ethyl acetate needs to be mixed in the microemulsion.

The relative density and API gravity of the diesel, ethyl acetate, different proofs of ethanol, and various ethanol–ethyl acetate–diesel microemulsions at 15 °C are shown in Table 3. The relative density of the diesel was found to be 0.8444. The relative density of diesel which was compared to BIS diesel specification lies in the range 0.82–0.86. The reported values of relative density of diesel are in the range 0.830–0.840.[11,12] The relative density of ethyl acetate surfactant was found as 0.906. The relative density of 200°, 190°, 180°, and 170° proof ethanol was found as 0.792, 0.811, 0.826, and 0.842, respectively. The relative density of 200° and 180° proof ethanol were reported as 0.780 and 0.810, respectively.[13] Our results have been corroborated by the results of similar reported studies. The relative density of 12 microemulsions, viz. 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, 190°-20/29/51, 180°-10/35/55, 180°-15/39/46, 180°-20/40/40, 170°-10/43/47, 170°-15/45/40, and 170°-20/50/30 were found to be 0.843, 0.840, 0.837, 0.850, 0.851, 0.851, 0.860, 0.861, 0.862, 0.866, 0.867, and 0.870, respectively.[13] It is evident from the above results that the microemulsions having lower proof of ethanol had higher relative density. This is due to the presence of more water in the proof as well as higher content of ethyl acetate in them. Table 3 also shows the API gravity of diesel as 36.7 as well as API gravity of microemulsions designated as 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, and 190°-20/29/51 as 36.6, 37.0, 37.6, 35.0, 31, and 31, respectively. The above observations indicate that API gravity of microemulsions prepared using 200° and 190° proof ethanol are close to that of diesel. Statistical analysis of experimental data is found significant at an alpha of 0.05 (1.2×10^{-27} is less than 0.05).

The kinematic viscosity of diesel, ethyl acetate, different proofs of ethanol, and 12 microemulsions in terms of Redwood seconds measured at 38 °C are shown in Table 3. It was observed that the kinematic viscosity of diesel was 33.4 Redwood seconds. At 38 °C it lies in between 30.5 to 41.0 Redwood seconds.[14] The kinematic viscosity of ethyl acetate was observed as 24.9 Redwood seconds and that of 200°, 190°, 180°, and 170° proof ethanol as 27.6, 27.9, 27.9, and 28.2 Redwood seconds, respectively. The kinematic viscosity of selected microemulsions, i.e., 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, 190°-20/29/51, 180°-10/35/55, 180°-15/39/46, 180°-20/40/40, 170°-10/43/47, 170°-15/45/40, and 170°-20/50/30, was observed as 30.1, 29.5, 29.3, 28.1, 27.9, 27.5, 27.4, 27.3, 26.8, 26.8, 26.1, and 26.0 Redwood seconds, respectively.[15] The observed values of kinematic viscosity of microemulsions match closely with that of diesel (variation ranges from −10 to −22.3% from that of the diesel). The alpha value of the above parameter as found from statistical analysis is (3.25×10^{-29} is less than 0.05).

The gross heat of combustion of diesel, ethyl acetate, different ethanol proofs, and 12 microemulsions are shown in Table 3. The gross heat of combustion of the diesel is found to be 46.85 MJ/kg. As reported before, the gross heat of combustion of diesel is 44.96, 43.64, and 45.12 MJ/kg.[6,16,17] The gross heat of combustion of ethyl acetate was observed as 23.47 MJ/kg and that of 200°, 190°, 180°, and 170° proof ethanol as 30.73, 29.33, 26.51, and 26.11 MJ/kg, respectively. The reported values of 200°, 180°, and 170° proof ethanol are 31.15, 30.29, and 26.96 MJ/kg, respectively.[6] Similarly, the gross heats of combustion of 200° and 180° proof ethanol are 31.53 and 28.63 MJ/kg, respectively.[13] The observed gross heat of combustion of 12 microemulsions, i.e., 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, 190°-20/29/51, 180°-10/35/55, 180°-15/39/46, 180°-20/40/40, 170°-10/43/47, 170°-15/

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Table 4. Engine Performance and Emission Results of 3.73 kW Kirloskar AV1 Diesel Engine on Diesel and Selected Microemulsions at 100% Load Condition

	fuel type						
		alcohol–diesel microemulsion					
parameter	diesel	200°-10/9/81	200°-15/9.5/75.5	200°-20/10/70	190°-10/22/68	190°-15/25/60	190°-20/29/51
brake power, kW	3.73	3.82	3.75	3.76	3.74	3.76	3.75
fuel consumption, L/h	1.336	1.564	1.510	1.532	1.491	1.359	1.533
specific fuel consumption, kg/(kW h)	0.302	0.345	0.338	0.341	0.339	0.308	0.348
brake thermal efficiency, %	25.4	22.8	24.7	25.0	25.4	30.1	28.1
CO emission, %	0.72	0.48	0.40	0.59	0.55	0.71	0.47
HC emission, %	0.03	0.05	0.02	0.04	0.03	0.05	0.03
NO_x emission, ppm	203.5	195.8	179.8	216.1	183.1	206.4	154.2

45/40, and 170°-20/50/30, are 45.70, 43.05, 42.24, 41.84, 38.93, 36.80, 37.62, 36.00, 33.51, 31.3, 32.88, and 30.47 MJ/kg, respectively. It was observed that the microemulsions of anhydrous ethanol have gross heat of combustion close to that of diesel fuel. The gross heat of combustion of microemulsions having 200° proof ethanol, i.e., 200°-10/9/81, 200°-15/9.5/75.5, and 200°-20/10/70, were found to be 2.5, 8.1, and 9.9% less than that of diesel.[15] Table 3 also shows that the microemulsions having aqueous ethanol of 190°, 180°, and 170° proof have their gross heat of combustion in the range of 10.7–21.4%, 19.7–28.5%, and 25.9–35.0% lower than that of diesel. The observed values of gross heat of combustion indicated that with decrease in proof of ethanol in microemulsions the gross heat of combustion also decreased. This effect was produced due to very low gross heat of combustion of ethyl acetate (50% less than that of diesel) and the presence of higher water content in ethanol. The values were found significant at alpha of 0.05 (1.24×10^{-14} is less than 0.05).

The flash and fire point of the diesel, ethyl acetate, different proofs of ethanol, and selected microemulsions are shown in Table 3. The flash and fire point of diesel fuel were found as 60 and 67.7 °C, respectively. The flash point of diesel is reported as 80 and 51.7 °C, respectively.[12,18] The flash and fire point of ethyl acetate as observed in our experiments were −0.5 and 5 °C, respectively. The flash point of 200°, 190°, 180°, and 170° proof ethanol were observed as 16.7, 18.2, 20.2, and 20.8 °C, respectively, and fire point of the above proofs of ethanol were noted as 21.5, 23.8, 25.3, and 26.7 °C, respectively. Ethanol with 200°, 190°, 180°, and 170° had flash points of 12.2, 13.5, 15.2, and 16.2 °C and fire points of 18.5, 19.3, 23.5, and 25.5 °C, respectively.[19] The flash point of 12 microemulsions 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, 190°-20/29/51, 180°-10/35/55, 180°-15/39/46, 180°-20/40/40, 170°-10/43/47, 170°-15/45/40, and 170°-20/50/30 were found as 11.0, 15.0, 15.0, 11.0, 14.0, 12.8, 12.3, 11.5, 11.0, 9.5, 8.2, and 8.3 °C, respectively. The fire points of above microemulsions were observed as 20.5, 20.3, 19.7, 19.5, 19.8, 19.3, 17.0, 16.3, 15.5, 11.0, 12.5, and 11.5 °C, respectively. The above drop in flash and fire point of microemulsions may be attributed to the low flash and fire point of the ethyl acetate. There exists an appreciable difference between the flash point and fire point of microemulsions and diesel, even though these microemulsion fuels did not produce any accidental problem, while being tested in the CI engine.[20] However, it is recommended that a precautionary care may be necessary while handling these microemulsion fuels at high ambient temperature conditions.

The observed cloud and pour point of diesel, ethyl acetate, different proofs of ethanol, and microemulsions are shown in Table 3. The cloud and pour point of diesel were observed as 1.5 and −7.5 °C, while the reported values were 13.9 and −23 °C.[18] The cloud and pour point of ethyl acetate and 200°, 190°, 180°, and 170° proof ethanol were not observed even after reducing the temperature up to −10 °C. In the case of microemulsions 200°-10/9/81, 200°-15/9.5/75.5, 200°-20/10/70, 190°-10/22/68, 190°-15/25/60, 190°-20/29/51, 180°-10/35/55, 180°-15/39/46, 180°-20/40/40, 170°-10/43/47, 170°-15/45/40, and 170°-20/50/30, the values observed were −2.3, −2.8, −4.0, −2.2, −1.2, −0.7, 0.0, 1.0, 1.4, 3.2, 1.0, and 6.7 °C, respectively. The pour points of microemulsions prepared from 200° proof ethanol were not found until the temperature of −7 °C. The pour points of microemulsions having 190°, 180°, and 170° proof ethanol were noted as −5.3, −5.5, −1, −5.8, −0.6, −0.3, −2, −0.8, and −0.2 °C, respectively.[15] The observed values of cloud and pour point indicate that these values decrease sharply as the proof of ethanol is lowered in the microemulsions.

Table 4 shows the results of engine performance and exhaust emission characteristics of microemulsion fuels prepared using 200° and 190° proof ethanol. The engine developed marginally higher brake power at full load conditions than diesel. Microemulsions of 200° proof ethanol developed 0.5–2.4% increased power. However, the microemulsions of 190° proof ethanol developed 0.3–0.8% increased power when compared to diesel fuel. It has been previously reported that the blend of 15% anhydrous ethanol and 85% diesel has the effect of reducing engine power by 3–5% at maximum power, at low level of loads, but this reduction in power is less pronounced at high level of loads. The major cause of power drop was the reduced heating value of ethanol.[2] The fuel consumption of the engine gradually increases as diesel replacement increases. This may be due to reason that the heating values of microemulsions were 2.5–21.5% less than diesel. A similar trend on BSFC of the engine on various microemulsions was observed. Statistical analysis of power output experimental data is found significant at alpha of 0.05 (1.23×10^{-5} is less than 0.05), and for fuel consumption the value of calculated probability is 7.91×10^{-7}.

Brake thermal efficiency of the engine on 200° proof microemulsions ranged from 22.8% to 25.0% as against 25.4% on diesel at full engine load. However, the brake thermal efficiency on 190° proof ethanol microemulsion at 100% load

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condition ranged from 25.4% to 30.1%, which was marginally higher than diesel. The alcohol-fueled engine had 2–3% higher effective thermal efficiency than diesel fuel in moderate and high load zones.[21] Statistical analysis of experimental data is found significant at an alpha of 0.05 (7.78×10^{-10} is less than 0.05).

Carbon monoxide (CO) emissions on 200° proof ethanol microemulsions were found to decrease by 18–44% at full engine load. However, the decrease in CO on 190° proof ethanol microemulsions was found to decrease in the range 1.4–34.7% than in contrast to diesel fuel. The lowest emission of CO (0.40%) from the engine was observed when engine developed its rated power (3.73 kW) on 200°-15/9.5/75.5 microemulsion. The result further indicates that the emission of CO on microemulsion was lower when compared to diesel at full engine load. Similarly, the researchers also concluded that a fuel containing alcohol when burnt in a CI engine emits lesser amount of CO due to higher air–fuel ratio.[22] Alcohols have higher octane number than gasoline. A fuel with a higher octane number can endure higher compression ratios before engine starts knocking, thus giving engine an ability to deliver more power efficiently and economically. Alcohol burns cleaner than regular gasoline and produces lesser carbon monoxide, HC, and oxides of nitrogen.[23] Statistical analysis of experimental data is found significant at an alpha of 0.05 (1.92×10^{-7} is less than 0.05).

It was also observed that the emission of unburnt hydrocarbons (UBHC) was in a comparable range to that of diesel. The marginally higher emission of UBHC, particularly with the microemulsions prepared using 190° proof ethanol, may be due to slow vaporization and fuel–air mixing.[22] More complete combustion takes place with the alcohol–diesel blend than with the diesel. A reduction of 10% in soot emissions has been reported when the diesel engine was operated on 15% blend of ethanol.[2] Statistical analysis of experimental data is insignificant at alpha of 0.05 (0.17 is less than 0.05) for UBHC values.

Nitrogen oxides (NO_x) emission on microemulsion fuel prepared from 200° proof ethanol ranged from +6.2% to −11.6%. However, on 190° proof ethanol it varied from +1.4% to −24.2%. This showed a significant reduction of NOx on prepared microemulsion than diesel. This is due to the fact that alcohol has higher heat of vaporization; therefore, it reduces the peak temperature inside the combustion chamber, leading to lower NOx emissions and increased engine power.[23] Statistical analysis of experimental data is found significant at an alpha of 0.05 (3.5×10^{-7} is less than 0.05).

Conclusions

The selected alcohol–diesel microemulsions prepared from anhydrous and aqueous ethanol were found stable under a wide range of temperatures varying from 5 to 45 °C. Based on the observed fuel properties of microemulsions such as relative density, kinematic viscosity, heating value, and cloud and pour point, the use of 200° and 190° proof ethanol is recommended for preparation of ethanol–diesel microemulsions by using ethyl acetate as surfactant. These microemulsion fuels can supplement 19–49% diesel fuel in CI engine without any observed problem. The performance of the engine with respect to brake power, brake specific fuel consumption, brake thermal efficiency, and emission of CO, UBHC, and NO_x revealed that all microemulsions fuel can be used in a compression ignition engine during periods of lean supply of diesel.

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