Making of Biodiesel from Castor Oil and Performance Test of a Diesel Engine with Neat Diesel Fuel and Diesel-Biodiesel Blends

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ABSTRACT

The diesel engine exhausts are of many types and of them oxides of nitrogen (NOx), particulate matter (PM), total unburnt hydrocarbon (THC) is responsible for atmospheric pollution. Many research and development works have been done in recent year for the reduction of diesel engine emissions. In the present investigation fuel combustion and exhaust emissions with neat diesel fuel and diesel-biodiesel blends have been investigated. In this investigation, the making of biodiesel from non-edible castor oil has been done firstly by esterification. Biodiesel fuel (BDF) is chemically known as a mono-alkyl fatty acid ester. It is renewable in nature and is derived from plant oils including vegetable oils. BDF is non-toxic, biodegradable, and essentially free from sulfur and carcinogenic benzene. In the second phase of this investigation, experiment has been conducted with neat diesel fuel and diesel-biodiesel blends in a four stroke naturally aspirated (NA) direct injection (DI) diesel engine. However, compared with neat diesel fuel, diesel-biodiesel blends showed lower carbon monoxide (CO), and smoke emissions but higher NOx emission. Compared with conventional diesel fuel, NOx emission with diesel-biodiesel blends was slightly reduced when EGR was applied.

1. INTRODUCTION

As world’s petroleum supplies become constrained, attention has been directed to find out alternative sources of fuels for engines. The non-renewable nature and limited resources of petroleum fuels have become a matter of great concern. After the 1973 oil embargo, it had been very important to study the alternative sources of fuel for diesels because of the concern over the availability and the price of petroleum based fuels. The present source of fuels used in internal combustion (IC) engines including diesel will deplete within 40 years if consumed at an increasing rate estimated to be of the order of 3% per annum. All these aspects have drawn the attention to conserve and stretch the oil reserves by way of alternative fuel research.

In Bangladesh, diesel fuel is primarily used for transportation, agriculture and electric power generation. Despite, Bangladesh’s rapidly growing industries, it still has a very low per capita energy consumption of 245 kg of oil equivalent per year, as compared to 7200 kg for USA and 670 kg for China. As energy and economy are closely linked, it is realized that a growing economy will demand a much higher level of energy consumption.

Crops, which produce oil directly, are one among such sources. Of these oils, castor is the highest yielding oil producer. Commonly the processing of the castor fruit to extract the oil is done in plants, which use process residue to meet all plant fuel requirements. Because of these energy economics, the fossil fuel consumption to operate the entire castor oil production system is less than 10% of the energy contained in the castor oil produced.

Castor and neem oils are renewable sources of energy and they are growing abundantly in India and Bangladesh. Castor and neem oils are non-toxic. Castor Oil is regarded as one of the most valuable laxatives in medicine. Inspite of medical use, the esters of castor and neem oils have some important fuel properties that can be of help to use them as alternative fuels for diesel engine.

The problem with processing waste oils is that they usually contain large amount of free fatty acids that cannot be converted to biodiesel using an alkaline catalyst due to the formation of soaps. The soaps can prevent separation of the biodiesel from its co-product glycerin. An alternative way is to use acid catalysts, which have been claimed by some researchers [1] as more tolerant of free fatty acids. A process has also been developed [2-3] to produce fuel quality biodiesel from yellow and brown grease using acid catalyst.

Methyl esters have been prepared [4] from used frying oil and compared their fuel properties to Austrian standards valid for rapeseed oil methyl ester. The content of the free fatty acids of the oils was between 0.26 to 2.12%. After filtration at 40°C to remove solid particles, the oil was transesterified using alkaline catalyst. It has been noted that all specification values could be met by the used of vegetable oil esters except for the cold filter plugging point, which in most cases was over -8°C.

10% and 20% blends (by volume) of methyl ester of used frying oil have been prepared [5] with No. 2 diesel fuel and it was found that heating value and cetane number were a little lower than for No. 2 diesel fuel, most of the fuel properties of the blends were within the range of those for pure No. 2 diesel fuel.

The esters of used frying oil have been investigated [6] to determine their effects on engine performance and emissions. The esters of methanol, ethanol 1-propanol, 2-propanol, 2-butanol, and 2-ethoxymethanol were prepared using sulfuric acid and potassium hydroxide as acid and base catalysts respectively. It was found that all of the acid-catalyzed fuels had low viscosities, but all of the base-catalyzed fuels had higher viscosities, except for the methanol-based fuel, which was the least viscous of all fuels. It was also noted that the viscosity results of the esters correlated with the percentage of ester yield indicating that some of the fuels probably contained substantial amounts of unreacted and partially reacted oil. In that study, the three fuels with the lowest viscosity, namely, methyl ester prepared with base catalyst, ethyl ester prepared with acid catalyst, butyl ester prepared with acid catalyst, were tested in half hour runs in a high-speed diesel engine. No problems were observed with the engine in regard to starting at 25°C, smoothness of running, or smokiness of exhaust. It was also tested the methyl and ethyl esters in a Perkins P6 low speed diesel engine and no problems were observed in that engine either.

The engine performance and emissions of ethyl esters produced from waste hydrogenated soybean oil have been compared [7] with No. 2 diesel fuel. In this study, two types of engines were used. For the engine performance test, a direct injected, four-cylinder John Deere 4329t-turbocharged diesel engine was used. The emissions testing were conducted with a 1994 Dodge pickup equipped with a direct injected turbocharged and intercooled, 5.9L Cummins diesel engine. It was found that the biodiesel had a higher specific gravity and 1.9 times the viscosity of No. 2 diesel fuel at 40°C. The heat of combustion of the biodiesel was noticed 12% lower than that for diesel fuel. It was observed that the smoke opacity and engine power were lower by 71% and 4.8% respectively when the engine was operated with the biodiesel compared with No. 2 diesel fuel. But the peak engine torque was reduced by 6% and 3.2% at 1700 and 1300 rpm respectively. However, there was no significant difference in the thermal efficiencies. Emissions tests showed a 54% decrease in HC, 46% decrease in CO, 14.7% decrease in NOx, and 0.5% increase in CO_2 when biodiesel was used.

Waste cooking oils were converted [8] to their methyl and ethyl esters and tested pure biodiesel and 30% blend of biodiesel in diesel fuel in a diesel-powered bus using a chassis dynamometer. In this study no significant difference in power and performance was observed except for a visible reduction of smoke on acceleration with the esters of the used oil. It was also found that the smoke opacity was reduced by 60% of the diesel fuel value by the 30% blend and by 26% of the diesel value by the pure ester.

Several researchers [9-12] have observed that the exhaust emissions are affected by the use of biodiesel. It is known that biodiesel generally causes an increase in NOx emission and decrease in total unburned hydrocarbon (THC), CO and particulate matter (PM) emissions relative to diesel fuel. However, there are a few reports about the investigation of the effect of the purity of biodiesel on engine performance and emissions. A report [13] shows the refining step of biodiesel production. It has been mentioned in the report that to obtain pure biodiesel conformable to the standards, washing with hot distilled water and neutralization with sulfuric acid in a ratio of 1:1 were tested in the refining step. Washing with hot distilled water at 50°C was chosen as the best refining process. The purity of biodiesel obtained was 99%.

Many researchers have concluded that vegetable oils hold promise as alternative fuels for diesel engines [14-15]. However, using raw vegetable oils for diesel engines can cause numerous engine-related problems [16-17]. The increased viscosity and low volatility of vegetable oils lead to severe engine deposits, injector coking, and piston ring sticking [18-21]. However, these effects can be reduced or eliminated through transesterification of vegetable oil to form methyl ester [22]. Transesterification provides a fuel viscosity that is close to that of No. 2 diesel fuel.

In the present investigation fuel combustion and exhaust gas emission have been investigated with neat diesel fuel and diesel-biodiesel blends. The methyl esters of castor oil (COME) have been made first and then blended with conventional diesel fuel. Finally the exhaust gas emissions with biodiesel blends have been investigated and compared with those of neat diesel fuel.

1.1 Feasibility Study of Producing Biodiesel in Bangladesh

While the country is short of petroleum reserve, it has large arable land as well as good climatic conditions (tropical) with adequate rainfall in large parts of the area to account for large biomass production each year. For the reason of edible oil demand being higher than its domestic production, there is no possibility of diverting this oil for production of biodiesel. Fortunately there is a large junk of degraded forestland and unutilized public land, field boundaries and fallow lands of farmers where nonedible oil-seeds can be grown. There are many tree species, which bear seeds rich in oil. Of these some promising tree species have been evaluated and it has been found that there are a number of them such as *neem tree and castor plants*, which would be very suitable in tropical conditions. It will use lands, which are largely unproductive for the time being and are located in poverty stricken areas and in degraded forests. It will also be planted on farmers' field boundaries and fallow lands.

1.2 Proposed Castor Plants

Castor plant has been found the most suitable plant specie in Bangladesh for the following reasons. It can be grown as a quick yielding plant even in adverse land situations viz. degraded and barren lands under forest and nonforest use, dry and drought prone areas, marginal lands and as agroforestry crop. It can be planted on fallow lands and as well as on vacant lands alongside highways, irrigation canals and unused lands in townships etc. under public/private sector undertakings.

- The seeds of castor are available during the non-rainy season, which facilitates better collection and processing. The cost of plantation is largely incurred in the first year and improved planting material can make a huge difference in yield.
- Raising castor plant and its maintenance creates jobs for the rural poor, particularly the landless, in plantation and primary processing through expellers.
- Retains soil moisture and improve land capability and environment.
- Castor plantation adds to the capital stock of the farmers and the community, for sustainable

generation of income and employment.

2. COMPUTATION TECHNIQUE FOR ADIABATIC FLAME TEMPERATURE (AFT) AND NOx EMISSION

AFT and NOx emission of Fig. 10 are computational data. The computation has been done in the following way:

The combustion products of the fuels with C-H-O components were derived from Eq. (1) for whole chemical reactions, which was conformed by considering chemical equilibrium as will be mentioned later.

$$C_{\alpha} H_{\beta} O_{\gamma} + \varepsilon \frac{1}{\phi}\left(O_2 + \frac{0.79}{0.21} N_2\right) \rightarrow y_1 CO + y_2 CO_2 + y_3 O_2 + y_4 H_2 + y_5 H_2O + y_6 OH + y_7 H + y_8 O + y_9 NO + y_{10} N_2 \text{ - - - - - - - - - - - - (1)}$$

Again,

$$\varepsilon = \frac{1}{\alpha + \beta/4 - \gamma/2} \text{ -------------------(2)}$$

y_i and T_b were computed by considering the following chemical equilibrium and enthalpy balance in combustion reaction. NOx emission was derived from y_9 in Eq. (1) for whole chemical reaction. The computation was carried out under the standard atmospheric condition.

$CO_2 \leftrightarrows CO + 1/2O_2$ (equilibrium constant K_1)
$H_2O \leftrightarrows H_2 + 1/2O_2$ (equilibrium constant K_2)
$H_2O \leftrightarrows 1/2H_2 + OH$ (equilibrium constant K_3)
$1/2H_2 \leftrightarrows H$ (equilibrium constant K_4)
$1/2O_2 \leftrightarrows O$ (equilibrium constant K_5)
$1/2O_2 + 1/2N_2 \leftrightarrows NO$ (equilibrium constant K_6)

The equilibrium constants were treated as a function of T. AFT was computed by balancing of H_u and H_b. H_u and H_b were described by Eqs. (3) and (4), respectively.

$$H_u = H^0_{fuel}(T) + \frac{1}{\varepsilon\phi}\left[H^0{}_{O_2}(T) + \frac{0.79}{0.21} H^0{}_{N_2}(T)\right] \text{ -----------------(3)}$$

$$H_b = \sum_{i=1}^{10}\left[y_i H^0{}_i(T_b)\right] \text{ --------------- (4)}$$

$$H^0{}_i(T) = \int_{T_0}^{T} C_p{}^0 dT + \Delta_f H^0{}_i(T_0) \text{ ------(5)}$$

Thermodynamic properties of combustion gases in JANAF [23] table and the programs of Mizutani [24] and Ferguson [25] were used for the computations.

3. EXPERIMENTAL SETUP AND PROCEDURE OF EXPERIMENTATION

The engine used in this experiment was a single cylinder water-cooled, NA, DI diesel engine. The specifications of the engine have been given in Table 1. The experiment was conducted with conventional diesel fuel, and COME. The properties of the diesel fuel, and COME are shown in Table 2. The RPM was measured directly by the tachometer attached with the dynamometer. The outlet temperatures of cooling water and exhaust gas were taken directly from the thermometers attached to the corresponding passages. The fuel injection timing was set at 13°ATDC (after top dead center). The exhaust gases including smoke, NOx, CO, CO_2 were measured with a portable digital gas analyzer (IMR 1400). The data of exhaust emissions were taken in the exhaust pipe at 0.61m apart from the engine. The filter smoke number readings were taken as 6, 7, 7.5, 8 etc out of scale 10.

Table 1 Test Engine Specifications

ITEMS	SPECIFICATION
Model	S 195
Type	Single cylinder
Bore × stroke	95 × 115 mm
Rated output	9.8 kW / 2000 rpm
Compression ratio	20
Type of cooling	Water evaporative
Injection pressure	13.5 MPa

Table 2 Properties of Test Fuel/Oil

Test property	Diesel fuel	COME
Viscosity 25°C(cP)	6.8	15.8
Density @25°C (g/cc)	0.80	0.86
Heating value (MJ/kg)	44.5	39.4
Cetane number	49.0	52.5
Carbon mass (wt%)	86.8	77.0
Hydrogen (wt%)	13.1	12.4
Oxygen (wt%)	0.00	10.54
C/H ratio	6.63	6.21
Sulfur (wt%)	0.042	<0.005
Total glycerin (%)	-	0.028
Free glycerin (%)	-	0.00
Distillation (°C)		
10%	232	-
50%	275	-
90%	334	-

4. RESULTS AND DISCUSSIONS

4.1 Making of Biodiesel from Castor Oil

The process used for making laboratory quantities of non-edible vegetable oil (castor oil) ester was that it was first mixed the proportion of anhydrous lye catalyst (NaOH) to methyl alcohol (CH_3OH) and then this combination was mixed with the moisture-free castor oil. The temperature of the materials was maintained at 55-60°C and then allowed to settle by gravity for 24 hours. After that the translucent methyl ester of castor oil termed as biodiesel was produced. In all cases 0.6% of lye catalyst as a reagent and 20% methyl alcohol were used for making biodiesel. The process of methyl esterification of castor oil is shown in Figure 1.

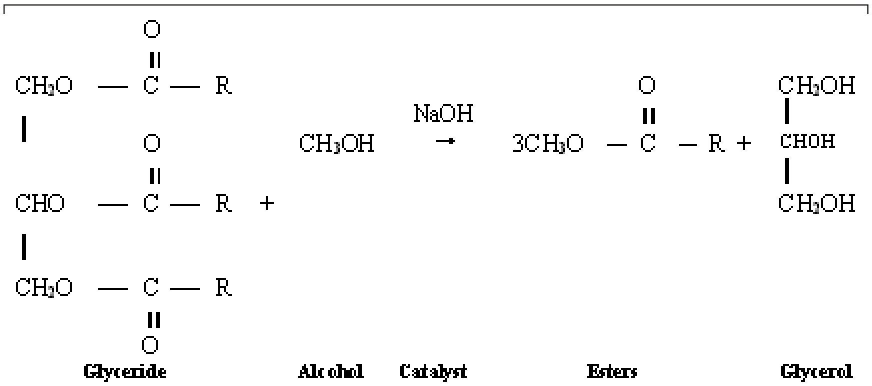

Fig.1 Process of methyl esterification of castor oil

4.2 Fourier Transform Infrared (FTIR) Spectroscopy of Esterified and Non Esterified Castor Oil

Figure 2 shows the ir-spectra, which is almost common to all petroleum products of esterified and non-esterified castor oil. The ir-spectra of neat esterified and non-esterified castor oil shows the pronounced functional groups, which indicate the presence of alkanes and lesser extent of aromatics and poly-aromatics groups, with a clear absence of phosphorus and sulfur. The ir-spectra of the esterified castor oil also show that they contain significant amount of esters. The esterified castor oil contains a little amount of water and this water was removed by heating the oil before using in the engine. The higher percentages of esters, alkanes and absence of phosphorus and sulfur make this esterified non-edible castor oil the future candidate for alternative environment-friendly diesel fuel. The comparative frequency ranges of ir-spectra, their corresponding functional groups and indicated compounds have been presented in Table 3.

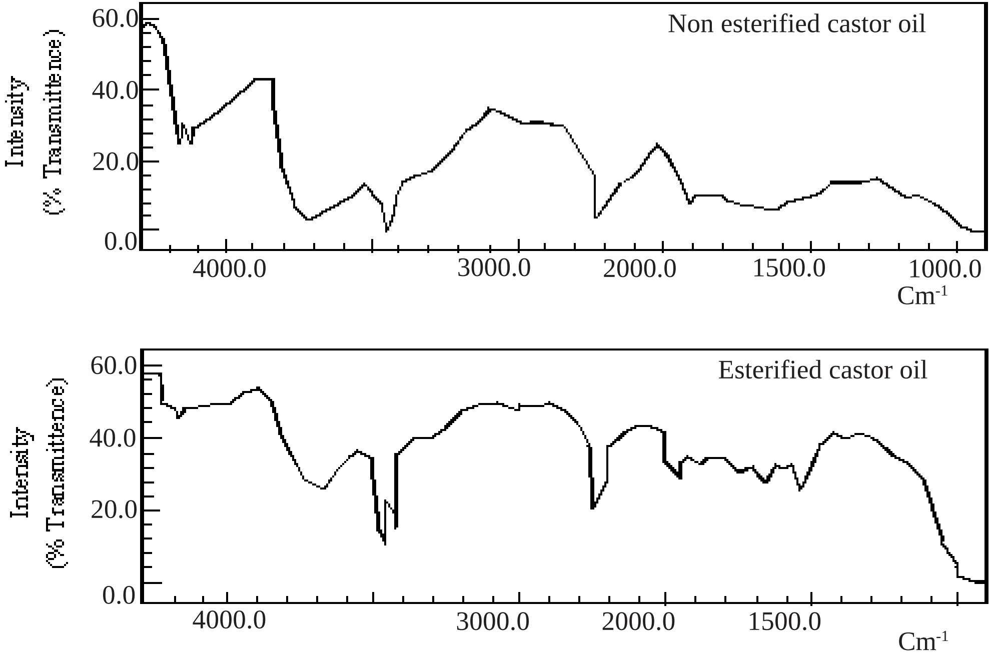

Fig.2 IR-spectra of non esterified and esterified castor oil

Table 3 FTIR Functional Groups and Indicated Compounds of
Etherified and Non-Etherified Castor Oil

Frequency Range (cm^{-1})	Non-esterified castor oil		Esterified castor oil	
	Functional group	Class of compound	Functional group	Class of compound
3700-3100	O-H stretching	Alcohol & Water impurities (Strong)	O-H stretching	Alcohol & water impurities (medium)
3100-2650	C-H bending C=C bending	Alkanes (weak) Alkenes (weak)	C-H stretching, C=C stretching	Alkanes, alkenes
2200-1950		Sulfur, phosphorus, silicon & isocyanides	-	-
1750-1650	C=O stretching	Acid (medium), oxygenated compound, aldehydes, ketones (medium)	C=O stretching	Acid (medium), oxygenated compound, aldehydes, ketones (medium)
1325-900		-	H-CO-O-R	Ether, ester, aromatic compound

4.3 Engine Speed Optimization

Figure 3 shows the brake thermal efficiency with neat diesel fuel at different engine speeds. To optimize the engine speed, brake thermal efficiency versus engine speed curve has been drawn. The brake thermal efficiency is defined as the actual brake work per cycle divided by the amount of fuel chemical energy as indicated by the fuel's lower heating value. It is seen from the Figure that with the increase in engine speed up to 1000 rpm, the brake thermal efficiency of the engine increases as the fuel supply increases, which causes the increase of output power in the cycle. The brake thermal efficiency of the engine decreases when the engine is run at a speed above 1000 rpm inspite of the fuel supply increases. The cause of decreasing brake thermal efficiency at an increased engine speed is to lesser amount supply of air, which causes improper burning of fuel in the combustion chamber. The engine speed of 1000 rpm at which the brake thermal efficiency reaches maximum was chosen for all other following experiments.

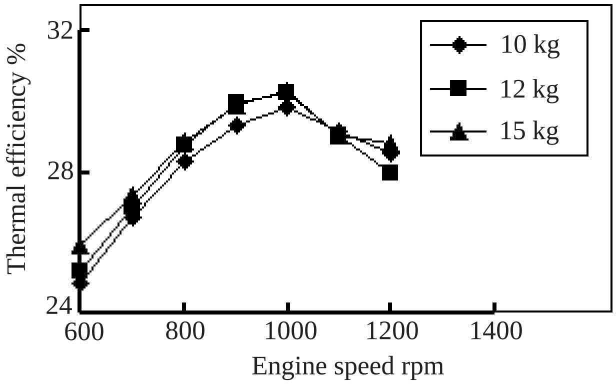

Fig.3 Effect of engine speed on brake thermal efficiency

4.4 Exhaust Emissions with Neat Diesel Fuel and Diesel-COME Blends

Figure 4 shows the exhaust emissions of neat diesel fuel, and blends of COME-diesel at medium load (12kg) condition. The volumetric blending ratios of COME to diesel fuel were set at 5 to 15%.

The engine speed was set at 1000 rpm (optimized earlier). The fuel injection timing was set at 13°ATDC. It is clear from the Figure that compared with conventional diesel fuel, the exhaust emissions including CO and smoke emissions decrease, while NOx emission increases with the increase of volumetric percentages of COME to diesel fuel. It is also found that the emissions with COME-diesel blend have no significant difference with neat diesel fuel operation, since the physical properties of COME are almost identical with diesel fuel. Compared to conventional diesel fuel, the NOx emission is increased by 5%, the CO and smoke emissions are decreased by 4% with 15% COME. This result is almost identical with the result of Canakci et al. [3], who found no significant difference on exhaust emissions with 20% Soybean oil methyl ester blend and 20% yellow grease methyl ester blend. The reason for decreasing exhaust emissions with diesel-COME blends is the presence of oxygen in the COME. The oxygen in the COME helps to reduce exhaust emission including CO and smoke emissions, while this may provide excess oxygen to produce higher NOx emission. The impact of fuel injection timing may also play a role in the higher NOx emissions with COME. Thus, with 15% COME; NOx emission can be reduced by proper adjustment of the fuel injection timing.

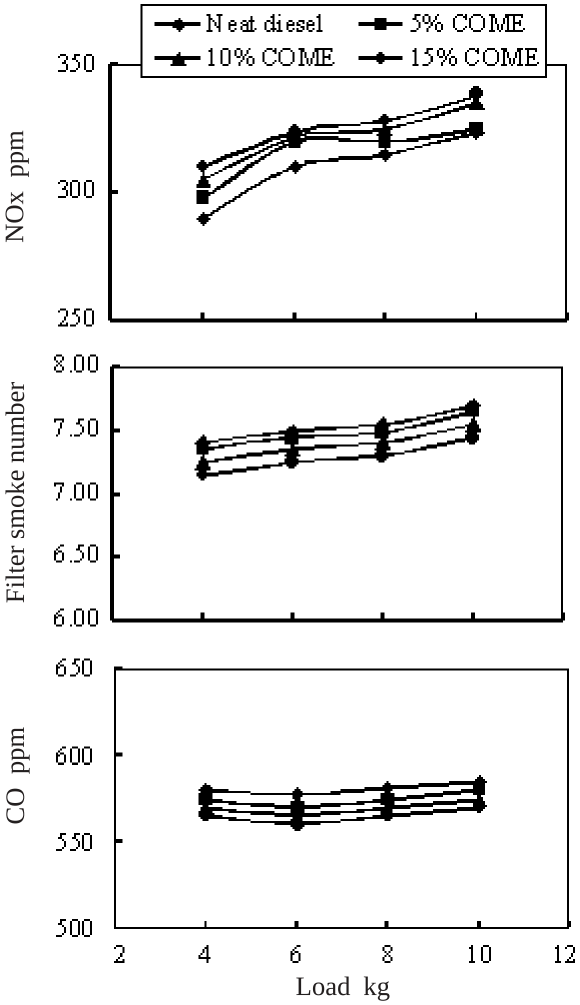

Fig.4 Exhaust emissions with neat diesel fuel and diesel-COME blends (engine speed = 1000 rpm)

4.5 Effect of EGR on Diesel Emissions with Neat Diesel Fuel and Diesel-COME Blends

4.5.1 Effect of EGR Rates on NOx Emission

As seen in Figure 4, the NOx emission with 15% diesel-COME blend is slightly higher than that of neat diesel fuel. To reduce NOx emission with diesel-COME blend, a technique of EGR was applied in a four-stroke DI diesel engine. The engine speed was set at 1000 rpm and load at 12 kg as earlier. The fuel injection timing was set at 13°ATDC. Figure 5 shows the effect of EGR rates on NOx emission. It can be seen from the Figure that with the increase in EGR rate, NOx emissions decrease for both neat diesel fuel and 15% COME blend. It is interesting to note that with 15% COME blend, NOx emission is slightly lower than that of neat diesel fuel for every EGR rate. This may be for the reason that as density of COME is slightly higher than that of neat diesel fuel, the mass of fuel burning for a certain cycle is higher for COME for a constant load and constant engine speed. The specific heat of CO_2 and H_2O are higher in the exhaust gas than those of other gas components. As the COME is denser then it is apparent that the concentrations of CO_2 and H_2O will be higher with COME. As a result the heat capacity of CO_2 and H_2O will be higher and the higher heat capacity of CO_2 and H_2O for COME may be responsible for lower NOx production for COME.

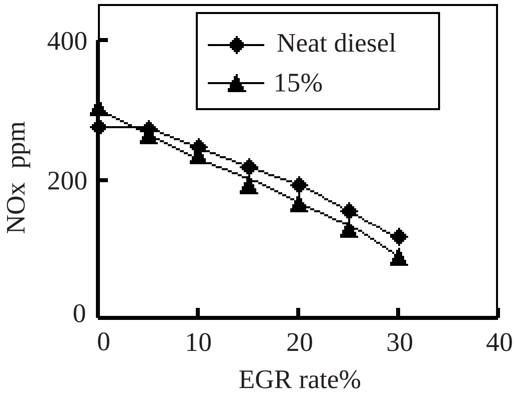

Fig.5 Effect of EGR on NOx emission with neat diesel and diesel-COME blends
(engine speed = 1000 rpm, load = 12 kg)

4.5.2 Effect of EGR Rates on CO Emission

Figure 6 shows the effect of EGR rates on CO emission. The engine operating conditions are same as stated for Figure 5. It can be seen from the Figure that with the increase in EGR rates, CO emissions increase for both neat diesel fuel and 15% COME blend. It is to be noted that with 15% COME blend, CO emission is almost identical or slightly lower than that of neat diesel fuel for every EGR rate. Since COME presents some oxygen itself, this oxygen may help to reduce CO emission during combustion.

4.5.3 Effect of EGR Rates on Smoke Emission

Figure 7 shows the effect of EGR rates on smoke emission at an engine speed of 1000 rpm and at a load of 12 kg. It can be observed from the Figure that with the increase in EGR rates, smoke emissions increase for both neat diesel fuel and 15% COME blend. It is to be noted that with 15% COME blend, smoke emission is lower than that of neat diesel fuel for every EGR rate. The reason for smoke reduction with 15% COME blend is almost the same as explained earlier in Figure 6.

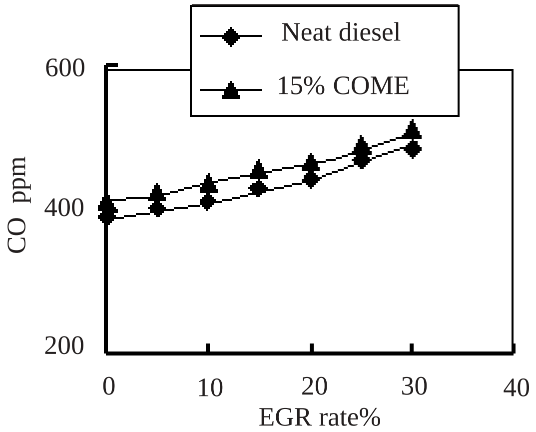

Fig.6 Effect of EGR on CO emission with neat diesel and diesel-COME blends
(engine speed = 1000 rpm, load = 12 kg)

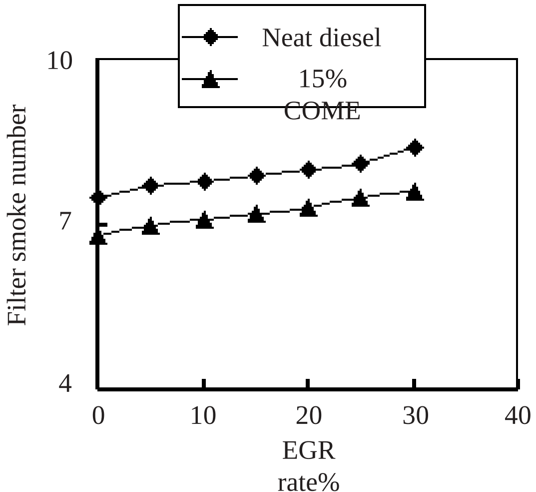

Fig.7 Effect of EGR on smoke emission with neat diesel and diesel-COME blends
(engine speed = 1000 rpm, load = 12 kg)

4.5.4 Comparison of Brake Thermal Efficiency of Neat Diesel Fuel and Diesel-COME Blends with EGR

Figure 8 shows the effect of EGR on brake thermal efficiency with neat diesel fuel and diesel-COME blends for the engine operating conditions of speed at 1000 rpm, and a load of 12 kg as earlier. It is evident from the Figure that with the increase in EGR rate, the brake thermal efficiency for both neat diesel fuel and diesel-COME blend decreases, but when compared to the neat diesel fuel, the brake thermal efficiency of diesel-COME blend gives higher values for better properties of the fuel like cetane number etc.

4.7 Engine Noise with Neat Diesel Fuel and Diesel-COME Blends

Figure 9 shows engine noise for neat diesel fuel, and diesel-COME blends at an engine speed of 1000 rpm and a load of 12 kg. The engine noise was measured at 0.5m apart from the engine with a sound level meter (CEL-228 Impulse sound level meter and analyzer). It is evident from the Figure that the engine noise is significantly reduced for all diesel-COME blends as compared to neat diesel fuel. The reduction in engine noise with 15% COME blend may result from the much better combustion than that of neat diesel fuel.

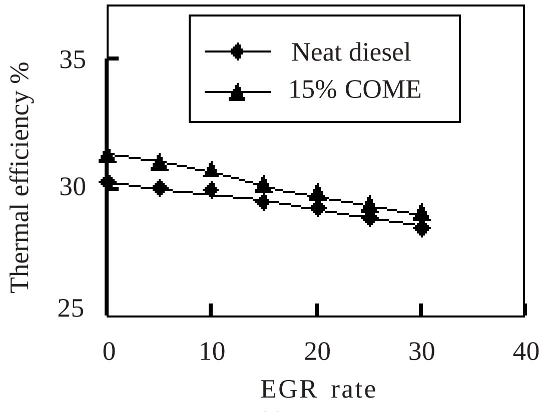

Fig.8 Effect of EGR on brake thermal efficiency with neat diesel and diesel-COME blends
(Engine speed = 1000 rpm, load = 12 kg)

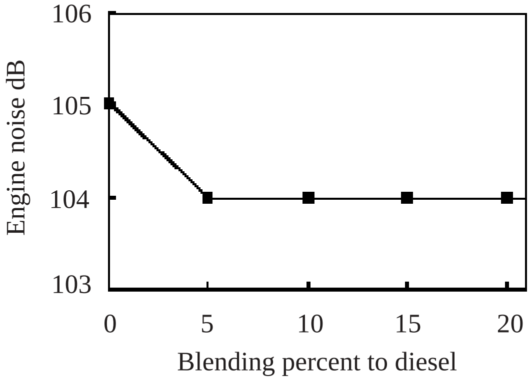

Fig. 9 Engine noise with neat diesel and diesel-COME blend
(engine speed = 1000 rpm, load = 12 kg)

4.8 AFT and NOx Emission

Figure 10 shows the effect of equivalence ratio on adiabatic flame temperature (AFT) and NOx emission for neat diesel fuel and neat COME. As explained earlier, AFT and NOx emission are computational data. For both the fuels, the AFT increases as equivalence ratio increases up to about 1.10 and then AFT decreases although the equivalence ratio increases. This is may be associated with higher proportion of fuel contained in the mixture. Again for both diesel fuel and COME, NOx emission increases with the increase in equivalence ratios up to 0.97 and then decreases and become minimum at equivalence ratios of 0.4. The AFT is found maximum at an equivalence ratio of about 1.1, while NOx is found maximum at about 0.97. This behavior is quantitatively changed a little but qualitatively unchanged for both neat diesel fuel and COME. It is interesting to note that the NOx emission for neat COME is lower than that of diesel fuel resulting from the lower adiabatic flame temperature of COME. This indicates that AFT changes alone cannot adequately explain the higher level of NOx formation with COME as found in the experimental result.

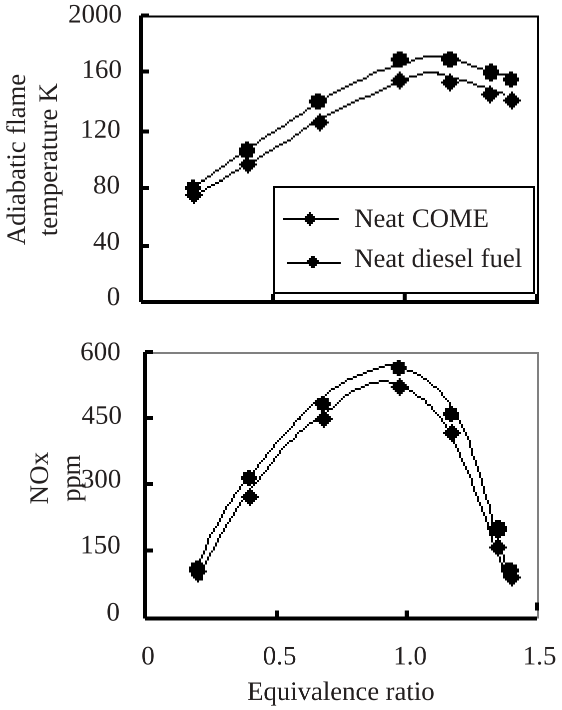

Fig. 10 Effect of equivalence ratios on AFT and NOx emission for neat diesel fuel and neat COME

5. CONCLUSIONS

In this report fuel combustion and exhaust emission were investigated with neat diesel fuel and diesel-COME blends. The study consists of two phases. In the first phase of this study, making of biodiesel was done and in the next phase, fuel combustion and exhaust emissions were investigated with typical diesel fuel and the blends of diesel and esterified oil. The results of this study may be summarized as follows:

- Methyl ester of non-edible castor oil was prepared with lye catalyst and methanol.
- Compared with conventional diesel fuel, diesel exhaust emissions including smoke and CO were reduced, while NOx emission was increased with diesel-COME blends. The reductions in CO and smoke emissions and the increase in NOx emission with diesel-COME blends may be associated with the oxygen content in the fuel.
- The engine noise with diesel-COME blends was reduced significantly.
- Compared with usual diesel fuel, the computed result shows lower NOx emission with COME resulting from lower AFT.
- Castor oil is a nonedible vegetable oil. This is renewable in nature. The ester of this oil can be used as environment-friendly alternative fuel for diesel engine and thus food versus fuel conflict will not arise.

6. ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. Md. Mostafizur Rahman and Mr. Md. Faruk-E-Azam, graduate students of Rajshahi University of Engineering and Technology, Bangladesh for their cooperation in this investigation. Thanks are due to the Institute of Fuel Research and Development, the Analytical Research Division of Bangladesh, Council of Science and Industrial Research (BCSIR), Dhaka for elemental analysis and the Department of Chemistry of Rajshahi University of Bangladesh for FTIR analysis.

7. NOMENCLATURE

CP^0	specific heat at constant pressure of each species (J/mol/K)
H_b	gas mol enthalpies after combustion (J/mol)
$\Delta_f H^0 i(T)$	mol enthalpy of each species (J/mol)
H_u	gas mol enthalpies before combustion (J/mol)
T	gas temperature (K)
T_b	adiabatic flame temperature (K)
T_0	initial atmospheric temperature (K)
y_i	mol fraction of each species in combustion products Greek symbols
α	mol number of carbon in unit mol of fuel
β	mol number of hydrogen in unit mol of fuel
γ	mol number of oxygen in unit mol of fuel
ϕ	equivalence ratio

8. REFERENCES

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