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PAH and other emissions from coconut oil blended fuels

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This paper presents results of a multi-cylinder diesel engine operated on blends of ordinary coconut oil (COCO; 10%, 20%, 30%, 40%, 50%) with ordinary diesel oil (OD). Methyl esters from cooking oil are less encouraging to be used as biofuel because this affects food-fuel crisis. However, biofuel obtained from waste cooking oil is more appreciated due to energy savings and environmental issues. Test results indicated that COCO blended fuels (10-30 %) produced similar brake power and net heat release rate as OD. Increasing coconut oil in blend decreases exhaust emissions. Carbon deposited on injector nozzles was observed where no hard carbon was found on injector tip when engine run on COCO blends.

Keywords: Biofuel, Carbon deposit, Coconut oil, Diesel engine, Emission, PAH

Introduction

Higher amount of particulate matter (PM), unburned hydrocarbon (HC), polycyclic aromatic hydrocarbon (PAH), oxides of nitrogen (NOx), carbon dioxide (CO_2) and oxides of sulfur (SOx) are produced from fossil fueled diesel engines exhaust emissions. Diesel engines running on coconut oil as alternative fuel contains insignificant levels of PAH, whereas petroleum based diesel fuel has 1-4% PAHs[1]. Seed oils (soybean, safflower, rapeseed, palm, coconut oil and their esters), which are renewable, non-toxic, biodegradable and their physicochemical properties are comparable with ordinary diesel (OD) fuel, are considered as viable biofuels for diesel engines[2,3].

This paper presents effect of coconut oil (COCO) blends on engine performance, by measuring brake power and exhaust emissions [carbon monoxide (CO), NOx, HC, smoke, benzene and PAH] of all COCO blends. All results from COCO blends have been compared with that of pure OD fuel.

Experimental Setup and Procedures

Test characteristics are shown in Table 1. Bosch gas analyzer model ETT 008.36 was used to measure CO, CO_2 (% by vol). A Bacharach model CA300NSX analyzer (Standard version, k-type probe) was used to measure NOx. To determine level of CO, CO_2 and NOx, systems used non-dispersive infrared detectors. HORIBA model MEXA 9100D was used to measure HCs. A gelman-A glass fiber absolute filter (99% efficient for particles with 0.3 µm diam) was used to collect particulate emissions. Exhaust particulate extraction and analysis were done according to standard methods[4,5]. Hewlett-Packard 5890 series II GC with a FID detector was used for analyzing PAH.

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Gas Chromatograph (GC) Analysis Condition for PAH Sample

Hewlett-Packard 5890 series II GC with an FID detector; air = 400ml/min (35psi), H_2= 33 ml/min (40 psi), He = 20 ml/min (30psi); Detector temp. =320°C, Columns head pressure 2.2 psi; Column: 5 m*0.53 mm*2.65um film thickness, US pat 4293415; Carrier: He at 15 psi = 28 cm/sec @70°C and 20 cm./sec @ 300°C (40 psi); Injector: HP cool on- column injection directly into column using syringe with a fasted silica needle, 1 µl injection volume; Temp. prog. 70°C for 3 min, then to 320°C @ 10/min; hold 10 min.

Samples were screened for following PAH components: naphthalene, dimethylanthracene, methylanthracene, acenaphthylene, 9-ethylanthracene, acenaphthene, fluorene, phenanthrene, anthracene fluoranthene, pyrene, 9,10-dimethylanthracene, perylene, 1,2-benzanthracene 2,3- benzofluorene, benzo (d,e,f)phenan, benzo-a-pyrene, trans-stilbene. The data was evaluated as follows:

Table 1—Test characteristics

Parameters	Characteristics
Ordinary coconut oil (COCO)	It remains a white crystalline solid < 20°C, but it is a clear liquid when blended with ordinary diesel (OD) fuel. Prior to running each set of tests, engine was conditioned on each new fuel by purging fuel system and operating under full load for ½ h.
Engine	Isuzu 4FB1, 4 cylinder, Bore 84 mm and stroke 82 mm, indirect injection diesel engine
Test 1	Performance and emissions analysis was done for constant 75% throttle position with varying speed (800-3600 rpm).
Test 2	Combustion analysis such as net heat release rate was measured at 3000 rpm with 75% throttle setting.
Test 3	Engine was operated at constant 2000 rpm with 75% throttle position to collect exhaust particulate in filter for measuring PAH conc. in COCO blends.

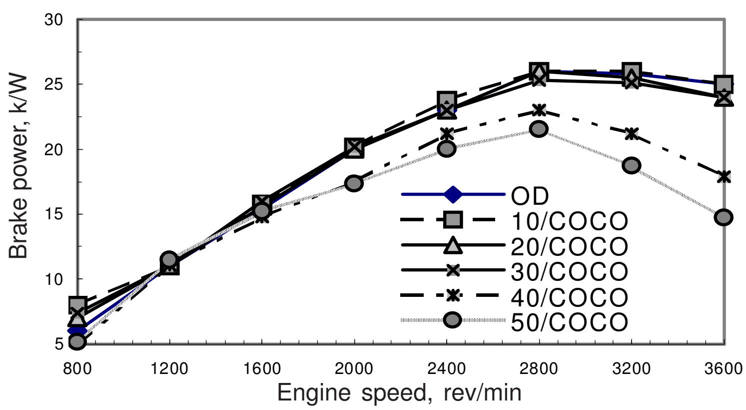

Fig. 1—Brake power versus engine speed

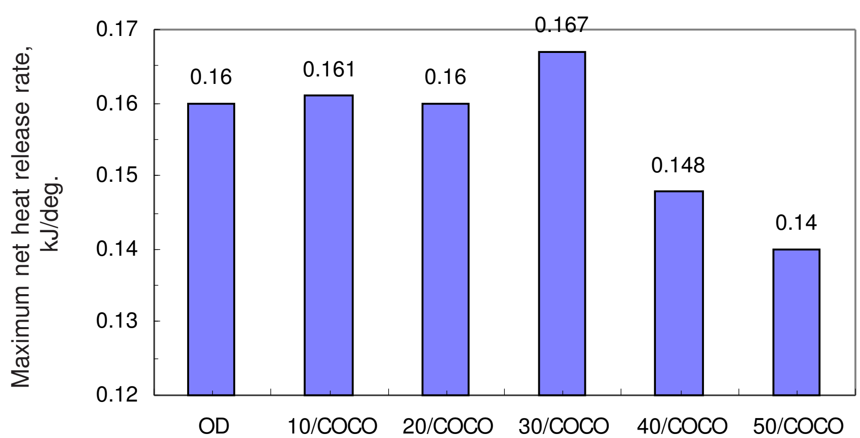

Fig. 2—Maximum net heat release rate for each fuel (Test 2)

Relative PAH emission (± %) =

$$\frac{(PAH\ emission\ from\ COCO\ blended\ fuel - PAH\ emission\ from\ base\ fuel,\ OD)}{PAH\ emission\ from\ base\ fuel,\ OD}\times 100$$

A steel injector, with controlled temperature by hot water jacked, was used to collect exhaust gas from engine and then injected to GC inlet to measure benzene concentration. Before measuring exhaust gas samples,

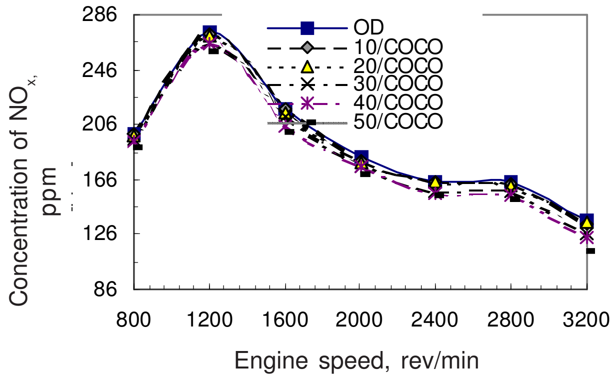

Fig. 3—NOx concentration versus engine speed

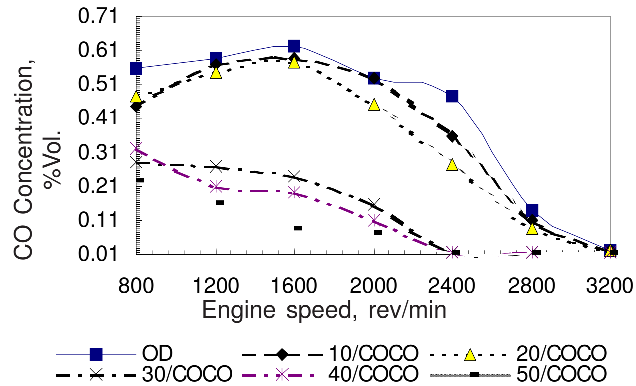

Fig. 6—CO concentration versus engine speed

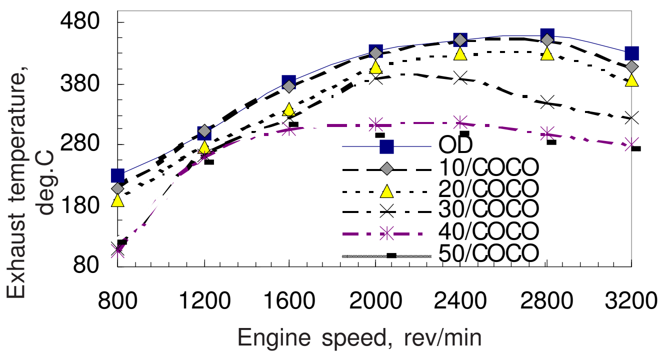

Fig. 4—Exhaust temperature versus engine speed

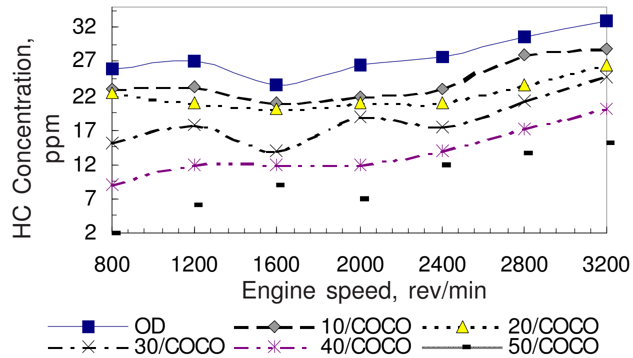

Fig. 7—HC concentration versus engine speed

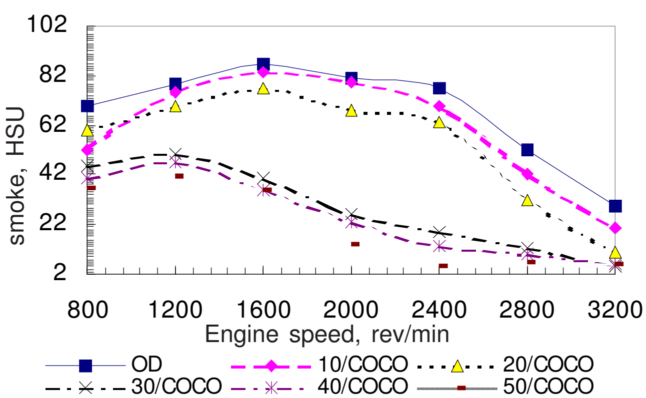

Fig. 5—Smoke concentration versus engine speed

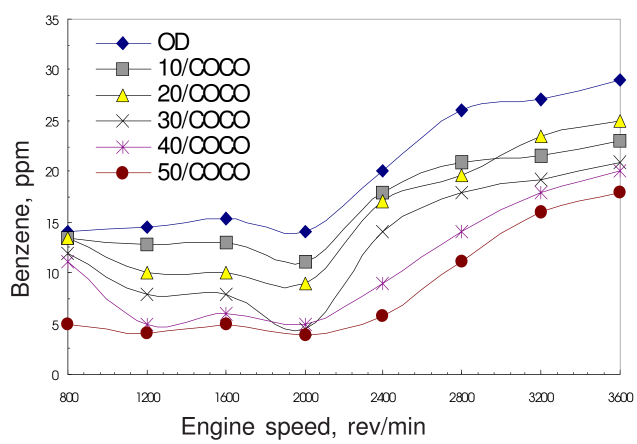

Fig. 8—Benzene concentration versus engine speed

GC was calibrated by standard benzene gas. Hewlett-Packard 5890 series II GC with a thermal conductivity detector (TCD) was used to measure benzene concentration. Exhaust gas sample was maintained above 86°C during entering GC column.

Results and Discussions

Engine Performance

Engine operated at 23-33°C did not have any initial starting difficulties by all COCO blends although viscosity of COCO blend is higher than that of OD. For

Table 2— Properties of fuels

Items	Test method	100%OD	10%COCO+ 90% OD	20%COCO+ 80% OD	30%COCO+ 70% OD	40%COCO+ 60% OD	50%COCO+ 50% OD	100%COCO
High calorific value, MJ/kg	ASTM 2382	45.91	43.81	43.52	43.28	42.18	41.50	37.26
Kinematic viscosity, cSt @ 40°C	ASTM D445	3.60	3.70	3.93	4.70	4.80	5.30	-
Specific density, g/cm^3	ASTM D1298	0.832	0.848	0.857	0.870	0.875	0.888	0.93
Conradson carbon residue, % wt	ASTM 189	0.14	0.12	0.11	0.11	0.10	0.06	-
Sulfur content, %wt	IP242	0.10	0.09	0.081	0.071	0.06	0.04	0.009
Cetane Number	ASTM D976	52	49	47	46	44	44	37

COCO, coconut oil; OD, ordinaty diesel

COCO blends compared to OD fuel, cylinder temperature measured from thermocouples was less by 15-35°C and engine combustion noise was less severe. After each fuel test, no significant carbon deposit on nozzle tips was observed with COCO blends in comparison to OD fuel. Fuel injection pump acted very efficiently as mechanical stirrer for blending agent. Maximum brake power for each fuel was obtained at 2800 rpm (Fig. 1) and COCO blends (10-30%) have developed similar brake power as OD, mainly due to close physicochemical properties (Table 2). COCO blends (40-50 %) produce lower brake power (Fig. 1) and lower net heat release rate (Fig. 2) in comparison to OD fuel mainly due to low content of internal energy and cooling effect that complete combustion in expansion stroke.

Exhaust Emissions

NOx concentration decreased with increase in COCO in blended fuels (Fig. 3) due to low combustion temperature in comparison to OD. Increasing COCO in blends, content of saturated fatty acid goes high, thereby increasing latent heat of vaporization, which reduce compression temperature as well as produce low level of combustion temperature. These effects improve thermal efficiency following reduction in temperatures throughout the cycle. Hence, exhaust temperature reduces with increasing COCO in blends (Fig. 4). Smoke emission [Fig. 5, in Hartridge Smoke Units (HSU)] decreases with increasing COCO in blends mainly due

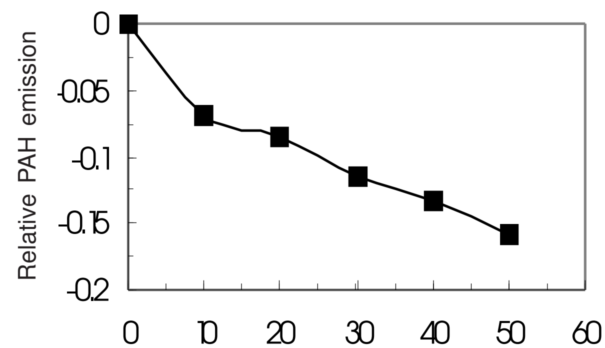

Fig. 9—Relative PAH emission for 0 - 50% coconut oil

to presence of oxygen molecules (COCO contains 10% O_2 by wt), which help to burn exhaust more readily and produce complete combustion. COCO blend does not affect much on CO concentration in diesel engine because diesel engine uses excessive air to burn fuel. Since operating condition is exclusively lean, with an air/fuel ratio of around 1.8 x stoichiometric, CO concentration value for all fuels is less than 0.7 (Fig. 6). Increasing COCO in cylinder[6] gives increased percentages of oxygen molecule, which oxidizes HC species rapidly to burn completely within combustion period. Thus, HC is reduced more with more COCO in blends (Fig. 7).

Benzene concentration reduces with increasing COCO in blends mainly due to reduction in aromatic content in compare to OD (Fig. 8). Overall PAH emission reduces (Fig. 9) with increasing COCO in blends.

Increasing COCO in blends reduced PM. Thus COCO blends are suitable to reduce PAH and PM contamination in environment mainly due to decreasing aromatic content.

Conclusions

Brake power and net heat release rate for COCO blends (10-30%) are found similar as OD. Exhaust emissions (NOx, exhaust temperature, smoke, CO, HC, benzene and PAH) reduce with increasing COCO in blends. Initial starting and combustion noise did not affect engine's smooth running during COCO blends. There was no significant carbon deposit on nozzle tips.

Acknowledgments

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References

1 Williams P T, Bartle K D & Andres G E, The relation between PAH in diesel fuel and exhaust particulates, *Fuel*, **65** (1986) 1118-1150.

2 Terry L U, Lobert L M & Daniel A M, Diesel fuel aromatic and cetane number effects on combustion and emissions from a 1991 prototype heavy duty diesel engine, *SAE Pap 902171*, 1991.

3 Asami Y & Shitani M, Effects of fuel properties on diesel engine exhaust emission characteristics, *SAE Pap 922214*, 1992.

4 Breuer G M C, Solvents and techniques for the extraction of polynuclear aromatic hydrocarbons from filter samples of diesel exhaust, Anal Lett, **17** (1984) 1293-1306.

5 Yu M-L & Hites R A, *Anal chem*, **53** (1981) 951-954.

6 Ladommatos N, Abdelhalim S M & Zhao H, Effects of exhaust gas recalculation temperature on diesel engine combustion and emissions, i:*IMechE Lond*, **212 D** (1998) 479-505.