Particulate Emissions Emitted from Diesel Engine Operated with Coffee Ground Pyrolysis Oil

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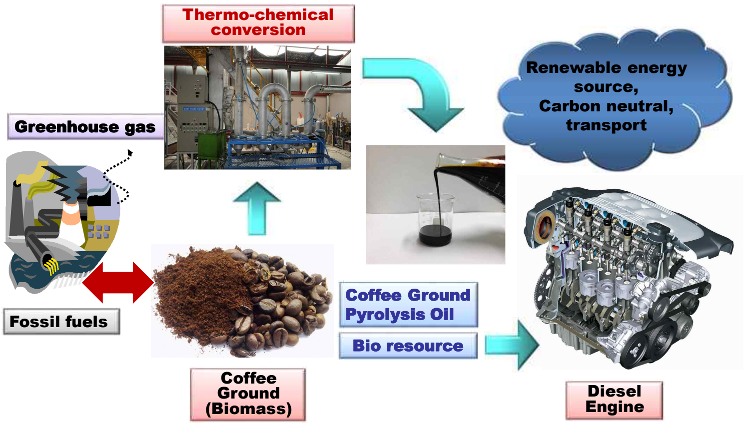
Introduction

1. Background of Using Coffee Ground Pyrolysis Oil in a Diesel Engine



- The emission and combustion characteristics of a biomass-based fuel, primarily comprised of coffee ground pyrolysis oil (CGO) and n-butanol, was investigated in a diesel generator and a diesel tractor. CGO is derived from coffee ground and has attracted interest as an alternative fuel for use in diesel engines. However, direct use of CGO in a diesel engine requires modification of the fuel supply system due to the poor fuel properties of CGO, such as high acidity, high viscosity, high water content and a low cetane number.
- Mixing CGO with alcohol fuels has the added benefit of significantly improving its storage and handling properties. As an organic solvent, n-butanol is capable of dissolving solid particles present in the CGO and suppressing polymerization. However, CGO-butanol blended fuel does not produce self-ignition. Hence, additional cetane enhancements (PEG 400 and 2-EHN) are added to the blended fuel.

Objectives

- In this study, CGO was used in diesel generator and tractor using the above mentioned strategies.
- We investigated the characteristics of particulate emissions of diesel engines operated with CGO-butanol blended fuel experimentally.

Experimental facility

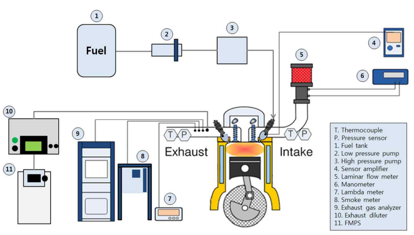
1. Test Fuels

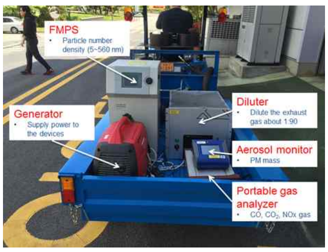
Fuel Characteristics of Coffee Ground Pyrolysis Oil

- Dark brown, Pungent Odor
- Combustible (not flammable)
- Not miscible with hydrocarbons
- Moisture content: ~23%
- Density : ~1.0 kg/Liter
- Acid : pH 2.3~2.6 (corrosion of injection system)
- Viscosity is increased with time.
- Coffee ground pyrolysis oil contains tar and polymerizes in the form of gummy-like materials.
- Formation of deposits in the injection system (clogging) and carbonaceous deposits in the combustion

Fuel	Viscosity (cSt at 40˚C)	LHV (kJ/kg)	Water content	C (wt%)	H (wt%)	O (wt%)	Density (kg/m³)	Cetane number
CGO	9.2	33.9	23%	54.6	9.6	34.5	1005	N/A
Diesel	2.7	42.6	-	86.1	13.9	-	821.0	52.6
n-Butanol	3.6	33.1	-	64.8	13.6	21.6	810.0	17
PEG400	40.4	23.2	0.3%	52.2	9.2	38.6	1128.0	N/A
2-EHN	1.3	15.8	<0.1%	54.9	9.7	27.4	960.0	N/A

2. Test Engine Specifications

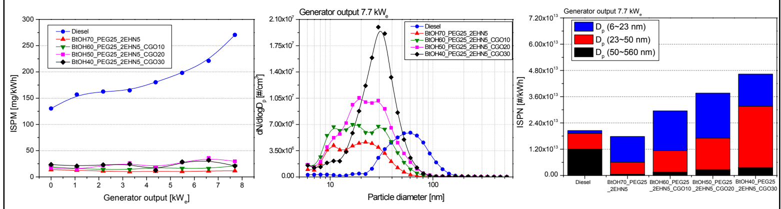




Parameters	Test diesel engine	
	Generator	Tractor
Cylinders	2	3
Displacement	794 cm³	761 cm³
Bore/Stoke	80 mm / 79 mm	67 mm / 71 mm
Compression ratio	23	23.5
Engine rated output	12.5 kW / 3,000 rpm	13.4 kW / 3,200 rpm
Generator rated output	8.5 kW$_e$ / 3,600 rpm	-

Results and Discussion

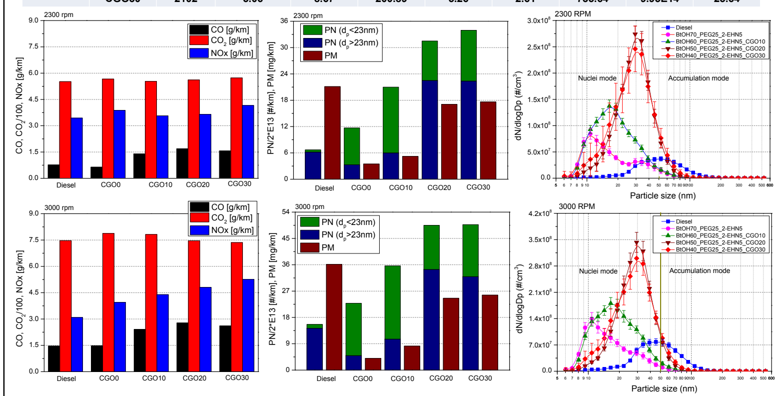
1. Engine bench test results (Diesel generator)



- PM mass from diesel tends to increase with increasing generator output. Diesel shows 5-10 times higher PM mass than the blended fuels. This may be attributed to the high oxygen content in the blended fuels.
- The particles in nuclei mode (< 50 nm) from the blended fuels shows higher concentrations than did those in diesel. However, diesel showed higher concentrations for the particles in accumulation mode (50-1000 nm), therefore, an increase in soot occurred.

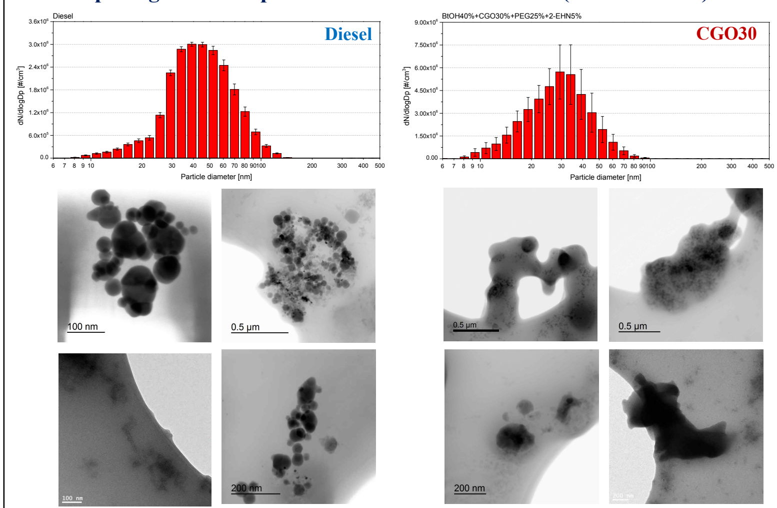
2. On-road test results (Diesel tractor)

Engine speed	Fuel	Time [sec]	Distance [km]	Avg. Speed [km/h]	Avg. Exhaust Temp. [deg]	NOx [g/km]	CO [g/km]	CO_2 [g/km]	PN [#/km]	PM [mg/km]
2300 rpm	Diesel	2284	5.02	7.91	164.46	3.44	0.77	551.64	1.34E14	21.11
	CGO0	2282	5.03	7.94	158.22	3.88	0.64	566.38	2.34E14	3.47
	CGO10	2294	5.07	7.96	161.80	3.57	1.40	553.15	4.20E14	5.21
	CGO20	2268	5.00	7.94	163.02	3.65	1.69	561.35	6.40E14	17.07
	CGO30	2282	5.04	7.95	163.65	4.16	1.57	573.07	6.59E14	17.63
3000 rpm	Diesel	2108	5.06	8.64	197.47	3.09	1.46	746.55	3.12E14	36.15
	CGO0	2110	5.04	8.60	194.60	3.95	1.48	787.70	4.57E14	4.01
	CGO10	2104	5.03	8.62	199.47	4.39	2.41	781.89	7.14E14	8.21
	CGO20	2100	4.99	8.55	198.62	4.81	2.78	746.00	9.90E14	24.58
	CGO30	2102	5.06	8.67	200.89	5.26	2.61	735.64	9.95E14	25.64



- The blended fuel showed similar level of CO_2 emission than the diesel. However, the NOx level of the blended fuel was higher than that of diesel.
- The blended fuel showed higher particle number and lower PM mass compared to diesel due to the high oxygen content of the CGO and n-butanol.

3. Morphologies of soot particles from diesel and CGO (Diesel tractor)



- Soot particles in the exhaust gas were collected on TEM grid under same engine load.
- For the CGO blended fuels, the morphological features of soot particles were drastically changed compared to diesel soot particles due to the compositional difference of fuels.
- High oxygen and water contents in the blended fuels might be related to the formation of carbon nanotube types of particulate emission.

Conclusion

- In this study, we investigated the characteristics of PM formation in a diesel engine fueled with CGO/butanol blended fuel. The high oxygen contents in CGO and butanol help the oxidation of already formed soot, breaking the C-C bonds, so that carbon atoms are easily converted into tiny soot particles (nuclei mode) during the combustion processes.