Particulate Emissions Emitted from DI Diesel Engine Operated with Wood Pyrolysis Oil

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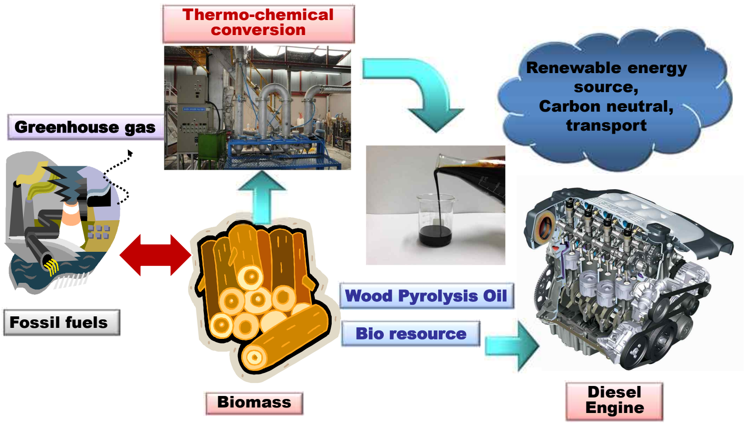
Introduction

1. Background of Using Wood Pyrolysis Oil in a Diesel Engine



- Fast pyrolysis of biomass is one of possible paths by which we can convert biomass to higher value products. The wood pyrolysis oil (WPO) has been regarded as an alternative fuel for petroleum fuels to be used in engines. Because WPO is an oxygenated fuel which contains more than 40% of oxygen, WPO can significantly reduce the PM generation in a diesel engine. However, the use of WPO in diesel engines requires modifications due to low energy density, poor auto-ignitability, high water contents, and high viscosity of the WPO.
- There are several methods to apply WPO in diesel engines. At first, the most widely used approaches to adopt WPO to diesel engine without engine modifications are the emulsification of WPO with diesel and biodiesel (BD). Secondly, blending WPO with n-butanol and cetane enhancements is another viable method to apply WPO in diesel engines. Lastly, dual-injection strategy was adopted. In this strategy, a pilot fuel with a high cetane number such as diesel was injected as first action to develop a flame in the combustion chamber with which the main WPO-ethanol blended fuel was stably combusted.

Objectives

- In this study, WPO was applied in a single-cylinder DI diesel engine using the above mentioned strategies.
- We investigated the characteristics of PM formation in a diesel engine fueled with WPO experimentally.
- PM mass and particle number (PN) concentration were measured using aerosol monitor and FMPS to evaluate the effect of oxygen contents in WPO on the PM formation.

Experimental methods

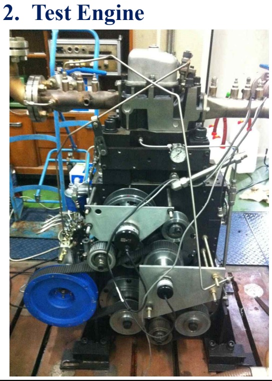
1. Test Fuels

Fuel Characteristics of Wood Pyrolysis Oil

- Dark brown
- Pungent Odor
- Combustible (not flammable)
- Not miscible with hydrocarbons
- Moisture content: ~30%
- Heating value : 3,800~4,100 kcal/kg
- Density : ~1.2 kg/Liter
- Acid : pH 2.3~2.6 (corrosion of injection system)
- Viscosity is increased with time.
- Wood 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
WPO	9.5	15.9	33.6%	41.0	10.1	48.8	1193.5	5-25
Diesel	2.7	42.6	-	85	12.6	-	821.0	52.6
n-Butanol	3.1	33.1	-	13.6	64.8	21.6	810.0	17
Ethanol	1.1	26.9	<0.3%	52.1	13.2	34.7	772.0	8-10
PEG400	40.4	23.5	0.3%	52.2	9.2	38.6	1130.0	N/A
2-EHN	1.8 (at 20˚C)	27.6	<0.1%	54.9	9.7	27.4	970.0	N/A

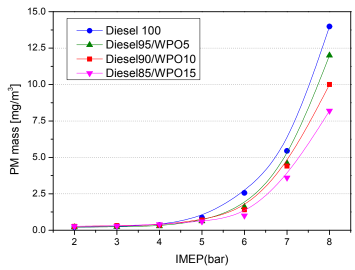
2. Test Engine

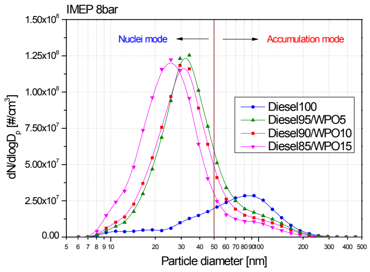


Specifications	Resources
Cylinders	1
Displacements	1,858 cc
Bore/Stroke	130/140 mm
Compression Ratio	28 for WPO blended fuels 17.1 for emulsion & dual-injection
WPO contents	Emulsion : WPO ~ 15% Blended fuel : WPO ~ 30% Dual-injection : WPO ~ 40%
Injection pressure	120 Mpa
Engine speed	1,000 rpm
Engine load	IMEP 0.2 ~ 0.8 Mpa

Results and Discussion

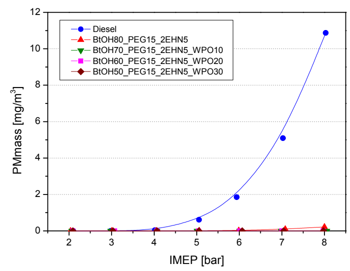
1. Diesel/WPO emulsions

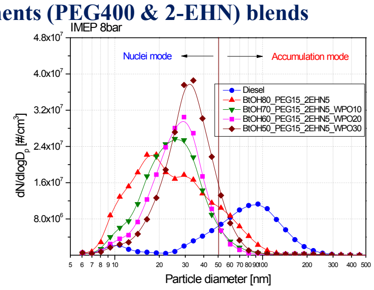




- PM mass tends to increase with increasing engine load, especially higher than IMEP 0.5 MPa. Diesel shows higher PM mass than emulsion fuels. This may be attributed to the high oxygen content in the WPO.
- The particles in nuclei mode from the emulsions shows higher concentrations than did those in diesel. However, diesel showed higher concentrations for the particles in accumulation mode, especially for the particles larger than 70 nm, therefore, an increase in soot occurred.

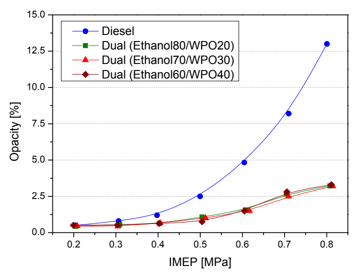
2. N-butanol/WPO/Cetane enhancements (PEG400 & 2-EHN) blends

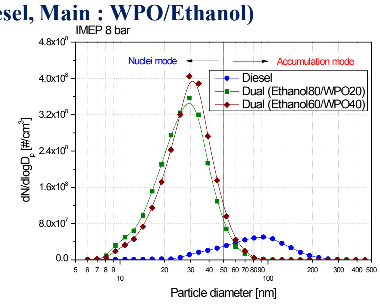




- PM mass of diesel rapidly increases as the engine load increases beyond IMEP 0.4 MPa. It is difficult to identify differences in PM mass between the blended fuels as they have almost zero-level emissions for the entire range of the test conditions.
- The blended fuels have relatively large numbers of nuclei-mode particles and relatively small numbers of accumulation-mode particles (50 ~ 1000 nm) compared to diesel.
- The oxygen atoms help the oxidation of carbon atoms, breaking the bonds, so that carbon atoms are easily converted into gaseous carbon monoxide, or in carbon oxide and solid-state, small-soot particles during the combustion processes.

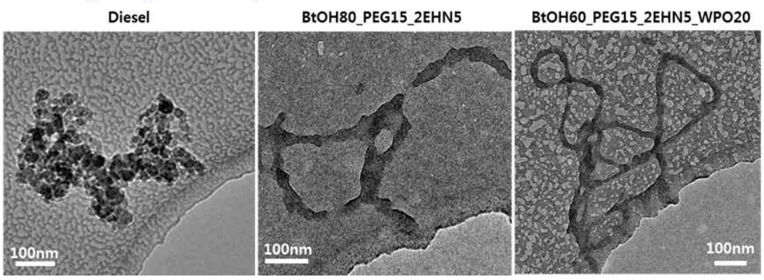
3. Dual-injection strategy (Pilot : Diesel, Main : WPO/Ethanol)





- Opacity increased slightly according to engine load for dual-injection combustion; however, with diesel combustion, there was a sudden increase in PM concentration over IMEP 0.5 MPa. Oxygenated fuels reduce the production of soot precursor species during the fuel rich-premixed ignition and help to oxidize the already-formed soot in a diffusion flame.
- Dual-injection combustion yielded a significantly higher particle number in nuclei mode than diesel only combustion. The highest concentration of particles in accumulation mode was found for diesel combustion; therefore, an abrupt increase in PM occurred.

4. Morphologies of soot particles from diesel and WPO



- Soot particles in the exhaust gas were collected on TEM grid under same engine load.
- For the blended fuels, the morphological features of soot particles were drastically changed compared to diesel soot particles due to the compositional difference of fuels.
- We anticipated the 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 WPO. The high oxygen contents in WPO 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.