Soluble organic fraction of particle emissions and PAH emissions from a non-road engine fuelled with a sulphur free EN590 diesel fuel and biobased alternatives

K. Nuutinen[1], M. Ihalainen[1], K. Kuuspalo[1], T. Karhunen[1], J. Jokiniemi[1,2]

[1] Fine Particle and Aerosol Technology Laboratory, Department of Environmental Science, University of Kuopio, FI-70211 Kuopio, Finland
[2] VTT, Technical Research Centre of Finland, Fine Particles, FI-02044 VTT, Espoo, Finland

Soluble organic fraction, SOF, is defined as the fraction of particle mass soluble in organic solvents like toluene or DCM. In the extraction, the organic species adsorbed on the surface of soot agglomerates during the cooling of the exhaust gas are dissolved. The health-harming potency of particles is often associated with the organic constituents in particles, like PAHs. Thus measuring SOF may give some indication of the toxicological properties of the particles. Also the efficiency of the particle reduction by catalytic converters is affected by the chemical properties of the particles. In this study, soluble organic fraction of particles, SOF, and PAH content were analysed from diesel engine emissions.

In the experiments, EPA Tier 1 / EU Stage 2 Kubota D1105-T diesel engine was used in combination with a 30 kW Froude Consine eddy current dynamometer system.

Table 1. Engine, fuels and modes

Engine				
Model	Kubota D1105-T			
Type	4-cycle diesel			
Displacement [l]	1.123			
ISO Gross [kW/rpm]	24.5/3000			
Fuels	EN590[a], HVO[b], RME[c]			
Lubricant	fully synthetic Neste Turbo E6 SAE 10W-40			
Modes				
	RS100	RS50	RS10	IS75
Speed [rpm]	3000	3000	3000	2050
Torque [Nm]	70.7	35.3	7.1	59.9

[a] sulphur free petroleum based diesel fuel
[b] hydrotreated vegetable oil NExBTL (Rantanen *et al.*, 2005)
[c] rapeseed methyl ester, a first generation biodiesel

The fuels used were sulphur free EN590, HVO and RME. Particle samples were taken from four modes of the test cycle C1 (ISO 8178-4:1996(E)). Engine, fuels and modes are presented in Table 1. Also tests with a DOC+POC-X catalytic converter made by Ecocat Ltd. were conducted; the converter is described in Lehtoranta *et al.*, 2007.

Soluble organic fraction of particles, SOF, was measured by drawing a particle sample on a weighed filter (Emfab, Pall, 47 mm) from a dilution tunnel (ISO 8178). Filters were weighed before and after a 16-hour-extraction with toluene in a Soxhlet apparatus. The soluble organic fraction is the fraction of particles dissolved during the extraction. From the extracts, ten polycyclic aromatic hydrocarbons (PAH) were analyzed with a GC–MS (Agilent). The sample handling procedure is described in Hytönen *et al.* (2009).

Emissions of soluble organic particles (Fig. 1) and PAHs increased with decreasing load, probably due to a lower combustion temperature. HVO had the lowest SOF emissions. The decrease in the average SOF emissions was, depending on the mode, from 4% to 51% when EN590 was replaced with HVO. The same trend was found, for example, in particle mass emission (Ihalainen *et al.*, 2009). This is most likely due to the higher cetane number and the lack of heavy aromatics in HVO. The average reduction of SOF emissions by the DOC+POC-X ranged from 75% to 99%; the soluble particle material was reduced more efficiently than the insoluble material.

SOF emission from the blends of vegetable oil ester and petroleum based

diesel fuel has been reported to be higher than the emission from pure petroleum diesel; a reason for this can be that in biodiesel combustion, products of incomplete combustion are less volatile (Lin *et al.*, 2008, Bagley *et al.*, 1998).

Lehtoranta *et al.* (2007) found that DOC+POC-X reduced SOF emissions from heavy duty diesel engine fuelled with EN590 by 81-90%, which is in a good agreement with our results.

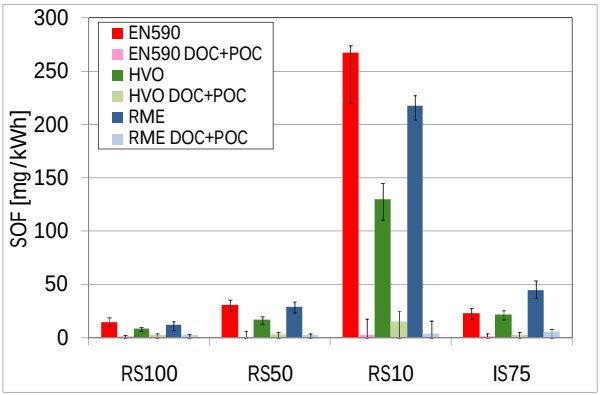


Figure 1. Soluble organic fraction of particle emissions (mg/kWh).

Concerning particle phase PAHs, HVO and RME had generally lower emissions than EN590; the reduction varied between the modes. PAH emissions from RS100 mode are presented as an example; the most abundant PAHs in the particle phase were fluoranthene and pyrene (Fig. 2). DOC+POC-X was successful in reducing PAH emissions; the average reduction ranged from 12% to 94%.

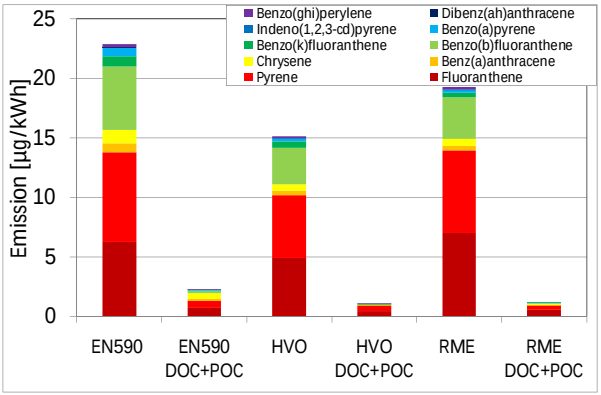


Figure 2. PAH emissions from RS100 mode (µg/kWh).

Rantanen *et al.* (2005) found the emission of 7 particle phase PAHs to be reduced by 70-80% when EN590 was replaced with a 85 vol-% HVO blend. Also according to Bagley *et al.* (1998), soy methyl ester fuel caused several tens of percents lower PAH emissions compared to low-sulphur petroleum diesel fuel.

This work was supported by Graduate School in Physics, Chemistry, Biology and Meteorology of Atmospheric Composition and Climate Change, Tekes, The Finnish Funding Agency for Technology and Innovation, Ecocat Oy, Neste Oil Corporation, Sisudiesel Oy and Preseco Oy.

Bagley, S.T., Gratz, L.D., Johnson, J.H. & McDonald, J.F. (1998). Environ. Sci. Technol. 32:1183-1191

Hytönen, K., Yli-Pirilä, P., Tissari, J., Gröhn, A., Riipinen, I., Lehtinen, K.E.J. & Jokiniemi, J. (2009). Aerosol Sci. Technol. 43:442-454

Ihalainen, M., Kuuspalo, K., Karhunen, T., Ruusunen, J., Willman, P., Tapanainen, M., Jalava, P., Salonen, R.O., Pennanen, A., Happo, M., Hirvonen, M-R. & Jokiniemi, J. (2009). The 13th ETH-Conference on Combustion Generated Nanoparticles, June 22nd – 24th 2009.

Lehtoranta, K., Matilainen, P., Åsenbrygg, J.M., Lievonen, A., Kinnunen, T.J.J., Keskinen, J. & Solla, A. (2007). SAE Technical Paper Series 2007-24-0093.

Lin, Y-C., Lee, W-J., Chao, H-R., Wang, S-L., Tsou, T-C., Chang-Chien, G-P. & Tsai, P-J. (2008). Environ. Sci. Technol. 42:3849–3855

Rantanen, L., Linnaila, R., Aakko, P. & Harju, T. (2005). SAE 2005-01-3771.

Soluble organic fraction of particle emission and PAH emissions from a non-road engine fuelled with a sulphur free EN590 diesel and biobased alternatives

Kati Nuutinen[1], Mika Ihalainen[1], Kari Kuuspalo[1], Tommi Karhunen[1], Jorma Jokiniemi [1,2]

[1]University of Kuopio, Dept. of Environmental Science, Fine Particle and Aerosol Technology Laboratory, P.O.Box 1627, FIN-70211 Kuopio, Finland
[2]VTT Technical Research Centre of Finland, Fine Particles, P.O. Box 1000, 02044 VTT, Espoo, Finland

introduction

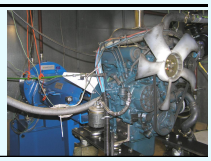
Soluble organic fraction, SOF, is determined by extracting particles collected from diesel exhaust emissions with organic solvent, for example with toluene or DCM. By this extraction, organic species adsorbed on the surface of soot agglomerates during the cooling of the exhaust gas are dissolved.

The health-harming potency of particles is often associated with organic constituents in particles, like PAHs. That is why measuring SOF may give indication of toxicological properties of particles.

methods

Engine, fuels, and modes

Engine				
Model	Kubota D1105-T			
Type	4-cycle diesel			
Displacement [l]	1.123			
ISO Gross [kW/rpm]	24.5/3000			
Fuels	EN590[a], HVO[b], RME[c]			
Lubricant	fully synthetic Neste Turbo E6 SAE 10W-40			
Modes				
	RS100	RS50	RS10	IS75
Speed [rpm]	3000	3000	3000	2050
Torque [Nm]	53	35.3	7.1	59.9



[a] sulphur free diesel
[b] hydrotreated vegetable oil NExBTL (Rantanen *et al.*, 2005)
[c] rapeseed methyl ester, a first generation biodiesel

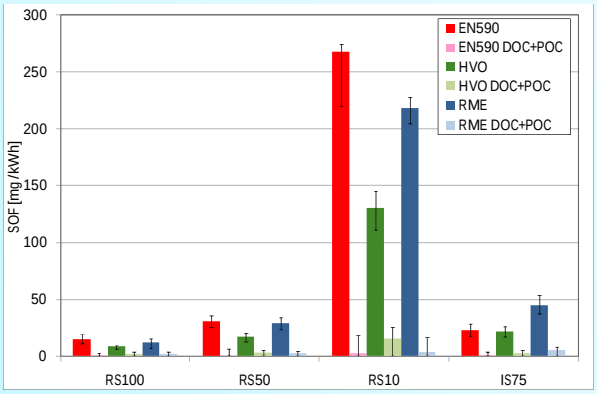
In the experiments, EPA Tier 1 / EU Stage 2 water cooled diesel Kubota D1105-T was used in combination with a 30 kW Froude Consine eddy current dynamometer system.

Tests with DOC+POC-X catalyst made by Ecocat Ltd. were conducted. The catalyst is described in Lehtoranta *et al.*, 2007.

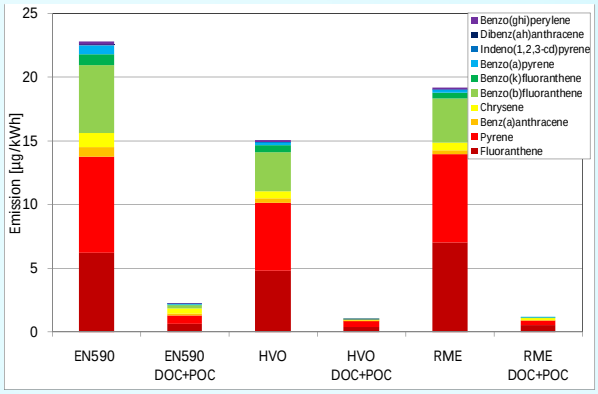
Particle samples were taken from four modes of the test cycle C1 (ISO 8178-4:1996(E)) by drawing particle sample on a weighed filter (Emfab, Pall, 47 mm) from dilution tunnel (ISO 8178). Filters were weighed before and after the 16-hour-extraction with toluene in Soxhlet apparatus.

The soluble organic fraction is the fraction of particles dissolved during the extraction. From the extracts, ten polycyclic aromatic hydrocarbons were analyzed with a GC-MS (Agilent). The sample handling procedure is described in Hytönen *et al.* (2009).

results & conclusions



Soluble organic fraction of particle emission (mg/kWh).



PAH emissions from RS100 mode (µg/kWh).

Emissions of soluble organic particles and PAHs increased with decreasing load, probably due to a lower combustion temperature.

HVO had the lowest SOF emissions. The decrease in the average SOF emission was, depending on the mode, from 4% to 51% when EN590 was replaced with HVO. The same trend was found, for example, in particle mass emission (Ihalainen *et al.*, 2009). This is most likely due to the higher cetane number and the lack of heavy aromatics in HVO. The average reduction of SOF emissions by the DOC+POC-X ranged from 75% to 99%; the soluble particle material was reduced more efficiently than the insoluble material.

PAH emission had not such a clear trend between the fuels as SOF content. The most abundant PAHs in the RS100 mode particle emission were fluoranthene and pyrene. The average reduction of PAH emissions by the DOC+POC-X ranged from 12% to 94%.

references & acknowledgements

▪ Hytönen *et al.* (2009). Aerosol Sci. Technol. 43:442-454
▪ Ihalainen *et al.* (2009). In the 13th ETH-Conference on Combustion Generated Nanoparticles, June 22nd – 24th 2009
▪ Lehtoranta *et al.* (2007). SAE Technical Paper Series 2007-24-0093.
▪ Rantanen *et al.* (2005). SAE 2005-01-3771.

This work was supported by Graduate School in Physics, Chemistry, Biology and Meteorology of Atmospheric Composition and Climate Change, The Finnish Funding Agency for Technology and Innovation Tekes, Ecocat Oy, Neste Oil Corporation, Sisudiesel Oy and Preseco Oy.