On emission and composition of PM from medium speed 4-stroke Diesel engines for biofuel operation

P. Lauer, MAN Diesel SE, Stadtbachstrasse 1, 86224 Augsburg, Germany

Keywords: Particulate matter, combustion aerosols, measurement, characterization, chemical composition, carbonaceous particles, volatile and nonvolatile fraction, exhaust gas after treatment, SCR catalyst, biofuel.

Motivation

Compared to gaseous emission components there is still limited knowledge available today of particulate emissions from large Diesel engines. The emission of particulates in the environment, the detailed chemical composition and aerosol properties are widely unknown. Therefore measurements have been performed on a large medium speed four stroke Diesel engine for stationary application (picture 1) at different engine loads. Waste edible fat as a biofuel was used in combination with catalytic exhaust gas aftertreatment and compared to conventional fossil fuels without exhaust gas aftertreatment.

Picture 1: Power plant at municipal sewage plant

Methods

Measurements have been performed on a 6 and 8 cylinder L21/31 medium speed four stroke Diesel engine (table 1).

Type	Bore	Stroke	Speed	Power
turbocharged inline	21 cm	31 cm	1000 rpm	215 kW/cyl

Table 1: Main engine data

The particulate matter (PM) was measured according to ISO-8178 with a mobile version of the AVL-472 Smart Sampler dilution system (picture 2) and the PM was collected on quartz fiber filters for chemical characterization.

Picture 2: Mobile dilution system for PM measurement

The PM constituents have been analyzed for elemental carbon (EC) and organic carbon (OC) thermographically and for sulfates (SO_4) ionchromatographically. The sulfate bound water (H_2O), organic material (OM) and ash constituents have been calculated from the analyzed sulfates, organic carbon and from the fuel and lube oil ash content.

The typical fuel used in marine transport is residual fuel oil e.g. heavy fuel oil (HFO), which is a waste product from refinery processes. The mean sulfur content of these fuels is in the range of 2.7% (Kassinger, 2005). For so-called "SO_x Emission Control Areas" like the Baltic Sea a maximum sulfur content of 1.5% is allowed according to IMO regulations (IMO MARPOL 73/78 Annex VI, 1997). It is expected that residual fuels will persist as the main fuel for ship propulsion in the future. For applications with even more restricted sulfur regulations marine gas oil (MGO) is used. For stationary applications renewable fuels can be used if enough quantity is available. For example waste edible fat can be collected, filtered and utilized in a power plant. The characteristic values of the investigated fuels are listed in (table 2).

Fuel	HFO	MGO	Waste fat
Origin	fossil	fossil	renewable
Category	residual	distillate	biological
Viscosity @ 50°C [mm²/s]	576	2,6	31
Density @ 15°C [kg/m³]	990	831	923
Hydrogen [% mass]	10.3	13.5	11,3
Carbon [% mass]	86.9	86.3	78.0
Oxygen [% mass]	n.a.	n.a.	10.7
Sulfur [% mass]	2.3	0.1	0.0035
Nitrogen [% mass]	0.5	0.1	n.a.
Ash [% mass]	0.05	0.01	0.0022
Lower heat value [kJ/kg]	40473	43168	36789

Table 2: Main fuel characteristics

Picture 3: Fuel samples

Exhaust gas after treatment can be employed, if prerequisites like fuel quality and certain exhaust gas temperatures are fulfilled. For example a selective catalytic reduction (SCR) to reduce nitrogen oxides (NO_x) and an oxidation catalyst (Oxi-Kat) to reduce carbon monoxides (CO), hydrocarbons (HC) and to avoid amonia slip from the NO_x reducing agent are used in this case for the waste edible fat.

Results

The PM emission from a large medium speed Diesel engine consist mainly of volatiles like organic material, sulfate bound water and sulfates. Different fuels show significantly different amounts of sulfates, sulfate bound water and ash according to their composition.

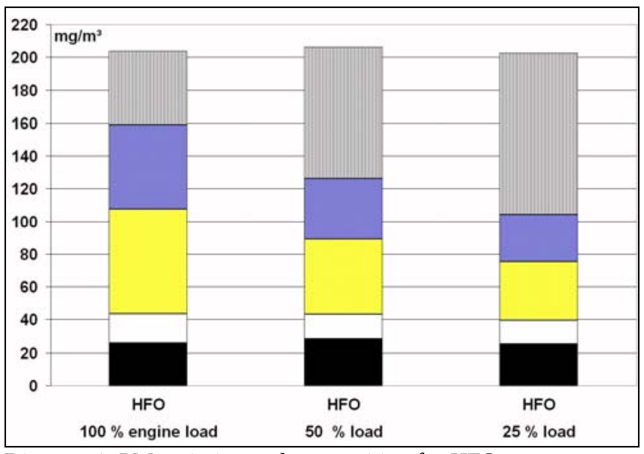

Diagram 1: PM emission and composition for HFO

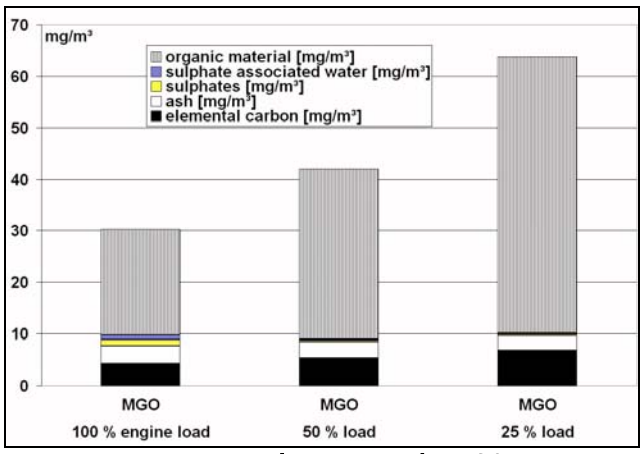

Diagram 2: PM emission and composition for MGO

With decreasing engine load the amounts of sulfates and sulfate bound water decreases whereas the amount of organic material increases. A lower fuel oil quality leads to an increased total particulate emission as can be seen in comparison between HFO and MGO. Compared to the MGO the waste edible fat shows a significantly higher amount of organic material whereas the elemental carbon amount is lower. This is due to the improved soot oxidation during combustion by the oxygen content of the waste fat.

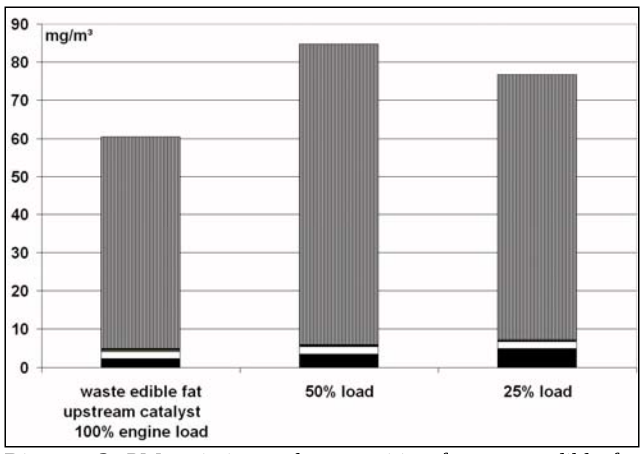

Diagram 3: PM emission and composition for waste edible fat upstream of catalyst

The catalyst shows a significant reduction of the organic material as well as a slight reduction of the elemental carbon. At the same time the sulfates and sulfate bound water increases due to oxidation of the sulfur from the fuel and lube oil by the catalyst.

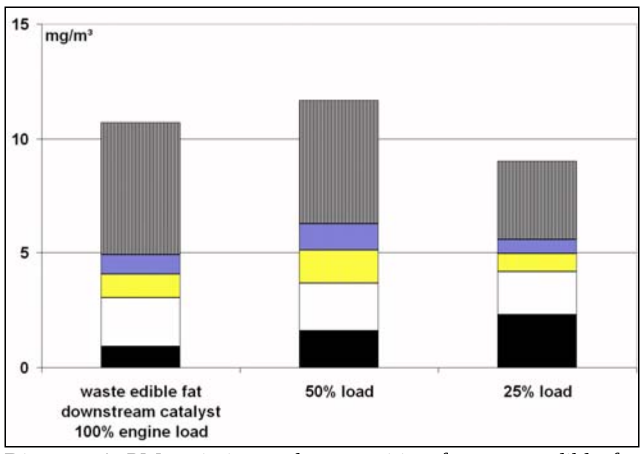

Diagram 4: PM emission and composition for waste edible fat downstream of catalyst

Alternative fuels will play a more important role also for large Diesel engines in the future because of the reduction/substitution potential of fossil CO_2 emissions. In contrary to pre processed or transesterified oils like fatty acid methyl ester (FAME, DIN EN 14214) for small high-speed engines not pre-processed fuels will be utilized in such large Diesel engines. Hence in the future there will be an increasing demand for large Diesel engines to operate on alternative fuels like waste edible fat/oil, rape oil, soy bean oil, palm oil, biodiesel or even recycled fat of dead animals. It could be successfully demonstrated that waste edible fat can be used for large Diesel engines in combination with exhaust gas aftertreatment.

Acknowledgements

Germanischer Lloyd, C. Kurok, Vorsetzen 32/35, 20459 Hamburg, Germany, for analyzing of the collected PM-filters.

Abwasserverband Hall in Tirol – Fritzens, K. Pfurtscheller, Innstraße 12, 6122 Fritzens, Austria, for the measurement opportunity.

References

Kassinger, R., Det Norske Veritas (DNV) *Haagen-Smit Symposium*, 2005.

International Maritime Organization, Regulation for the prevention of air pollution from ships, *IMO MARPOL 73/78 Annex VI*, 1997.

Author

Peter Lauer, MAN Diesel SE, Stadtbachstrasse 1, 86224 Augsburg, Germany.

On emission and composition of PM from medium speed 4-stroke Diesel engines for biofuel operation

Motivation

Compared to gaseous emission components there is still limited knowledge available today of particulate emissions from large Diesel engines. The emission of particulates in the environment, the detailed chemical composition and aerosol properties are widely unknown. Therefore measurements have been performed on a large medium speed four stroke Diesel engine for stationary application (picture 1) at different engine loads. Waste edible fat as a biofuel was used in combination with catalytic exhaust gas aftertreatment and compared to conventional fossil fuels without exhaust gas aftertreatment.

Picture 1: Power plant at municipal sewage plant

Methods

Measurements have been performed on a 6 and 8 cylinder L21/31 medium speed four stroke Diesel engine (table 1).

Type	Bore	Stroke	Speed	Power
turbocharged inline	21 cm	31 cm	1000 rpm	215 kW/cyl

Table 1: Main engine data

The particulate matter (PM) was measured according to ISO 8178 with a mobile version of the AVL-472 Smart Sampler dilution system (picture 2) and the PM was collected on quartz fiber filters for chemical characterization.

Picture 2: Mobile dilution system for PM measurement

The PM constituents have been analyzed for elemental carbon (EC) and organic carbon (OC) thermographically and for sulfates (SO4) ionchromatographically. The sulfate bound water (H2O), organic material (OM) and ash constituents have been calculated from the analyzed sulfates, organic carbon and from the fuel and lube oil ash content.

The typical fuel used in marine transport is residual fuel oil e.g. heavy fuel oil (HFO), which is a waste product from refinery processes. The mean sulfur content of these fuels is in the range of 2.7% (Kassinger, 2005). For so-called "SOx Emission Control Areas" like the Baltic Sea a maximum sulfur content of 1.5% is allowed according to IMO regulations (IMO MARPOL 73/78 Annex VI, 1997). It is expected that residual fuels will persist as the main fuel for ship propulsion in the future. For applications with even more restricted sulfur regulations marine gas oil (MGO) is used. For stationary applications renewable fuels can be used if enough quantity is available. For example waste edible fat can be collected, filtered and utilized in a power plant. The characteristic values of the investigated fuels are listed in (table 2).

Fuel	HFO	MGO	Waste fat
Origin	fossil	fossil	renewable
Category	residual	distillate	biological
Viscosity @ 50°C [mm²/s]	576	2,6	31
Density @ 15°C [kg/m³]	990	831	923
Hydrogen [% mass]	10.3	13.5	11,3
Carbon [% mass]	86.9	86.3	78.0
Oxygen [% mass]	n.a.	n.a.	10.7
Sulfur [% mass]	2.3	0.1	0.0035
Nitrogen [% mass]	0.5	0.1	n.a.
Ash [% mass]	0.05	0.01	0.0022
Lower heat value [kJ/kg]	40473	43168	36789

Table 2: Main fuel characteristics

Picture 3: Fuel samples

Exhaust gas after treatment can be employed, if prerequisites like fuel quality and certain exhaust gas temperatures are fulfilled. For example a selective catalytic reduction (SCR) to reduce nitrogen oxides (NOx) and an oxidation catalyst (Oxi-Kat) to reduce carbon monoxides (CO), hydrocarbons (HC) and to avoid amonia slip from the NOx reducing agent are used in this case for the waste edible fat.

Results

The PM emission from a large medium speed Diesel engine consist mainly of volatiles like organic material, sulfate bound water and sulfates. Different fuels show significantly different amounts of sulfates, sulfate bound water and ash according to their composition.

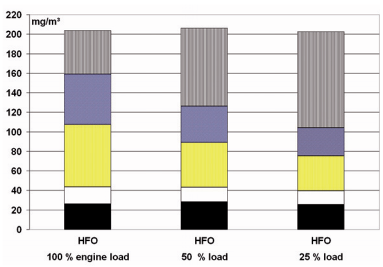

Diagram 1: PM emission and composition for HFO

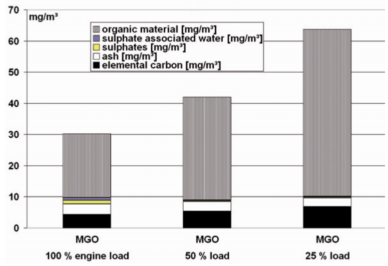

Diagram 2: PM emission and composition for MGO

With decreasing engine load the amounts of sulfates and sulfate bound water decreases whereas the amount of organic material increases. A lower fuel oil quality leads to an increased total particulate emission as can be seen in comparison between HFO and MGO. Compared to the MGO the waste edible fat shows a significantly higher amount of organic material whereas the elemental carbon amount is lower. This is due to the improved soot oxidation during combustion by the oxygen content of the waste fat.

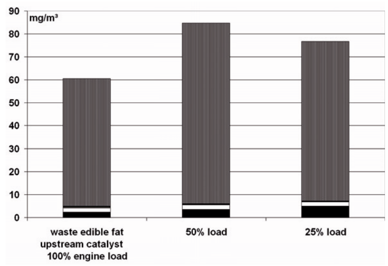

Diagram 3: PM emission and composition for waste edible fat upstream of catalyst

The catalyst shows a significant reduction of the organic material as well as a slight reduction of the elemental carbon. At the same time the sulfates and sulfate bound water increases due to oxidation of the sulfur from the fuel and lube oil by the catalyst.

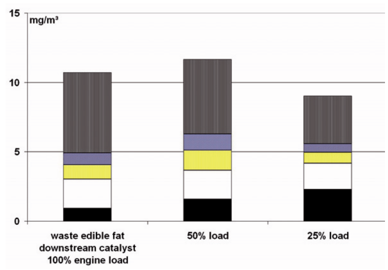

Diagram 4: PM emission and composition for waste edible fat downstream of catalyst

Alternative fuels will play a more important role also for large Diesel engines in the future because of the reduction/substitution potential of fossil CO2 emissions. In contrary to pre processed or transesterified oils like fatty acid methyl ester (FAME, DIN EN 14214) for small high-speed engines not pre-processed fuels will be utilized in such large Diesel engines. Hence in the future there will be an increasing demand for large Diesel engines to operate on alternative fuels like waste edible fat/oil, rape oil, soy bean oil, palm oil, biodiesel or even recycled fat of dead animals. It could be successfully demonstrated that waste edible fat can be used for large Diesel engines in combination with exhaust gas aftertreatment.

Acknowledgements

Germanischer Lloyd, C. Kurok, Vorsetzen 32/35, 20459 Hamburg, Germany, for analyzing of the collected PM-filters.
Abwasserverband Hall in Tirol – Fritzens, K. Pfurtscheller, Innstraße 12, 6122 Fritzens, Austria, for the measurement opportunity.

References

Kassinger, R.: Det Norske Veritas (DNV) Haagen-Smit Symposium, 2005.
International Maritime Organization, Regulation for the prevention of air pollution from ships, IMO MARPOL 73/78 Annex VI, 1997.

Author

P. Lauer, MAN Diesel SE AG, Stadtbachstrasse 1, 86224 Augsburg, Germany.

MAN Diesel