Field test in tractors with low ash engine oil, Shell Rimula R6 LM

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Introduction

Diesel particulate filters (DPF) are effective systems for reducing hazardous diesel soot particle emissions. As in construction, vehicles in agriculture and forestry are increasingly being retrofitted with DPFs due to more stringent exhaust emission regulations and in a few years, exhaust post-treatment systems will be standard equipment on agricultural and forestry vehicles.

A small quantity of engine oil always passes between piston rings and cylinder liner and is burnt in the combustion process. However, engine oil contains additives that are not completely burnt, forming ash that is captured in any DPF fitted (Illustration 1). Accumulation of ash in the filter causes a decrease in the deposition surface, producing a reduction in soot storage capacity and an increase in exhaust back pressure, which causes a reduction in power and increased fuel consumption.

To investigate the influence of engine oil quality on the quantity of ash, the Agroscope Reckenholz-Tänikon research station (ART) conducted a field test in association with Shell Global Solutions.

Illustration 1: Rod-shaped ash deposits in particle filters.

Methodology
Two agricultural tractors and one specialised forestry machine equipped with particulate filter systems (one Continuously Regenerating Technology (CRT©), one Catalysed Continuously Regenerating Technology (CCRT©) and one electric heating), which were already involved in the Retrofitting of Particulate Filters project at ART [1], were operated for one year with a conventional SAE 10W-40 engine oil (Table 1). These filter systems do not need fuel additives so ash produced by so-called fuel born catalysts (FBC) could be ruled out. During this time, the machines operated for between 410 and 670 hours.

Table 1: Vehicles used in field testing

			
Machine	**Fendt 411 Vario**	**Deutz-Fahr Agrotron K100**	**HSM 805HD**
Engine	Deutz BF 4M 2013C	Deutz BF 4M 2012C	Iveco F4AE 04841A*C
Regenerating technology	CRT©	Electric heated	CCRT©

After operating with the conventional engine oil, the filters were cleaned. The accumulated soot/ash mixture was carefully collected and then incinerated in an oven at 750°C for four hours, burning the residual soot, to leave only the ash. The engines were then converted to Shell Rimula R6 LM SAE 10W-40, which is the latest fully-synthetic, low SAPS (oil with low **s**ulphated **a**sh, **p**hosphorus and **s**ulphur content) heavy duty engine oil technology. The machines then worked under conditions similar to those with the conventional engine oil. During the field test, used oil samples were taken every 100 operating hours in order to monitor oil condition. Used oil viscosity, Total Base Number, Total Acid Number, Dispersancy and wear metal content were determined for each sample. Every 60 seconds, a data logger recorded exhaust back pressure and exhaust temperature. Fuel consumption and oil top up were recorded. After the same operating period as in the first part of the experiment, the filters were again cleaned and the ash quantity was determined. The chemical composition of the ash samples was determined using X-ray fluorescent analysis.

Results

The fully-synthetic, low SAPS engine oil Shell Rimula R6 LM SAE 10W-40 reduced the quantity of ash in all three test vehicles by 44 - 63 %. The used oil analysis data clearly indicated that both engine and engine oil were in a very good condition, with the dispersancy always being satisfactory, ensuring that sludge deposits were avoided. In all cases, oil consumption was low at less than 0.1% of fuel consumption. The ash samples were mainly calcium oxide, sulphur oxides and phosphates.

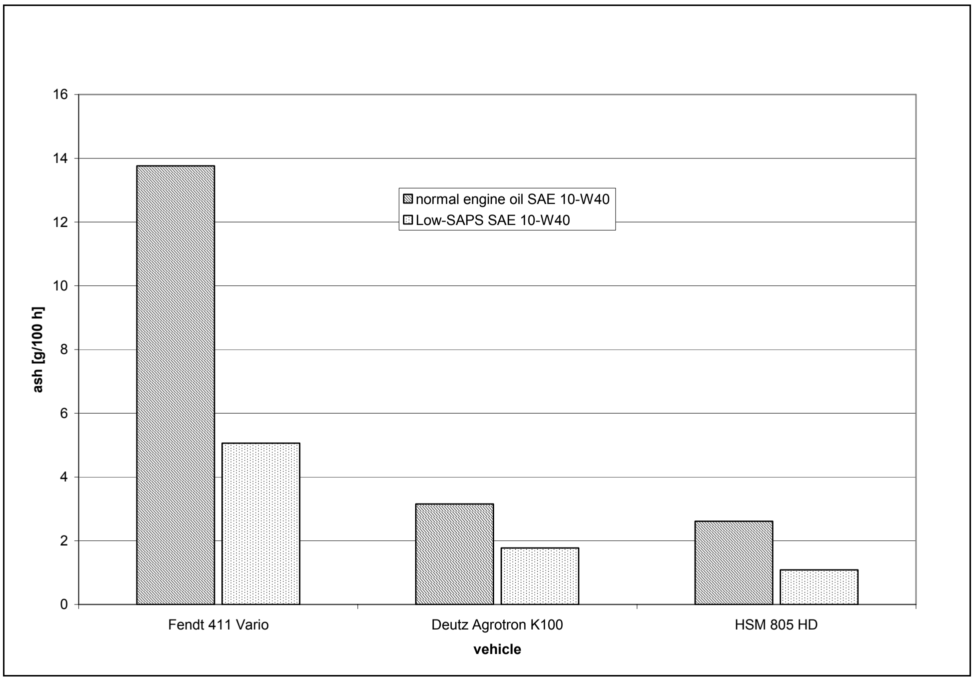

Illustration 2: Change in ash quantity based on 100 operating hours with different engine oils.

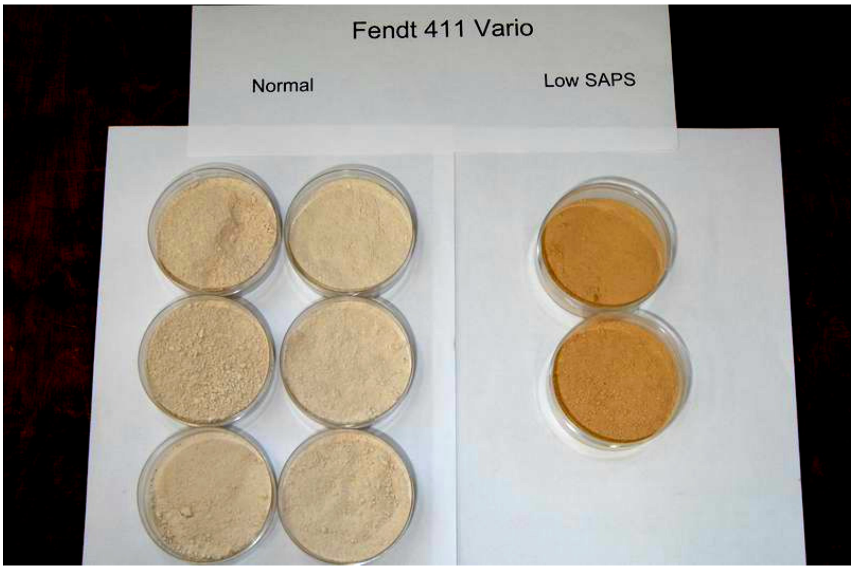

Illustration 3: Ash quantities from Fendt 411 Vario tractor with a CRT© filter. Operating time with each oil was 553 hours. Left: ash quantity with conventional engine oil (76 g), right: with Shell Rimula R6 LM SAE 10W-40 (28 g).

Conclusion

Using fully synthetic low SAPS-oil decreases significantly the amount of ash in the particulate filter. Operators will benefit from significantly lower maintenance costs in terms of DPF cleaning, engine durability and oil drain interval.

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Reduction of diesel exhaust particulates by retrofitting tractors with particulate filters

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Current knowledge indicates that the soot particles produced by diesel engines are among the constituents of PM-10 particulate which are most detrimental to health. Because individual particles are so small – 0.1 µm on average – they are able to penetrate the pulmonary alveoli. In Switzerland around 400 tonnes of diesel exhaust particulate are emitted by agricultural machinery every year [1]. Exhaust Gas Stage 3B will bring in more stringent mass-related particulate limits but, as it is not scheduled for introduction until 2011 and agricultural vehicles have a long service life, it seemed advisable to investigate the retrofitting of agricultural machinery with particulate filters.

A closed particulate filter generally comprises a honeycombed filter body made from silicon carbide, cordierite or sintered metal. Because the channels are alternately closed, the exhaust gas is forced to pass through the porous separating walls of the monolyte. The soot is deposited as it does so. Low flow speeds are needed to obtain good separation, making a certain overall filter size necessary. In order to prevent the filter becoming clogged, the soot is periodically or continuously burned to produce carbon dioxide gas (CO_2) and a small amount of ash. Soot consists mainly of carbon, and normally starts to burn at temperatures above 600°C (soot ignition point). As such high exhaust gas temperatures are hardly ever reached in practice, there are basically two strategies for burning the soot: in active filter systems additional thermal energy is supplied during regeneration, for example by means of electricity or a diesel burner. In passive filter systems the soot ignition point is reduced to under 300 °C by connecting an in-line oxidation catalytic converter upstream of the filter, coating the filter or introducing an additive to the fuel.

Experimental setup

The aim of the project, which received financial backing from the Federal Office for the Environment (FOEN, Bern, Switzerland), was to clarify all the requirements for the use of particulate filters on tractors. Robustness, convenience of operation, efficiency of particle elimination (in accordance with BAFU/SUVA filter list [2] and SNR 277205 [3]) and cost effectiveness were to be evaluated. For this purpose eight tractors and one self-propelled loader used in different areas of farming and forestry were chosen for retrofitting with filter systems. The exhaust gas temperatures of the trial vehicles were recorded over a prolonged period using a data logger. On the basis of the recordings the suppliers selected and installed an appropriate particulate filter system. Both active and passive filter systems were used.

Fig. 1: Tractor retrofitted with a particulate filter.

Practical experience

The mounting position proved difficult, with few exceptions. Attachments such as front-end loaders severely restricted the space available. The commonest solution was a vertical arrangement along the A-pillar of the cab (Fig. 1), which restricted the field of vision to a greater or lesser extent.

The back pressures logged on the trial vehicles varied between 50 and 150 mbar in operation. By means of adequate particulate filter dimensioning the aim was to obtain exhaust back pressures equal to or only slightly higher than those with the original exhaust system (Fig. 2). Individual maximum values reached 200 mbar, some therefore being higher than those permitted by the engine manufacturers. On specific trial installations the filter selected produced excessive back pressure, so a larger filter had to be fitted.

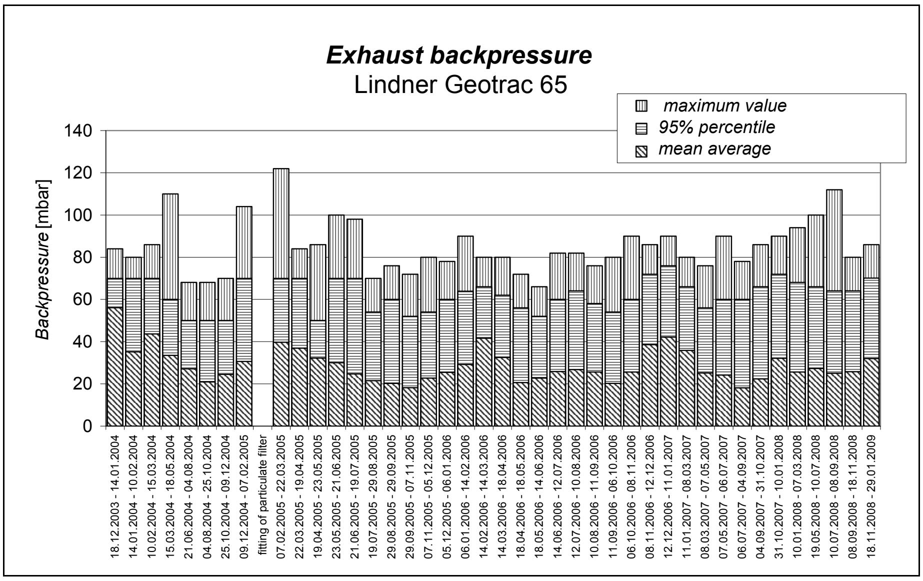

Fig. 2: Development of exhaust backpressure with and without particulate filter (Lindner Geotrac 65 tractor)

Two trial vehicles are in problem-free use, and one has already completed over 1800 hours without any faults being reported. Certain trial vehicles featured ideal operating conditions for the passive filter system, in that high exhaust temperatures occurred regularly, for example when a mixing trailer was used or heavy handling or field work was carried out. The active systems operated at low exhaust temperatures, easily burning the accumulated soot with electrical energy from the mains or using a diesel burner during a definite increase in back pressure (i.e. increasing filter loading). This had to be done after about every eight to 35 operating hours, depending on use, and took around one hour with the electrical system, around 15 minutes with the burner system.

Defects, such as a defective diesel burner glow plug or faults in the electronic filter monitoring system, occurred during the operation of some vehicles, but these could be rectified relatively quickly. In a very few cases the filters clogged, which meant that work had to be interrupted for filter cleaning.

Serious malfunctions requiring removal of the particulate filter occurred in five vehicles. The failures were caused, for example, by the unfavourable operative range of the trial vehicle, working at low loading in conjunction with a passive filter or the use of filters which were still at the prototype stage.

High filter efficiency

The number of particles was counted for particle measurement. The advantage of this over particle weighing is that it takes into account even the ultrafine particles which barely signify during weighing. All the closed filter systems tested had a high separation rate of over 99 % when new (Fig. 3). The FAT 6-level cycle was used for exhaust measurements [4]. This cycle comprises six different points from the entire engine map. Power was taken from the tractors' power take-off shaft. The power only had to be measured hydraulically in the case of the self-propelled loader. Measuring point 1 is at high engine speed and high loading, measuring point 6 corresponds to the lower idle speed of the engine. At such low engine loading the particle concentration in the exhaust downstream of the filter was lower than in the ambient air, proof of high filter efficiency.

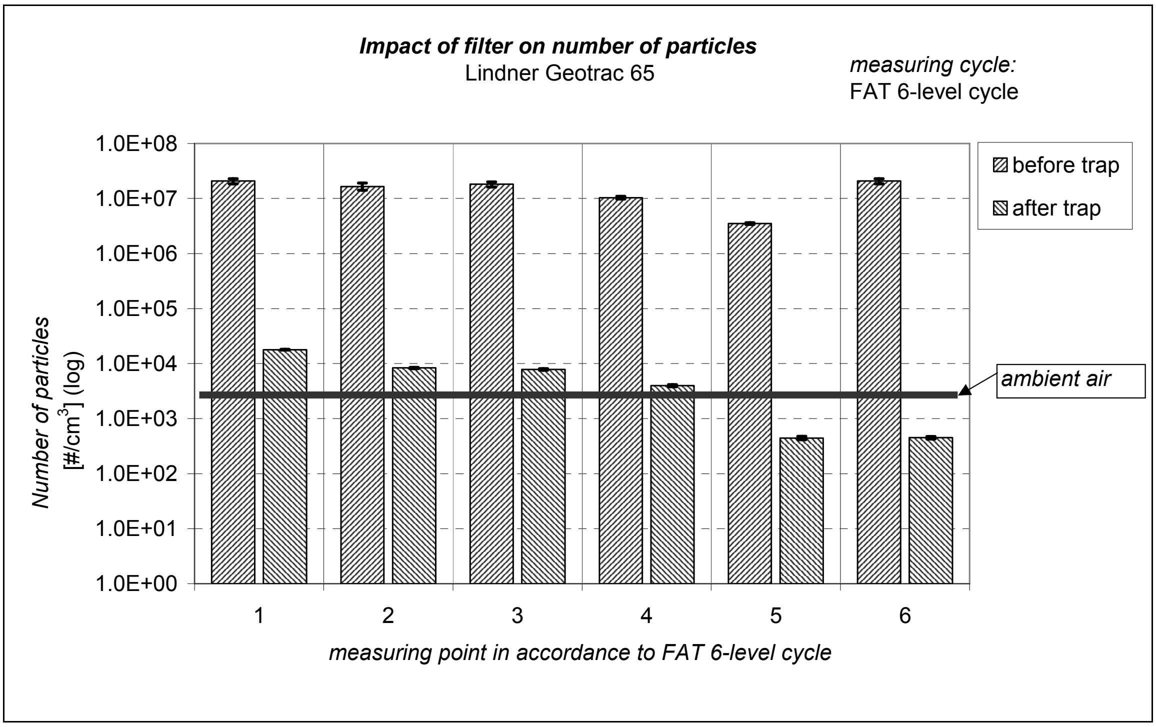

Fig. 3: Impact of filter on number of particles. Measuring points according to FAT 6-level test.

Cost

The capital expenditure for the installation of a particulate filter in a medium-sized tractor is between EUR 5,000 and 10,000. This price includes fitting. The price depends on various factors: engine size, particulate filter system, and especially the effort involved in fitting. As it is still impossible to say how long a filter will last, it is extremely difficult to estimate the anticipated extra cost per operating hour. In addition to the cost of purchase there is the recurring cost of servicing and maintenance. Cleaning ash from the filter, which has to be done every 250 to 1000 operating hours, costs approximately an extra EUR 300 each time. Further additional expenses may be incurred, such as the cost of electricity for regeneration in electrical systems, additive costs for additive systems, fuel costs for regeneration using a burner system.

Summary and outlook

Particulate filters for the reduction of particulate emissions were retrofitted to eight tractors and one self-propelled loader. The vehicles were used in various areas of agriculture and forestry in order to cover as many different types of work as possible. The closed particulate filters were made by different manufacturers and had different regeneration systems.

The effectiveness of all the filters measured was exceptionally high when new, with a separation level of 99 % in relation to the fine particle count. Various problems arose during fitting and operation: large space requirement for the filter during assembly, failure to reach the requisite exhaust temperatures, filter insufficiently dimensioned to prevent a rise in back pressure, failure of the filter monitoring electronics to the point of filter write-off, though none of these ever caused engine damage.

In legislation at European level, EU Stage IIIB will considerably reduce the particulate limit for vehicles > 37 kW in 2011 to 2013, graduated by power rating [5]. This limit value relates to particle mass, however, not particle number. For compliance with this limit value the following technical solutions are conceivable:

- Engine with exhaust gas recirculation and a closed particulate filter. It is assumed here that engine control is adjusted to the particle filter and can control regeneration reliably
- Engine with exhaust gas recirculation and an open filter or oxidation catalytic converter
- Engine with SCR (**s**elective **c**atalytic **r**eduction) system or SCRT system.

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- [4] Rinaldi M., Erzinger S. u. Stark R. 2005: Treibstoffverbrauch und Emissionen von Traktoren bei landwirtschaftlichen Arbeiten. FAT-Schriftenreihe Nr. 65, Ettenhausen.
- [5] Commission Directive 2005/13/EC of 21 February 2005 amending Directive 2000/25/EC of the European Parliament and of the Council relating to the emission of gaseous and particulate pollutants by engines intended to power agricultural or forestry tractors, and amending Annex I to Directive 2003/37/EC of the European Parliament and of the Council relating to type approval for agricultural and forestry tractors.

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INTRODUCTION

A small quantity of engine oil always passes between piston rings and cylinder liner and is burnt in the combustion process. However, engine oil contains additives that are not completely burnt, forming ash that is captured in any diesel particulate filters (DPF) fitted.

Accumulation of ash in the filter causes a decrease in the deposition surface, producing a reduction in soot storage capacity and an increase in exhaust back pressure.

To investigate the influence of engine oil quality on the quantity of ash, Agroscope Reckenholz-Tänikon (ART) Research Station conducted a field test in association with Shell Global Solutions.

Fig. 1: Particulate filter ash deposits

Table 1: Vehicles used in field testing

Fendt 411 Vario	Deutz-Fahr Agrotron K100	HSM 805 HD

METHODS

Two agricultural tractors and one specialised forestry machine retrofitted with particulate filter systems were operated for one year with a conventional SAE 10W-40 engine oil.

After operating with the conventional engine oil, the filters were cleaned. The accumulated soot/ash mixture was carefully collected and then incinerated in an oven at 750°C for four hours, burning the residual soot, to leave only the ash.

The engines were then converted to Shell Rimula R6 LM SAE 10W-40, which is the latest fully-synthetic, low SAPS (oil with low sulphated ash, phosphorus and sulphur content) heavy duty engine oil technology. The machines then worked under conditions similar to those with the conventional engine oil. After the same operating period as in the first part of the experiment the filters were again cleaned and the ash quantity was determined.

RESULTS

The fully-synthetic, low SAPS engine oil Shell Rimula R6 LM SAE 10W-40 reduced the quantity of ash in all three test vehicles by 44-63 %. The reduction in ash quantity increased as the amount of lubricating oil consumed by the engines increased. Engine oil consumption was under 0.1 % of fuel consumption in all the vehicles.

Due to lower ash deposits in the particulate filter, the increase in exhaust back pressure slowed as operating time increased. Lower exhaust back pressure results in less power loss and hence in fuel saving. No noticeable differences in ash composition were found between the two types of oil. The only significant difference was the quantity of ash.

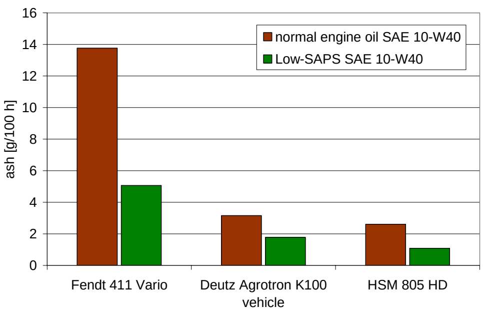

Chart 1: Ash accumulated in the particulate filter per 100 operating hours

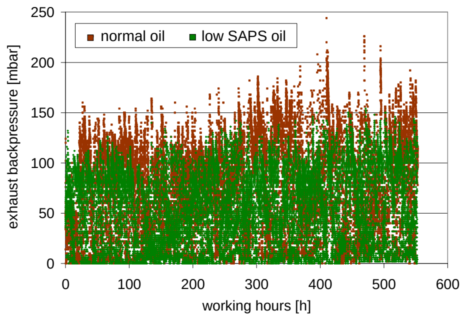

Chart 2: Exhaust back pressure variation in the Fendt 411 Vario

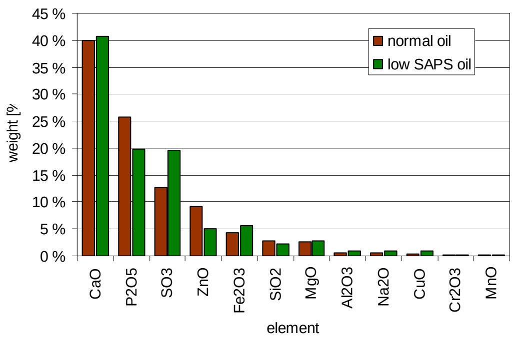

Chart 3: Ash composition in the Deutz-Fahr Agrotron K100, using x-ray fluorescence analysis

Fig 2: Ash quantities from Fendt 411 Vario tractor.
Left: ash quantity with conventional engine oil (76 g), right: with Shell Rimula R6 LM (28 g).

CONCLUSIONS

- The accumulation of ash could be reduced significantly in all three vehicles.
- The cleaning interval of particle filters can be extended due to lower ash formation.
- The used oil analysis data clearly indicated that both engine and engine oil were in a very good condition, with the dispersancy always being satisfactory, ensuring that sludge deposits were avoided.
- The ash residues in both engine-oil types used consisted mainly of calcium oxide, sulphur oxides and phosphates.

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