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Reduction Diesel Exhaust Particulates by Retrofitting Tractors with Particulate Filters

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. Although individual particles are so small – 0.1 ?m on the average – they can 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 initiate more stringent mass-related particulate limits, but since it is not scheduled for introduction until 2011 and agricultural vehicles have a long service life, it seemed advisable to investigate retrofitting agricultural machinery with particulate filters.

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Keywords

Diesel exhausts particulates, particulate filter, emission

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 less than 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 plant

The aim of the project, which received financial backing from the Federal Office for the Environment (BAFU, 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 farmyard 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.

Practical experience

The mounting position proved to be 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.

Two trial vehicles are in problem-free use, and one has already completed over 1300 hours without any faults being reported. Certain trial vehicles featured ideal operating conditions for the passive filter system, as high exhaust temperatures occurred regular-

Fig. 1: Tractor retrofitted with a particulate filter

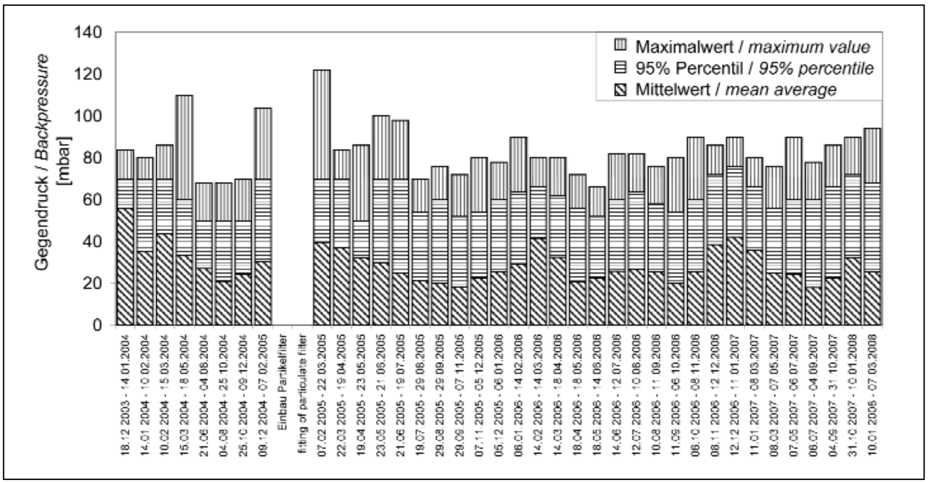

Fig. 2: Development of the exhaust backpressure with and without particulate filter (Lindner Geotrac 65 tractor)

ly, e.g. when a mixing trailer was used or heavy transport 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 some 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 four vehicles. The failures were caused, e.g. 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 farmyard loader. Measuring point 1 is at high engine speed and high load, 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.

Costs

The investment required for the installation of a particulate filter in a medium-sized tractor is between EUR 5,000 and 10,000. This price includes installation. 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 costs approximately an extra € 300 each time. This has to be done every 250 to 1000 operating hours, 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 farmyard 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 total 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 (selective catalytic reduction) system or SCRT system.

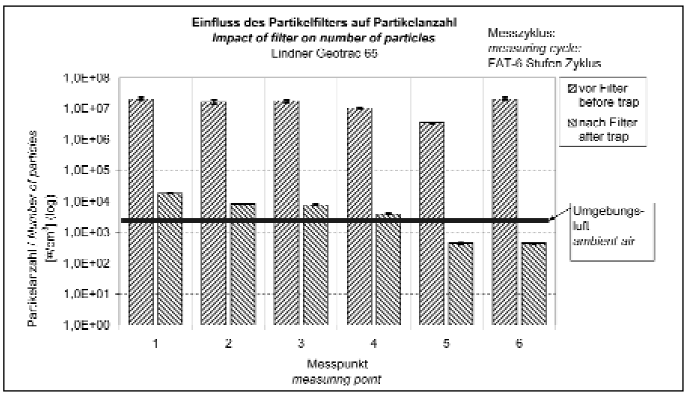

Fig. 3: Impact of the particulate filter on number of particles. Measuring points according to FAT 6-level test [4]

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