Diesel Particle Filters with Active Regeneration in Mining - Practical Experiences from Mines in North America and Europe

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Keywords: Diesel particle filters, active regeneration, diesel burner, exhaust gas temperature

1. Introduction

As the filtration efficiency of modern filter material is very high, system development for the after treatment of exhaust gas of diesel engines focuses on the regeneration of the loaded filter. To ensure the soot oxidation independently of engine characteristics, the exhaust gas temperature has to be increased actively. The use of diesel as energy supplier gives an advantage concerning the energy efficiency. With a diesel burner, the regeneration is realized in such a way. Such systems are technically more sophisticated than passive systems, but are the only solution to act independently from external energy sources and they ensure a homogeneous regeneration.

The company HUSS has experience in the development, production and implementation of diesel particle filters for off road diesel machines since 1985. In tunnels, hundreds of machines are equipped with filters from HUSS. In mines, the company's DPF are installed in North America as well as in Europe. Power and fuel consumption as well as temperatures and emissions during regeneration are discussed. Typical applications in the original equipment and retrofit market shall be mentioned.

2. The legislative situation

Diesel exhaust particles are carcinogenic. They are that fine that they are inhaled and they then deposit in the human lung and can even travel through the bloodstream all over the entire body including the brain, where they are considered to cause dangerous Illnesses, such as e.g. cancer. Depending on their size, soot particles can penetrate to varying depths into the lung. The finest particles range between 0.001 and 1 µm. There are therefore numerous laws requiring the mandatory use of a filter to protect people's health.

Since 1996 the technical regulation TRG 554 in Germany prescribes the use of these diesel particulate filters in closed or partially closed rooms. In addition, towns and built-up areas must adhere to certain limit values for respirable dust.

The retrofitting of filters in Switzerland has already been obligatory in underground construction (building tunnels) and also on large construction sites since March 2000. Large construction sites there have been subject to a filter retrofitting obligation for engines >37 kW since 1st Sept. 2003 and for engines of 18 to 37 kW as of 1st Sept. 2005.

Today, Switzerland is regarded as a pioneer in environmental protection. Filters must first conform to strict directives before they may be sold. They require VERT certification, which HUSS filter systems have.

Stricter laws apply in Denmark too, where a filter is obligatory for diesel vehicles. HUSS Umwelttechnik has been certified and approved by the Technological Institute of Denmark.

Austria also prescribes the use of diesel particulate filters for diesel engines > 18 kW on construction sites in accordance with the legal gazette no. 82.

This means that we will see a gradual reduction in pollutant emissions from exhaust gas in Europe over the coming years. Diesel particulate filters play a considerable role in exhaust aftertreatment. The EU respirable dust directive 1999/30/EC already regulates the limit values for respirable dust such as soot as follows: "50 µg/m3 PM10 may not be exceeded more than 35 times a year." (appendix III). As of January 2010 only a mere 7 limit violations will be permitted.
Internationally valid limit values for cars (Euro 1-5 standards) and commercial vehicles (Tier 1-3) and projects activated throughout the world show the efforts to combat carcinogenic soot with the aid of particle filters. It can be assumed that new vehicles in general will be equipped with filters.

3. Available technology for mining applications

In mining especially robust filter systems are required. As with many other construction machines the exhaust gas temperature can be very low, depending on the application. For regeneration of the loaded filter, the soot ignition temperature has to be reached. The regeneration of a particle filter with diesel burner is called active regeneration procedure. This enables to regenerate the filter from the soot independently from engine load. Active systems influence the exhaust gas after treatment in the way that they increase the exhaust gas temperature or directly the filter material up to the level which is needed for burning the soot. This can include also the use of additive, catalytic coating, influence of the engine management and other measures for changing the exhaust gas temperature. Such systems are technically more sophisticated than passive systems, but are the only solution to act independently from external energy sources and they ensure a homogeneous regeneration [1].

Standstill burners are situated upstream of the particle filter and use diesel fuel burners for the regeneration of the filter. The burner is turned on when the loading of the filter reaches a certain limit value (expressed in a back pressure in the exhaust gas of the engine) and is turned off when the filter is regenerated. The engine has to be turned off while the burner is regenerating the filter. Therefore, this system is used in applications where such standstill periods are acceptable. Since there is no interfering with engine load such systems have advantages especially in retrofit applications.

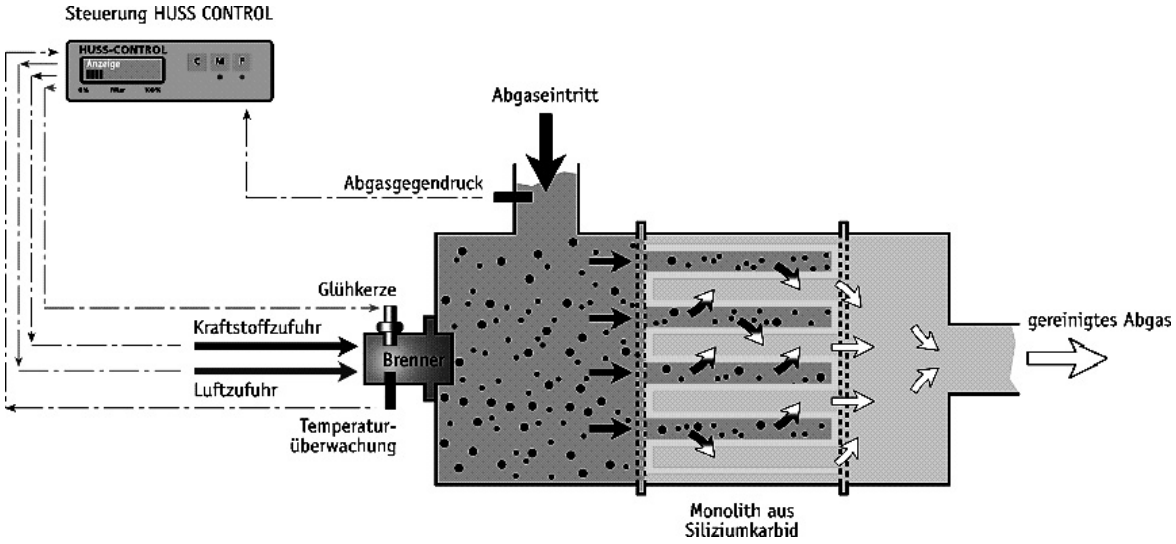

Figure 1: Schematic diagram of a diesel particle filter system with diesel burner for regeneration (HUSS Umwelttechnik/Nuremberg)

4. Power and fuel consumption

Depending on the strategy for regeneration the power demand can be very different. The most energy was needed when the burner would heat up the exhaust gas stream while the engine is running and no catalytic decrease of the soot ignition temperature was used. Then for sufficient regeneration the whole exhaust gas volume flow would have to be heated up to the level of 600°C. The demanded burner power then reaches the magnitude of the engine power itself (about 20 – 50%).

Stand still burners can work with less energy consumption, since here not the exhaust gas has to be heated up but only the filter itself. Depending on engine size the filter size has to be determined in order to realize a sufficient soot loading time till regeneration. Therefore, the diesel consumption varies between 100 to 500 ml per regeneration depending on the chosen filter size. Depending on the application the increase in diesel consumption is below 1 %.

5. Temperatures and emission during regeneration

Because of locally varying soot load during the regeneration temperatures above 1000°C can occur (see figure 2). This demands special filter material with a very good heat transfer coefficient to avoid high temperature gradients within the material so that tension caused by heat differences will not destroy the material. Ceramic filter media like Silicon Carbide meet such demands. A further point is the quality of the regeneration process, which will be homogeneous and complete only when a sufficient heat transfer transports the heat necessary for the soot oxidation to all parts inside the filter material.

As can be seen from the curves in figure 4 the temperature inside an actively heated filter increases very fast as soon as the diesel burner is started. When the soot starts to burn the pressure drop curve decreases sharply. For a homogeneous regeneration all over the filter monolith the whole process takes about 8 min. Then also in the back parts of the filter the temperature curves have reached their maximum value and the exothermic soot oxidation is finished.

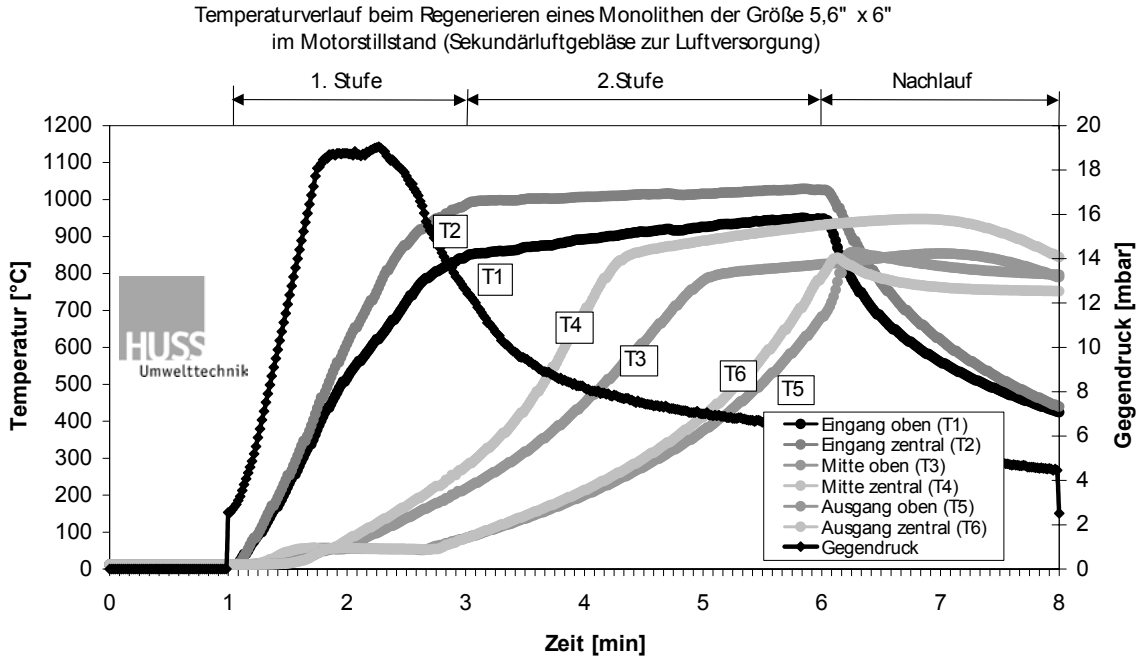

Figure 2: Temperature distribution along a filter monolith with a diameter of 5,6“ and a length of 6“ during regeneration in standstill modus (HUSS Umwelttechnik /Nuremberg)

Secondary emissions, as far as limited components like CO, HC und NO_x are concerned, can be kept very low during the oxidation of the soot when regeneration takes place in the standstill modus (see figure 3 and 4). If the regeneration has to take place while the engine is running eventually additional measures like catalysts have to be considered.

The secondary emissions can be controlled by parameters like the soot loading. Depending on limit values given in the application the soot loading and therefore secondary gaseous emissions during the regeneration process can be influenced by choosing the right time of regeneration. This effect is shown in figure 3, where a comparatively high CO emission was realised, because the soot loading was chosen to be very high (>15 g/l). Then a lot of the oxygen available in the system will be consumed by the soot oxidation, so that CO is build instead of harmless CO_2. Choosing an earlier time of regeneration with less soot loading (< 10g/l) can decrease the CO emissions by a factor of 10 to 20. The amount of gaseous emissions during the relatively short time of regeneration therefore can be neglected compared to the relatively long time of engine running mode. Nevertheless, filters certificated according to VERT like the HUSS products have to proof that no secondary mission higher than the level of engine exhaust emission occur.

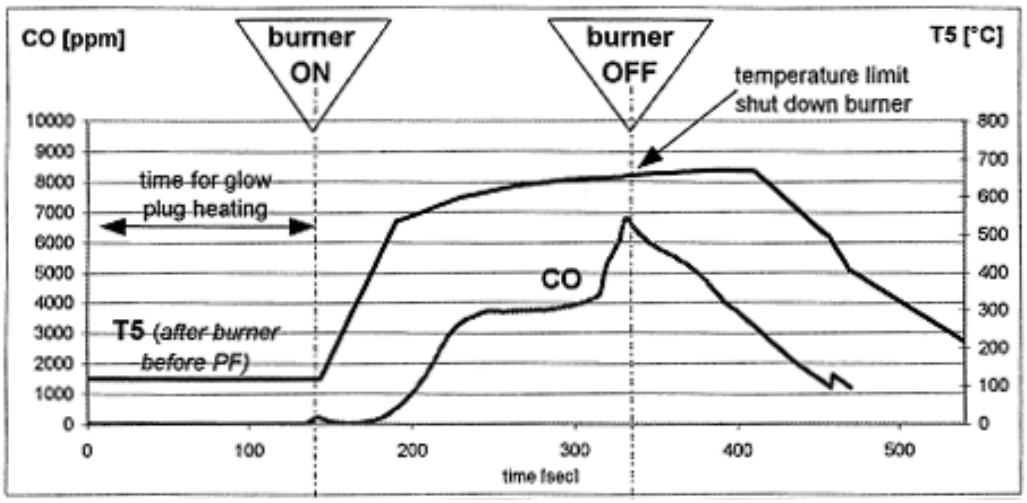

Figure 3: Emission of CO during regeneration with a diesel burner in standstill modus [3]

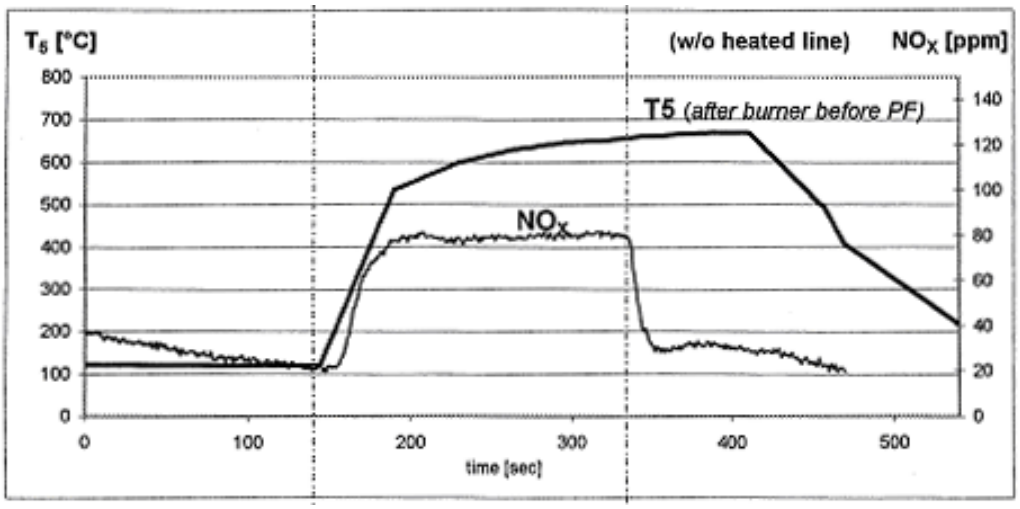

Figure 4: Emission of NO_x during regeneration with a diesel burner in standstill modus [3]

6. Summary

To reach future demands for all limited components a combination of engine management, diesel particle filter and catalyst will play a mayor role in many applications.

Inline burners and also catalytic burners, which have to consider the engine load will be restricted manly to serial applications in OEM business, because of the expensive installation and adjustment procedure. There, they are an interesting technical solution which can ensure also with low engine exhaust gas temperatures a secure regeneration of the diesel particle filter.

In the retrofit business neither the engine management can be changed nor a complicated adjustment to each engine load situation can be done. There only filter and regeneration strategies can be used which are flexible, very robust and independent of exhaust gas temperature and components like standstill burners.

6. References

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[2] Zelenka, P.: Brennerunterstützte Regeneration von Partikelfiltern, HdT-Seminar: Minimierung der Partikelemissionen von Verbrennungsmotoren, München, 2003

[3] VERT report, Abgasprüfstelle Biel (CH), 2002