Predicting Diesel Particulate Filter Performance

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The diesel particulate filter (DPF) has been used for many years in the control of diesel particulate matter (DPM) emissions. This technology is characterised by extremely high efficiency and high sensitivity to the application conditions. Research and testing performed by Diesel Controls Ltd. over the past two years has resulted in improved methods for predicting the application based performance of a DPF. The main goal of this research was to increase the accuracy of the technique. This improvement should yield two results: Improved performance in the field, and an increased range of possible applications.

The DPF may be manufactured from different materials (Cordierite or Silicon Carbide for example) and in its most common form consists of a substrate of narrow channels in which each channel is blocked at one end. Adjacent channels have this blockage at alternate ends (Figure #1). With this construction exhaust gas may enter at one end, but must pass through the wall of a channel before exiting and is thus termed a wall flow device.

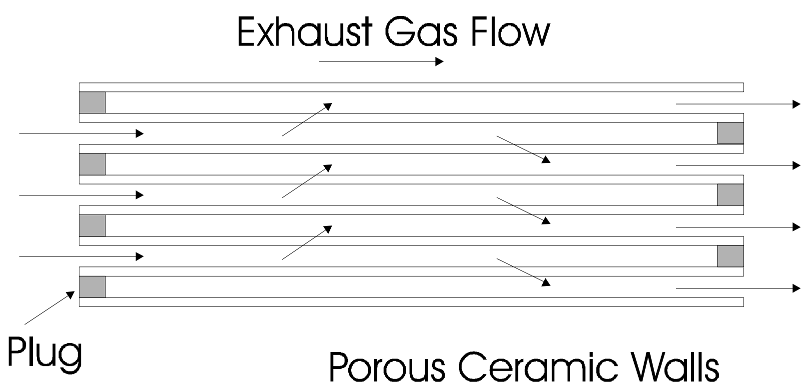

Figure #1: Schematic of DPF Construction

Field and laboratory experience has demonstrated that the DPF is easily capable of retaining more than 80% of total DPM emissions. This excellent efficiency is maintained for the range of particle sizes commonly found in diesel exhaust. As the DPM accumulates the exhaust backpressure caused by the combination of the DPF and its contained DPM increases. To date the challenge for the DPF has been reliability. For reliable passive operation the DPF is very sensitive to the characteristics of the engine operation. With the currently available technology this demands a careful study of each new application. The requirements are to accurately identity possible applications and to accurately select an appropriate DPF.

In order to fulfil these requirements an understanding of the DPF operation is necessary. The actual filtration mechanism may be adequately described by the concepts of direct interception and Brownian diffusion and this results in the accumulation of DPM within the filter. Were this accumulation mode to continue indefinitely the exhaust backpressure would quickly rise beyond acceptable levels. In order to operate for any length of time combustion of the accumulated DPM must occur. This combustion is termed regeneration and its occurrence depends on the conditions within the DPF. Additionally the regeneration may occur slowly or quickly depending on these conditions. In order to apply the DPF successfully, regeneration of the filter must occur in order to provide acceptable engine exhaust backpressure. It is the difficulty of predicting this behaviour that is the principal disadvantage of the DPF. Therefore, there is need for a tool to aid in predicting the performance of the DPF-engine system.

In the past, rules of thumb based on the exhaust temperature and engine size have been developed. Typically a temperature limit is chosen based on experience, and the exhaust temperature must exceed this limit for a minimum percentage of the operational cycle: Example >400°C for 20% time. The filter is then sized according to the displacement of the engine. The problem with this technique is that it fails to adequately account for the nature of the application.

In order to avoid failed filters and to increase the number of possible applications DCL has undertaken to develop an improved method of predicting the DPF performance, based on an understanding of the parameters which control regeneration. The most important variables are the temperature and mass of the accumulated DPM, and the mass flow rate of oxygen. None of these are easily measured directly, but by measuring the exhaust temperature, the exhaust flow rate and the oxygen concentration we may calculate the necessary values. Additionally the exhaust flow rate may be estimated from other values such as engine speed and load or fuel flow and air flow. With these requirements DCL has chosen to instrument several mining machines, for which the DPF has been proposed as an emission reduction technique. Measurements of temperature and pressure as well as engine speed and O_2 concentration are recorded electronically during a typical operation cycle, and these provide the input for an improved technique of performance evaluation.

A mathematical model which considers the entire DPF as the control volume for balances of mass and energy may be used to predict the performance of the DPF.

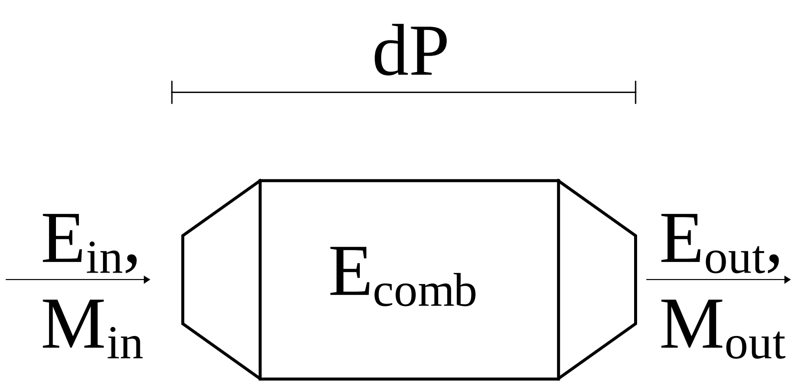

Figure #2: DPF Control Volume

A computerised version of this model including lump conductance heat transfer, the Arrhenius expression for combustion, and Darcy's law of porous flow allows the engineer to study the influence of various filter properties and duty cycles. Parametric studies based on this computer model may lead to an improved understanding of the processes which control DPF performance. The model is used to predict the temperature of the substrate, the mass of accumulated DPM and the total backpressure over the proposed duty cycle. Figure #3 demonstrates the use of the computer model in predicting DPF performance. A duty cycle recorded on a Load Haul Dump vehicle working in an underground mine is simulated in the laboratory. The same cycle also simulated using the computer model.

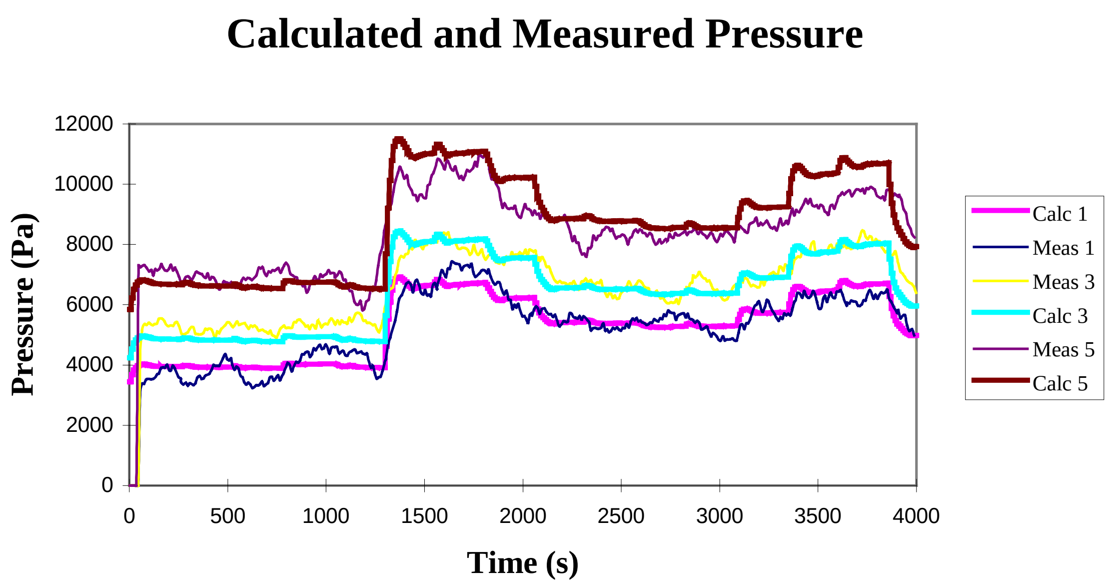

Figure #3: Calculated and Measure Exhaust Pressure

The results indicate that in this case the DPF pressure is increasing with each repetition of the duty cycle. In addition the calculated and measured pressures are very similar validating the model for this DPF-engine system.

Using the computer model it can be demonstrated that the rate of regeneration is most sensitive to the exhaust gas temperature. In addition a brief high temperature excursion followed by a period of high oxygen concentration (low idle immediately after full load) can create conditions which may cause the DPF to fail due to excessive temperature. These results may be used to aid in selecting the correct filter volume which will provide acceptable exhaust backpressure and sufficient regeneration. By modifying the constants used in the Arrhenius equation or changing the filter properties different technologies may be compared. Figure #4 compares the calculated response of two different filter materials to a step change in exhaust gas temperature.

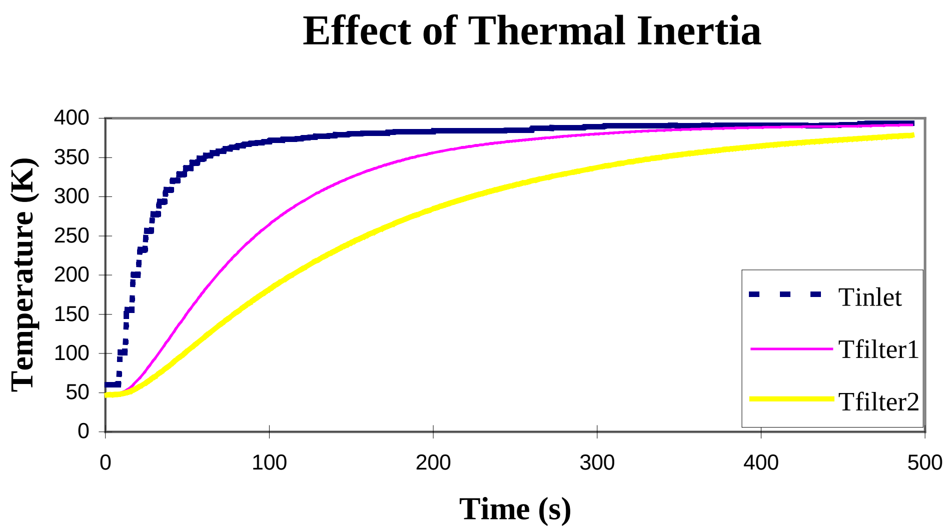

Figure #4: Predicted Effect of Thermal Inertia

The computer model results clearly indicate the influence of thermal inertia on the filter temperature. This information may then be used by the engineer when selecting a material for DPF construction.

With this improved method for predicting DPF performance DCL hopes to ensure the success of its DPF installations and to broaden the range of possible DPF applications. Additionally future research into the benefits of various filter materials will be guided by a sound understanding of the fundamental principles of DPF operation.

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