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The Turbulent Precipitator for Diesel Exhaust Filtering

THE TURBULENT PRECIPITATOR FOR DIESEL EXHAUST FILTERING

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Summary
A novel filter type for diesel soot filtering is introduced: the turbulent precipitator. The aim with the design is to create a robust, flexible, catalytically active diesel soot filter which can circumvent all known problems with diesel soot filtering. This is possible by using soot collection plates in an open channel.
The filter is tested in an experimental setup using a diesel engine, filter efficiency is determined with an ELPI. Results show that diffusion collection and impaction collection are important filtering mechanisms. Up until now a filter efficiency of 50% has been reached. CFD is used to speed up design, but needs improvement.

Introduction
To meet future legislation for diesel soot emissions, soot filters will be unavoidable. A few filter types, like wall flow monoliths, ceramic foams, knitted fibers and fiber sheet filters, are studied and/or used today for filtering diesel soot.
In our group we are working on a novel filter type which can circumvent all known problems in soot filtration: turbulent precipitator [1]. The aim is to develop a robust system with a low pressure drop. Furthermore continuous oxidation of the soot is aimed for at the average exhaust temperature of the diesel engine using a molten salt catalyst [2] or fuel additives [3]. Periodical regeneration can also be induced by an advanced motor management system.

Turbulent Precipitator

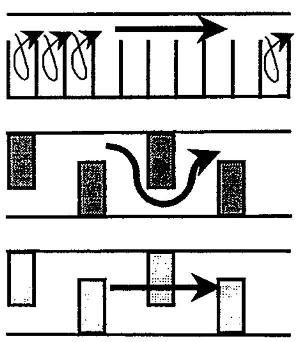

Figure 1: Turbulent precipitator in different forms (arrow shows gas flow): (a.) metal plates; (b.) fine foam plates; (c.) coarse foam plates.

The turbulent precipitator was first introduced by Dullien [4] (figure 1(a.)). In Dullien's proposal, turbulent gas flows in the straight channel in the top (with suspended particulates), turbulent eddies penetrate into the stagnant lower zone and decay, leaving particulates to deposit on the collector plates.
The turbulent precipitator is a straightforward filter: it consists of an open channel with soot collection plates. The open channel provides some interesting advantages: firstly, the pressure drop is low and secondly, it cannot get plugged even if the catalyst completely deactivates. The collector plates give intrinsic flexibility because not only spacing between the plates can be varied but also their form (figure 1.) and construction material (metals or ceramics). This makes it possible to design a 'custom made' filter for every diesel engine.

Materials and Methods
The general method of work is to use experimental work in combination with computational fluid dynamics (CFD) to speed up design.
To ensure realistic experiments, the turbulent precipitator is tested in an experimental setup downstream a diesel engine. There are four components in the experimental setup. First the engine: a 930 cc two cylinder LPW2 Lister-Petter diesel engine. Second, the turbulent

precipitator, placed in a sidestream of the exhaust. Third, a wall flow monolith to filter the sidestream further. Fourth, a vacuum pump that draws a continuous flow of exhaust gas through the sidestream of up to 200 normal liters per minute. Trapping efficiency is determined with an Electrical Low Pressure Impactor, in short ELPI, from Dekati.
For CFD calculations the FLUENT 5.04 commercial code is used. An Eulerian-Lagrangian simulation method is used to calculate particle trajectories.

Results and Discussion

Figure 2 shows trapping efficiencies of the geometries shown in figure 1. The fine foam collector plates are made from 1600 cpm silicon carbide foam. From comparison with foam filters using the same foam with the same equivalent filter length (measured trapping efficiency 60%) it was concluded that the gas flows around the collector plates in wiggling motion due to high pressure drop over the foam. The coarse foam collector plates are very open, allowing the gas to flow through. Two mechanisms of filtration are important in these systems: diffusion collection, for particles smaller than 0.3 μm, and interception collection for particles larger than 0.3 μm. These mechanisms clearly show in figure 2 as different regions having decreasing and increasing filter efficiency with increasing particle size. Diffusion collection is the most explicit with the metal collector plates, this is very useful because modern diesels tend to produce more particulates towards the nano-particle range, also nano-particulates have a more serious impact on public health. Interception collection does not change much with particle size, here the fine foam performs best. With the design of a turbulent precipitator filter both mechanisms can used and tuned to specific needs. So every diesel can have its own, specially designed diesel soot filter.

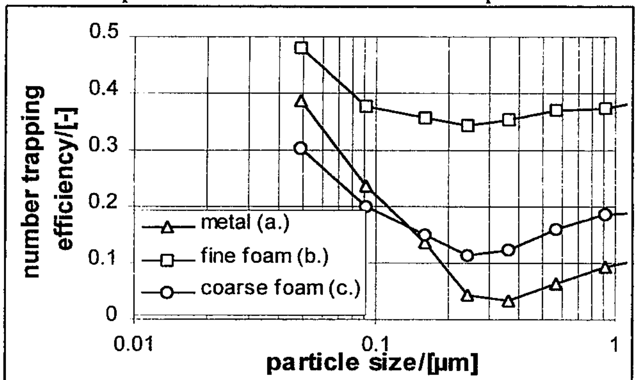

Figure 2: Trapping efficiency of turbulent precipitator, geometries as in figure 1.; 1.09 m/s superficial velocity.

CFD results so far have shown that it is possible to optimize geometry by calculation of the particle trajectories but some topics need further investigation. Especially incorporation the nano-particle movement and trapping into the fluent codes.

Conclusions

The turbulent precipitator is a novel filter type that can circumvent all known problems associated with diesel soot traps, because of its open channel. The turbulent precipitator makes a promising filter for future implementation, because of its intrinsic flexibility; which makes it possible to design 'custom made' filters, because of its efficiency; even without geometric optimalization trapping efficiency is up to 50%, and because of selective nano-particle trapping with metal plates. The turbulent precipitator can be optimized with CFD, which speeds up the designing process.

References

[1]: R. van Hardeveld, M. Makkee, J.A. Moulijn, S.J. Jelles, International patent WO97/23268, (1997).

[2]: S.J. Jelles, B.A.A.L. van Setten, M. Makkee and J.A. Moulijn, Applied catalysis B: Environmental, 21(1999).

[3]: S.J. Jelles, M. Makkee, J.A. Moulijn, G.J.K Acres and J.D Peter-Hoblyn, SAE paper 990113, (1999).

[4]: F.A.L. Dullien, International patent WO93/15822, (1993).

Diesel Soot Filtering and Particle Size Analysis

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TU Delft

Objective

Design of a robust and durable catalytic diesel soot filter

Contents

- Industrial Catalysis diesel project
- Experimental setup
- Soot characterization with ELPI
- Filter efficiency Turbulent Precipitator
- Preliminary results Computational Fluid Dynamics

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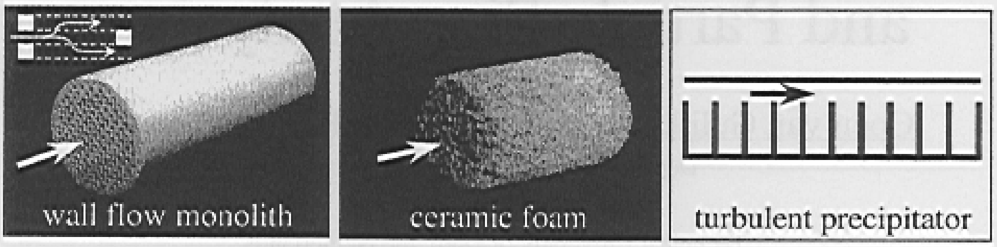
diesel project: 3 alternative systems



wall flow monolith	ceramic foam	turbulent precipitator
high pressure drop	medium pressure drop	low pressure drop
plugging	plugging	no plugging
Additives with NO_2	molten salt catalyst	molten salt catalyst

turbulent precipitator is ROBUST AND DURABLE

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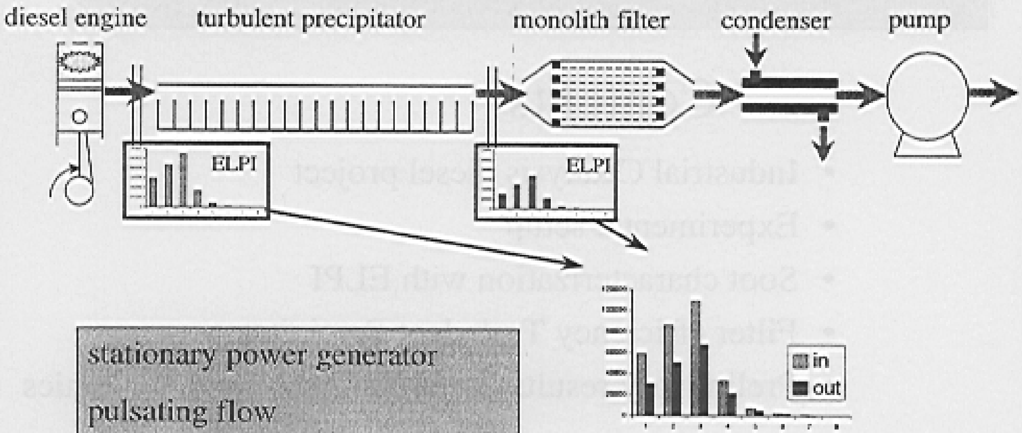
Experimental setup



stationary power generator

pulsating flow

temperature gradients

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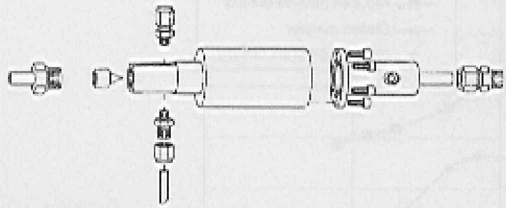
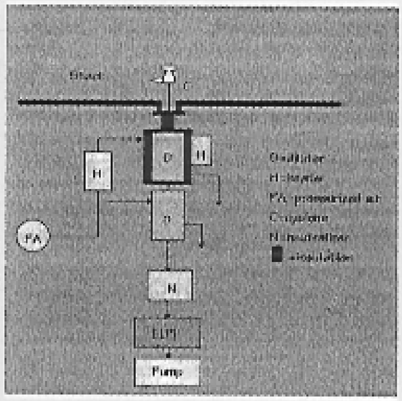
ELPI and sampling setup





particle bounce

particle deposition in diluter

CURRENTLY LIMITED QUANTITATIVE CAPABILITIES

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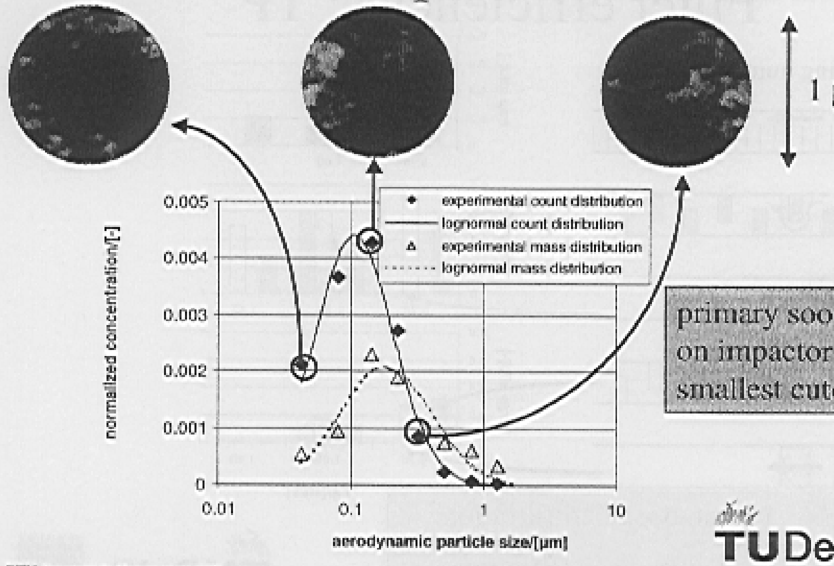
Characterization: particle size distribution



primary soot particles on impactor plate with smallest cutoff size

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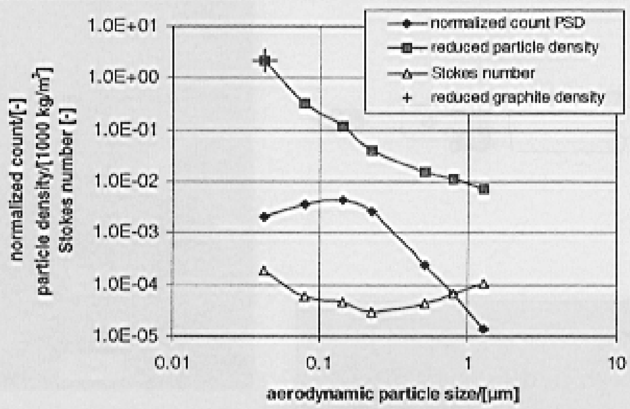
Characterization: particle density



density strong function of particle size
elementary particles have graphite density
low Stokes: PARTICLES FOLLOW GAS

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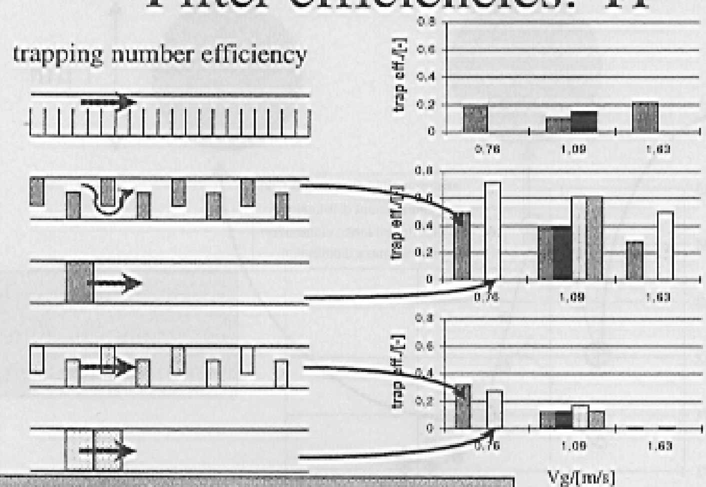
Filter efficiencies: TP



400 cpm SiC plates: deep bed filtration
1600 cpm SiC plates: surface filtration

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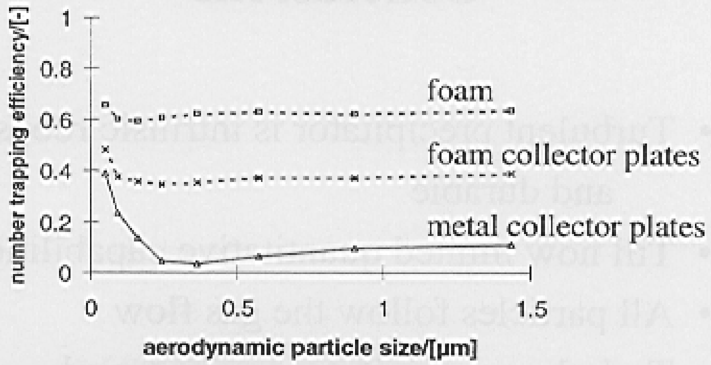
Efficiency as function of particle size



metal plate: diffusion trapping
fine foam plate: impaction trapping
TUNING OF FILTER POSSIBLE

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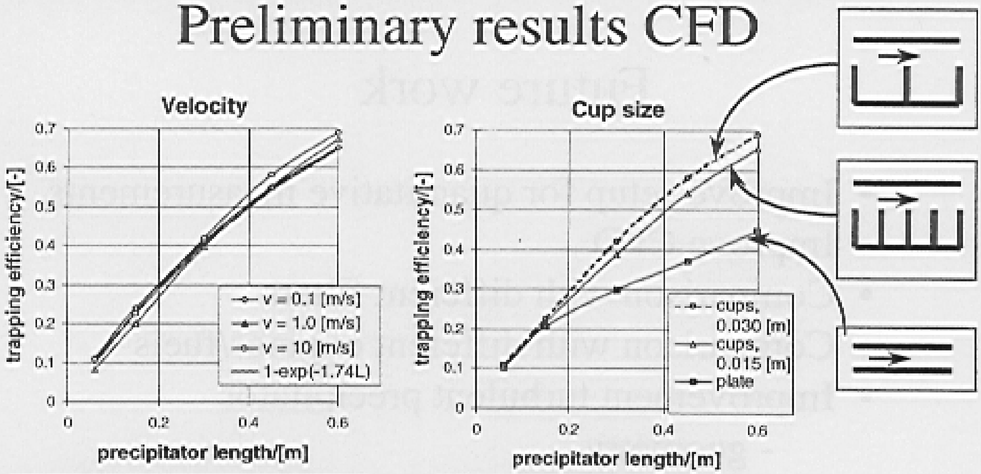
Preliminary results CFD



no influence gas velocity: physically correct?

different geometry: different efficiency!

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Conclusions

- Turbulent precipitator is intrinsic robust and durable
- Till now limited quantitative capabilities
- All particles follow the gas flow
- Turbulent precipitator can be tuned
- CFD can be used but with caution

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Future work

- Improve setup for quantitative measurements
- Improve CFD
- Comparison with different filters
- Comparison with different engines/fuels
- Improvement turbulent precipitator
  - geometry
  - construction material
  - …………..

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