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
regeneration can also be induced by an advanced motor management system.

Turbulent Precipitator

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
device: 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. 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 optimization 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
Diesel Soot Filtering and Particle Size Analysis

Coen van Gulijk, Michiel Makkee & Jacob A. Moulijn
Department of Chemical Engineering
Section Industrial Catalysis
Technical University of Delft, the Netherlands

International ETH workshop on Nanoparticle Measurement
9-10 august 1999, Zürich

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
**diesel project: 3 alternative systems**

- **wall flow monolith**: high pressure drop, plugging, Additives with NO₂
- **ceramic foam**: medium pressure drop, plugging, molten salt catalyst
- **turbulent precipitator**: low pressure drop, no plugging, molten salt catalyst

*turbulent precipitator is ROBUST AND DURABLE*

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**Experimental setup**

- **diesel engine**
- **turbulent precipitator**
- **monolith filter**
- **condenser**
- **pump**

**Stationary power generator**
- **pulsating flow**
- **temperature gradients**

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*TU Delft*
ELPI and sampling setup

- Particle bounce
- Particle deposition in diluter

CURRENTLY LIMITED QUANTITATIVE CAPABILITIES

Characterization: particle size distribution

- Normalized concentration
- Experimental count distribution
- Lognormal count distribution
- Experimental mass distribution
- Lognormal mass distribution

Primary soot particles on impactor plate with smallest cutoff size
Characterization: particle density

- normalized count/PSD
- reduced particle density
- Stokes number
- reduced graphite density

Density strongly function of particle size. Elementary particles have graphite density, low Stokes; PARTICLES FOLLOW GAS.

Filter efficiencies: TP

- Trapping number efficiency

400 cpm SiC plates: deep bed filtration
1600 cpm SiC plates: surface filtration
Efficiency as function of particle size

- foam
- foam collector plates
- metal collector plates

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

Preliminary results CFD

Velocity

- $v = 0.3 \text{ [m/s]}$
- $v = 1.0 \text{ [m/s]}$
- $v = 10 \text{ [m/s]}$
- $v = \exp(-1.72L)$

Cup size

- cups, 0.005 [m]
- cups, 0.015 [m]
- plate

no influence gas velocity: physically correct?
different geometry: different efficiency!
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

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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