Introduction

Particle collection mechanisms at the leading edge and in open channels of honeycomb monoliths are usually neglected by engineers of these devices. Under specific conditions however, these phenomena can make an appreciable contribution to overall particle collection and deposits on channel walls may affect catalyst performance. Deposit loading tests conducted with a Diesel Particle Generator are used in this study to highlight the differences in capture efficiency and deposit evolution between bare and catalytic flow-through monoliths. A recently developed diesel particle collection model is extended to take into account the diffusion of active gaseous species in the deposit layer and their reaction with soot.

Experimental testing

- In previous work at the University of Cambridge, long-term loadings of flow-through monoliths were carried out using prototype and commercial versions of a Diesel Particle Generator (DPG) [1].

<table>
<thead>
<tr>
<th>Monolith design</th>
<th>Operating condition</th>
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<tbody>
<tr>
<td>cell density, wall thickness, length, coating</td>
<td>particle size, loading rate and duration, flow rate</td>
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- Measurements included particle emissions, monolith pressure drop, deposit mass (edge, channel distribution).
- Confocal laser microscopy images were used to study the deposit microstructure.

Mathematical modelling

- PM collection model [2]
  - 1-d axial discretization & multiple particle classes
  - Local collection efficiency as a function of particle size & deposit buildup in dendrite form
  - Loose contact catalytic soot oxidation
  - Oxygen spillover as described in [3]
  - Calculation of activated oxygen (O*) concentration profile

- Coupled diffusion-interception inside channel

Bare monolith results

- Measured parameters as a function of time
- Cumulative collection efficiency
- Pressure drop
- Deposit distribution
- All trends are predicted with sufficient accuracy

Effect of catalytic coating

- Very good prediction of both pressure drop and loading evolution
- Insignificant effect of coating on collection efficiency at clean state (~2.7%)
- Cumulative PM collection efficiency after 6h = 3.4% (vs 5.1% for bare)
- 58% of deposit collected in channel is oxidized according to the model
- Loose contact mechanism (insignificant oxidation with NOx)
- No oxidation of deposit collected at the leading edge

Outlook and conclusions

- The effect of coating on PM collection in flow-through monoliths was studied experimentally and theoretically using a specially developed model
- 87% less mass is collected in the channel as a result of lower collection efficiency and catalytic oxidation of soot
- The buildup of deposit at the leading edge is not affected by coating
- Significant initial backpressure penalty but minimal increase during loading

References


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Measurement and Modelling of PM Loading in Bare and Catalytic Flow-Through Monoliths

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1 Introduction

The honeycomb monolith is the most prevalent geometry in automotive exhaust aftertreatment, with applications including oxidation catalysts, partial-flow and wall-flow filters. Particle collection mechanisms at the leading edge and in open channels of honeycomb monoliths are usually neglected by engineers of these devices. Under specific conditions however, these phenomena can make an appreciable contribution to overall particle collection and deposits on channel walls may affect catalyst performance. Deposit loading tests conducted with a Diesel Particle Generator are used in this study to highlight the differences in capture efficiency and deposit evolution between bare and catalytic flow-through monoliths. A recently developed diesel particle collection model is extended to take into account the diffusion of active gaseous species in the deposit layer and their reaction with soot.

2 Experimental testing

In previous work at the University of Cambridge, long-term loadings of flow-through monoliths were carried out using prototype and commercial versions of a Diesel Particle Generator (DPG) (1). Four monolith designs were used to study the effect of cell density, wall thickness, and coating. One of these monoliths, was a sliced and assembled in four pieces

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in order to evaluate the effect of length and turbulence intensity. Furthermore two versions of the DPG were used covering different operating conditions in terms of particle size, flow rate, loading rate and duration. Measurements included particle emissions, monolith pressure drop, deposit mass (edge, channel distribution), while digital and confocal laser microscopy images (Fig. 2) were used to study the deposit micro-structure.

3 Mathematical model

![Image of PM collection mechanisms](https://example.com/image1)

(a) PM collection mechanisms

![Image of loose contact catalytic soot oxidation](https://example.com/image2)

(b) Loose contact catalytic soot oxidation

Figure 3: Basic modelling assumptions

A recently published model(2) was used to simulate the tests. 1-d axial discretization and multiple particle classes were employed to predict local collection efficiency as a function of particle size and deposit buildup in dendrite form. The model was further extended with a loose-contact catalytic soot oxidation mechanism in accordance with the oxygen spillover described in (3). The mechanism comprised of the following steps: (1) activated oxygen ($O^*$) production on the catalytic surface (2) Brownian diffusion of $O^*$ in the deposit layer and (3) oxidation of deposit with $O^*$.

4 Bare monolith results

![Graph of cumulative mass collection efficiency](https://example.com/graph1)

![Graph of pressure drop](https://example.com/graph2)

Figure 4: Performance of tested monoliths as a function of time (lines=simulations, points=measurements).
The model predicted with sufficient accuracy the evolution of cumulative collection efficiency, pressure drop and deposit distribution, as shown in Fig. 4.

5 Effect of catalytic coating

A 600 cpsi monolith, coated with $Pt-Pd/Al_2O_3$, was loaded on the commercial DPG ($T = 240^\circ C$, $\dot{m} = 200kg/h$) to assert the effect of catalytic coating. As shown in Fig. 5, the extended model was successfully employed to predict the pressure drop and loading evolution in both cases. The model suggests that the coating has insignificant effect on the mass collection efficiency at clean state (2.7%), which after 6h diverges to 3.5% for the coated and 5.1% for the bare monolith (cumulative values). The final deposit loading value reveals that 58% of the amount collected in the channel is oxidized. This is attributed to the loose contact mechanism included in the model, while insignificant oxidation with $NO_2$ is expected (20% $O_2$, 4ppm $NO_x$). In contrast, the amount of deposit is collected at the leading edge does not change, implying absence of any catalytic effect in this region.

6 Outlook and conclusions

Loading experiments were conducted on bare and coated flow-through monoliths to study the effect of coating on particle collection mechanisms. To this end a model for bare monoliths was extended with a loose-contact oxidation mechanism to cover coated monoliths. The analysis of the experimental results using the model, showed that the coating has insignificant effect on the collection efficiency at clean state, however an appreciable effect is evident during the loading. 87% less mass is collected in the channel as a result of lower collection efficiency and catalytic oxidation of soot, while the buildup of deposit at the leading edge is not affected by catalytic coating. As a result, the coating induces a significant initial back-pressure penalty accompanied by minimal increase during loading.

References

