CFD Modelling of an Axisymmetric Perforated Brick Catalyst

Ahmad Kamal Mat Yamin, Stephen F. Benjamin, Carol Ann Roberts (Coventry University)
Steven Pierson (Jaguar Land Rover)
• Introduction
• Methodology
• CFD prediction
• Results
• Conclusion
• Future work
INTRODUCTION

Automotive catalysts?

• Catalysts are substances capable of accelerating certain chemical reactions. In automotive exhaust systems, the chemical reactions convert poisonous gases to harmless gases.

Factors affecting the conversion efficiency:

• Flow uniformity
• Mass transfer
• Flow rate

Metallic perforated brick:

-2 layer of foils, i.e. one flat and one corrugated are perforated before winding them together
Typical Metallic Catalyst Brick

Straight-line exhaust flow in a traditional metallic catalyst brick
Radial flow between adjacent channels resulting from the perforated foils
**Laminar catalyst vs. turbulent catalyst**

The radial flow caused by perforated foils

- enhances flow uniformity
- improves mixing of gas species within and between channels
- results in improved conversion efficiency

![Diagram showing laminar and turbulent catalysts with explanations](image)
Aim:

To develop an axisymmetric CFD model of a perforated brick with the aid of experimental measurements.

Objectives:

- To determine the axial resistance coefficients from measurement under uniform inlet flow conditions

- To measure radial flow profiles and pressure drop under non-uniform inlet flow

- To find the transverse resistance coefficients by best matching CFD predictions to measurements
METHODOLOGY OF CFD MODELLING

1. The perforated brick was modelled as a porous medium

\[
\frac{\partial P}{\partial \xi_i} = -\alpha_i U_{s,i}^2 - \beta_i U_{s,i}
\]

(The pressure drop (\(\delta P\)) as a function of resistance coefficients (\(\alpha_i\) and \(\beta_i\)) and superficial velocity in the three mutually perpendicular directions)

2. Preliminary measurements showed the flow distribution downstream of the perforated brick was axi-symmetric

3. The axial alpha and axial beta were determined from pressure drop measurements under uniform inlet flow conditions

4. The radial flow profiles and axial pressure drop were measured under non-uniform inlet flow conditions

5. Determine the axial and transverse alpha values by best matching CFD predictions to measurements (Assumption: transverse beta is zero)
Initial values of axial alpha and transverse alpha

Run CFD predictions

Compare \( \Delta P \)

Compare radial velocity profile

Change axial alpha

START

FINISH
Schematics of the flow behaviour inside the channels of two-type of catalysts, i.e. standard and perforated catalysts.
Rig set-up for pressure drop measurement under uniform inlet flow

Pressure drop measurement across the perforated brick with flow straightener

Wall to wall velocity profile downstream of the perforated brick with flow straightener
Rig set-up for pressure drop and radial velocity profiles measurement under non-uniform inlet flow

Pressure drop and radial velocity profiles measurement under non-uniform inlet flow

Photograph of the rig
CFD PREDICTIONS

• Simulation tool: Star-CD
• Modelled as a 5-degree wedge and consisted of 5672 cells

![CFD model of the perforated brick](image-url)
Turbulence model

V2F – requires $y^+ < 1$ for cells adjacent to the walls

Differencing schemes:

• MARS – U, V & W momentum

• Upwind – turbulence kinetic energy and dissipation

Grid independence study

• Several built meshes showed consistency in pressure drop
RESULTS

Pressure loss across the perforated brick for uniform flow compared with that deduced from non-uniform CFD flow study.
Pressure loss characteristic across the perforated brick under non-uniform inlet flow

(Axial Alpha=25, Axial Beta=762, Transverse Alpha=3.0e+04, Transverse Beta=0.0001)
Velocity distribution across the Perforated Brick under non-uniform inlet velocity various flow rates
Normalised velocity distribution across the Perforated Brick under non-uniform inlet velocity
Velocity distribution across the Perforated Brick under non-uniform inlet velocity - CFD (Solid lines) vs measurement
CONCLUSION:

• The perforated brick can be modelled as an axisymmetric model as the flow profiles across the brick under non-uniform inlet flow appeared to be approximately axi-symmetric

• The axial alpha and transverse alpha were deduced by best-matching CFD predictions to the pressure drop and velocity profile measurement under non-uniform inlet flow.

• The axial alpha and transverse alpha were 25 and 30,000 respectively. The axial alpha was 55% smaller than determined from the least square method of the measurement for uniform flow due to the presence of cross flow.

• The alpha and beta values obtained are subject to confirmation in future work
FUTURE WORK:

1. Establish the generality of the method for obtaining resistance coefficients by investigating higher flow rates and geometrically different flow assemblies.

2. Include flow simulation in the diffuser upstream of the catalyst.

3. Heat and mass transfer simulation throughout the perforated brick.
REFERENCES:


THANK YOU