COMSOL CONFERENCE
ROTTERDAM2013

Metal Foam Tube Flow Modeling

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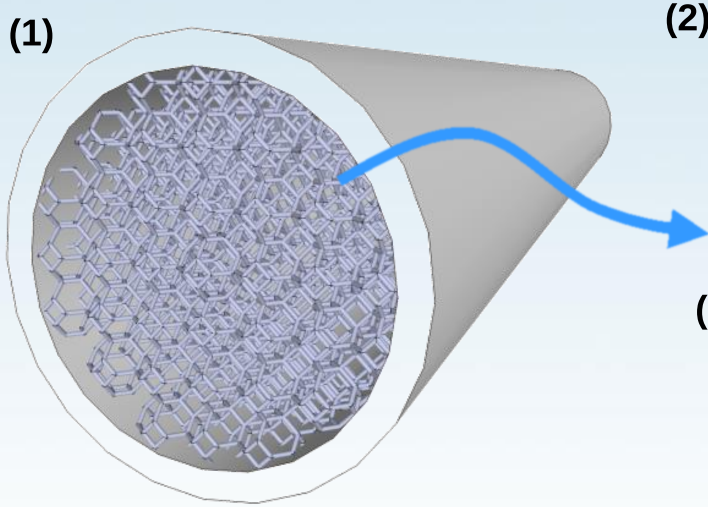
Incentive for Study

Test Objects: 3 types of aluminum foams brazed into 19mm(ID) x 200mm(L) tubes

- Metal foam inserts are much suggested inserts for convective heat transfer applications and designed reactors

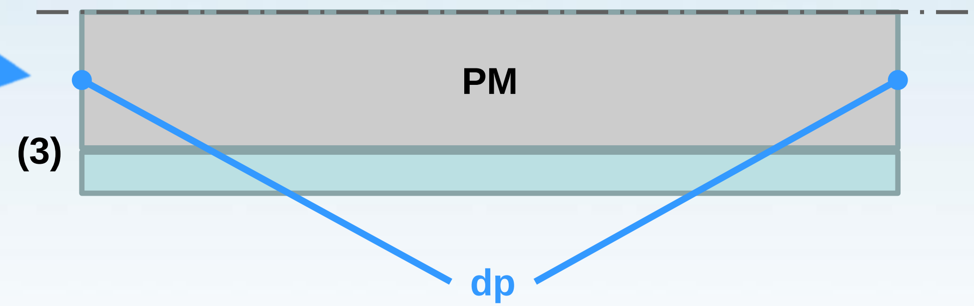
- Flow modeling provides useful insights into intensity of interaction between working fluid and solid ligament, having direct implications to system pressure drop

Modeling Approach



(2) ***Characteristic flow parameters:***
Permeability $K\ [m^2]$, Form Drag Factor $C\ [m^{-1}]$

$$\frac{\Delta p}{s_{\mathrm{cell}}} = -\frac{\mu}{K}u_x - \rho C u_x^2$$



(1) Pore-scale 3D Laminar Flow Model: dp_{cell} vs. u_{cell}.

(2) Fit to Forchheimer Porous Medium Model: Derivation of characteristic parameters (K_{foam}, C_{foam})

(3) Brinkmann-Forchheimer Porous-Medium Model of flow through Test Tubes: comparison to experimental pressure drop data

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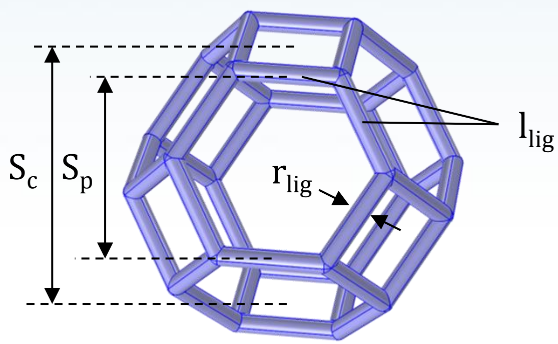
Test Objects and Modeling Approach

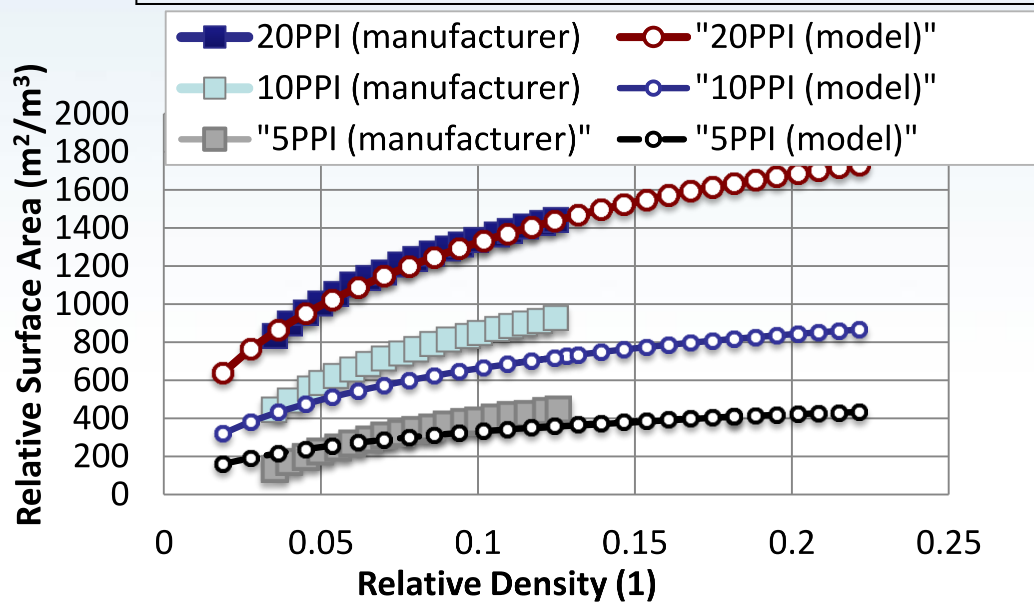
Test Objects: 3 types of aluminum foams brazed into 19mm(ID) x 200mm(L) tubes



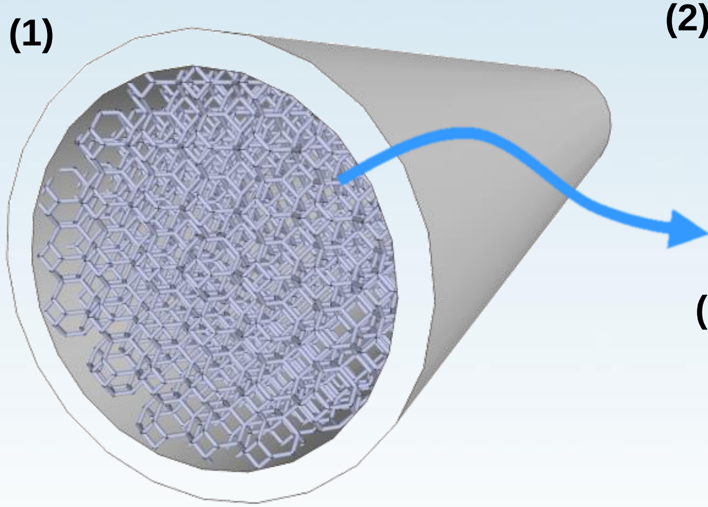
Idealized modeling cell: Tetrakaidecahedron made up of 36 rods of uniform length forming 8 hexagonal and 6 square faces with

Metal Foam Properties

No.	Pore Size	Rel. Density	Rel. Surf. Area
1	5 PPI	0.06-0.08	269-339 m^2/m^3
2	10 PPI	0.06-0.08	658-764 m^2/m^3
3	20 PPI	0.06-0.08	1103-1238 m^2/m^3



Modeling Approach



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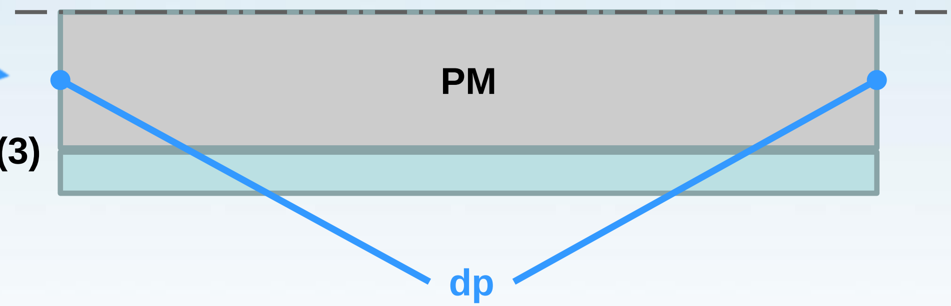

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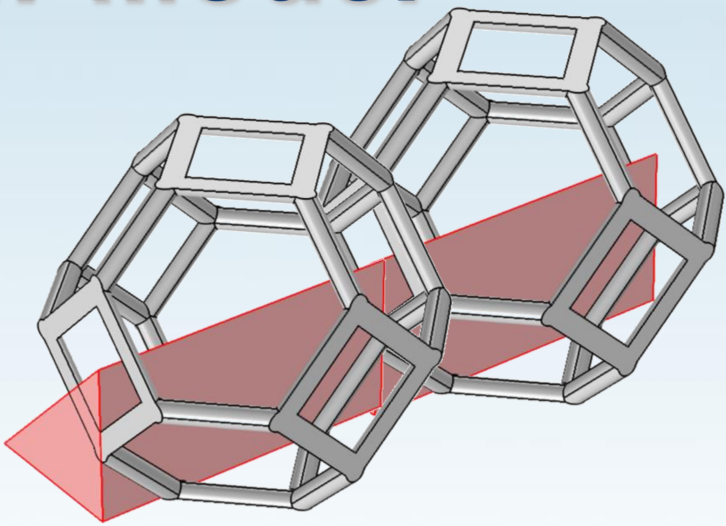
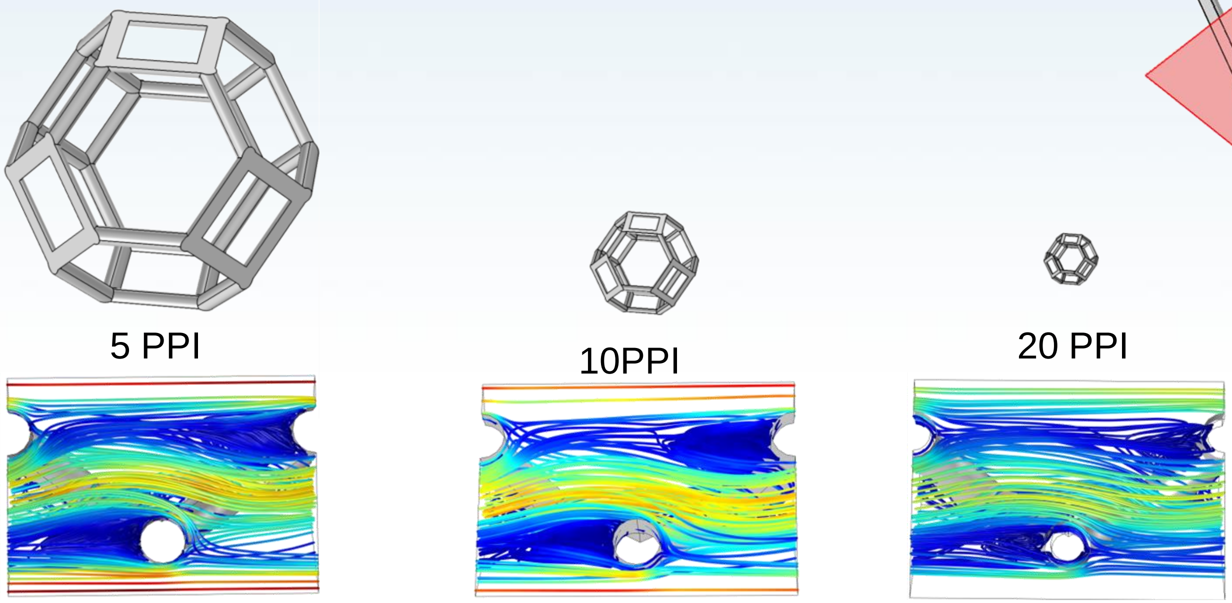
3D Laminar Flow Model

- Isothermal flow
- Air as incompressible fluid
- Array of 25 cells
- Normal mesh: >434,796 elements





0 5 10

Comparison of velocity streamlines of foams at $u_{in}=3m/s$

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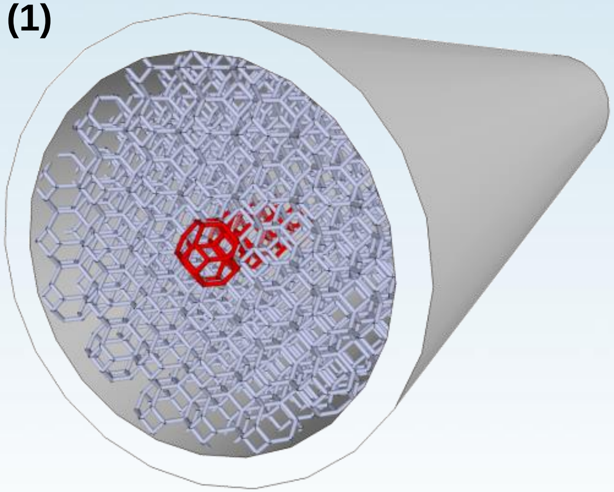
Modeling Approach

(1)

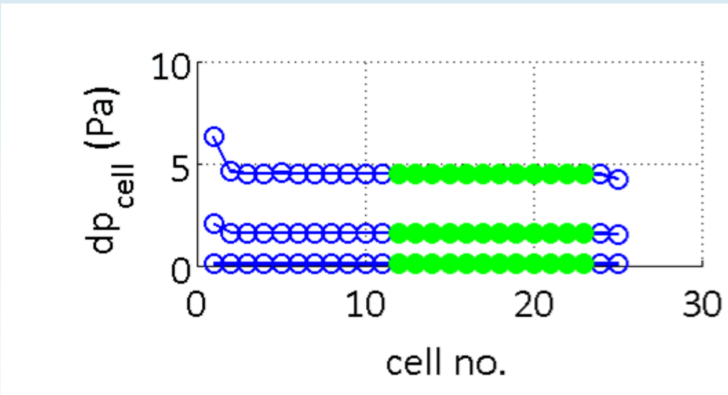


(2) ***Characteristic flow parameters:***
Permeability K *[*m^2*], Form Drag Factor* C *[*m^{-1}*]*

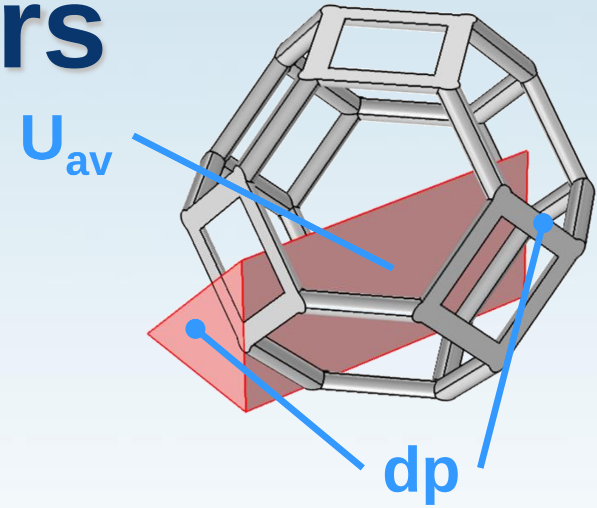
$$\frac{\Delta p}{s_{\mathrm{cell}}} = -\frac{\mu}{K} u_x - \rho C u_x^2$$

Derivation of Characterstic Flow Parameters

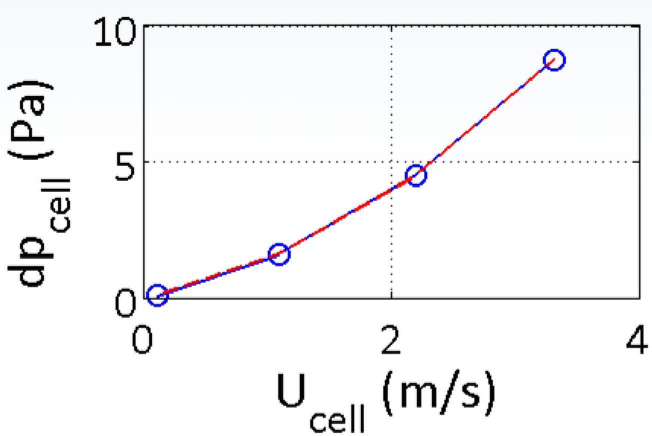
Determination of unit cell pressure drop



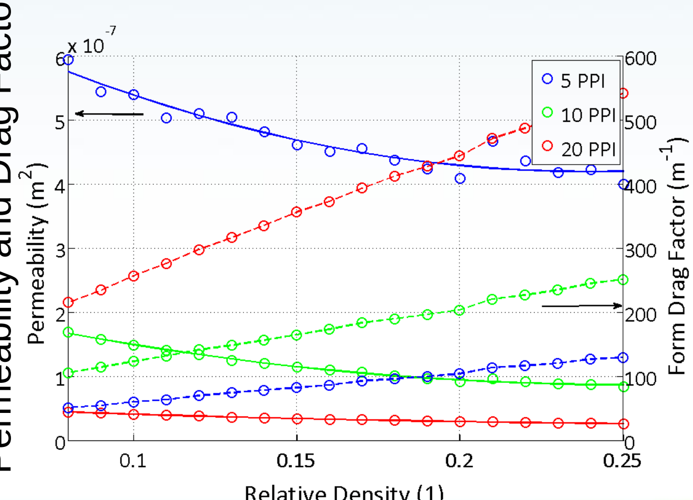
$$\frac{p}{\text{cell}} = -\frac{\mu}{K}u_x - \rho C u_x^2$$



Assessment of PM-model fit

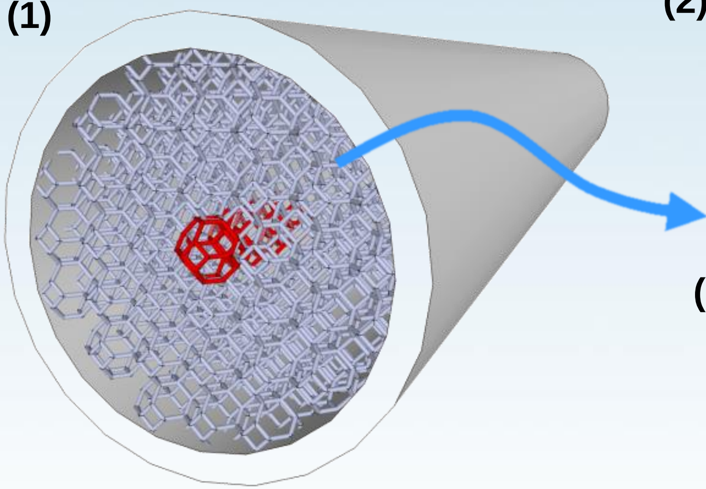


Resulting functions of Permeability and Drag Factor



Modeling Approach

(1)



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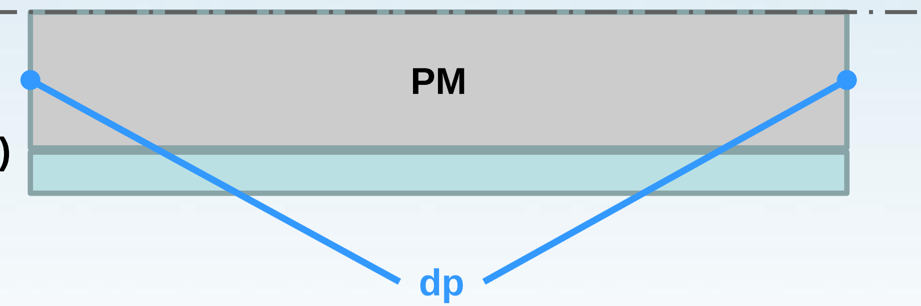
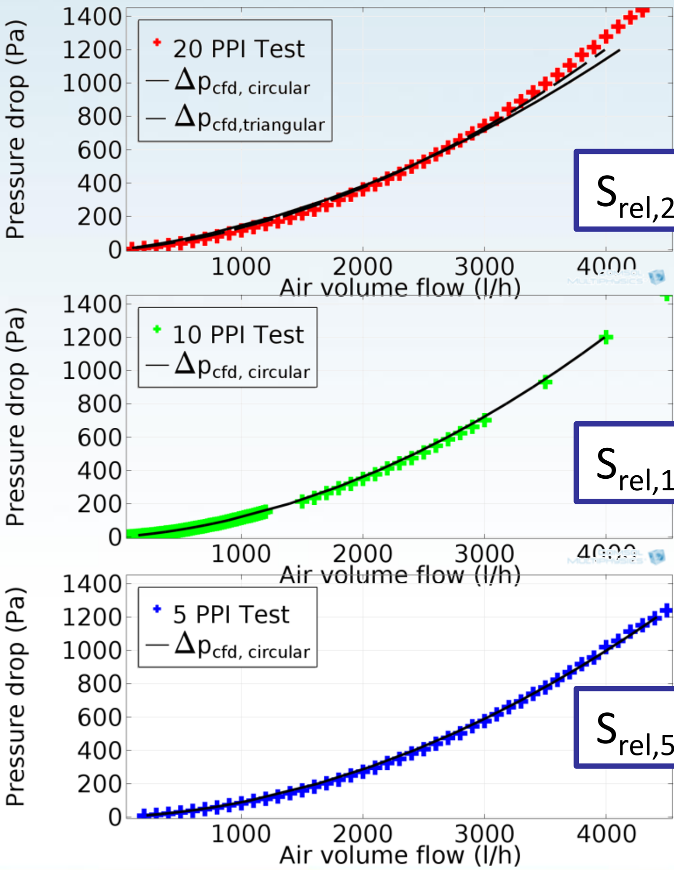
(3)



2D Porous Medium Model

$$\nabla\cdot\left[-pI+\frac{\mu}{\epsilon}(\nabla u+\nabla u^T)-\frac{2\mu}{3\epsilon}(\nabla\cdot u)I\right]=\left[\frac{\mu}{K}+C\rho|u|+\frac{\rho\nabla\cdot u}{\epsilon^2}\right]$$

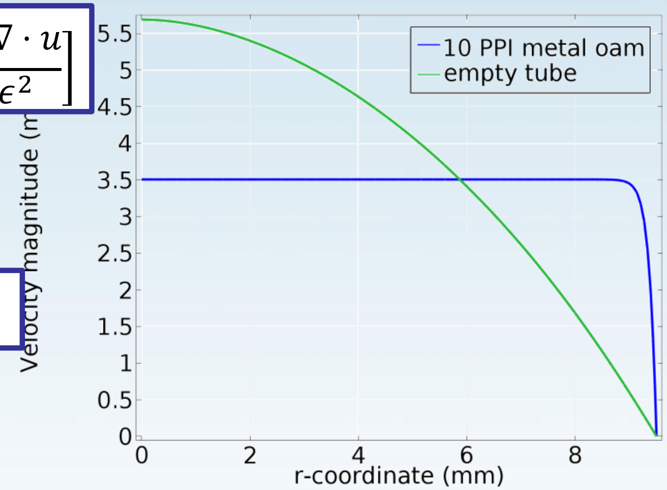
Comparison of modeling and experimental results



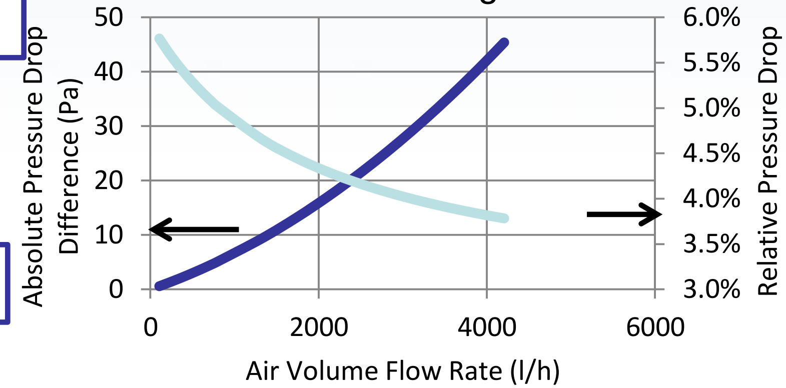
$S_{rel,20PPI}=1048m^2/m^3$

$S_{rel,10PPI}=785m^2/m^3$

$S_{rel,5PPI}=427m^2/m^3$



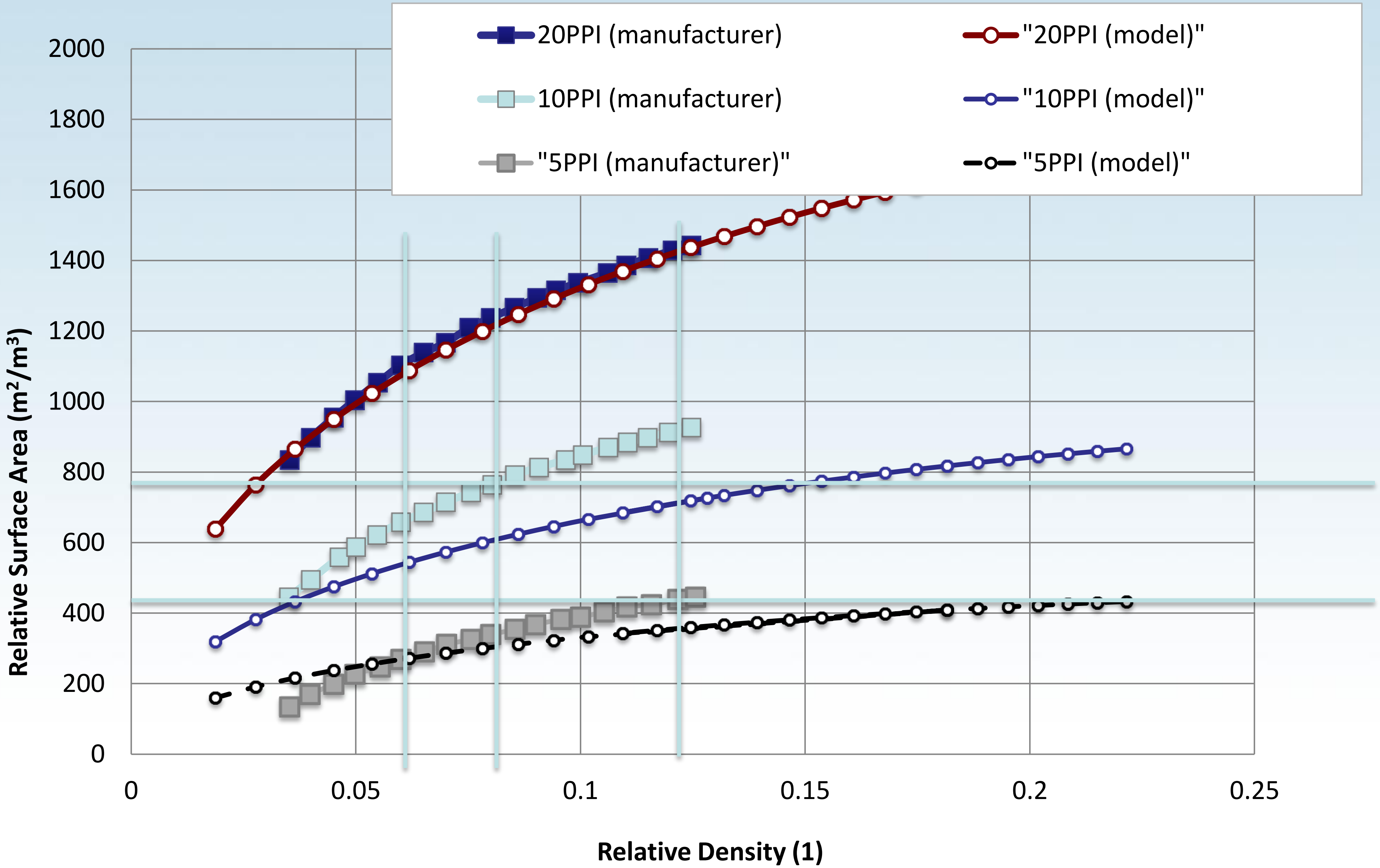
Effect of confining channel walls



Conclusions

- Porous medium flow characteristics have successfully been derived from 3D-pore scale flow modeling
- The confining tube-wall has a notable effect on overall the pressure drop
- The difference in surface area of ideal and actual structure required a correction which was more prominent at larger pore sizes
- The effect of ligament cross-section shape is stronger at smaller pore sizes

Thank you for your attention



20PPI (manufacturer)
"20PPI (model)"
10PPI (manufacturer)
"10PPI (model)"
"5PPI (manufacturer)"
"5PPI (model)"
Relative Surface Area (m²/m³)
Relative Density (1)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
0.05
0.1
0.15
0.2
0.25