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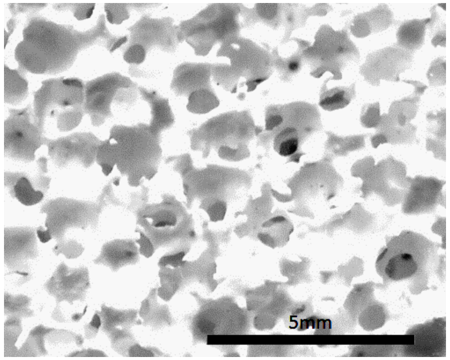

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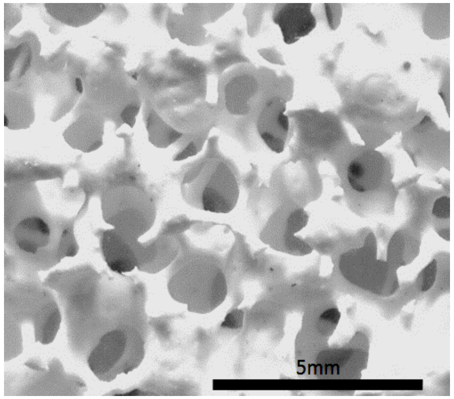
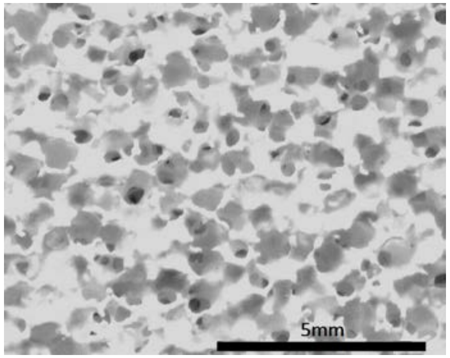


Determination and Verification of the Forchheimer Coefficients for Ceramic Foam Filters Using COMSOL CFD Modelling

Presented by M.W. Kennedy

Co-Authors: K. Zhang, J.A. Bakken, R.E. Aune



Excerpt from the Proceedings of the 2012 COMSOL Conference in Milan

Forchheimer Equation

$$\frac{\Delta P}{L} = \frac{\mu}{k_1} V_s + \frac{\rho}{k_2} V_s^2$$

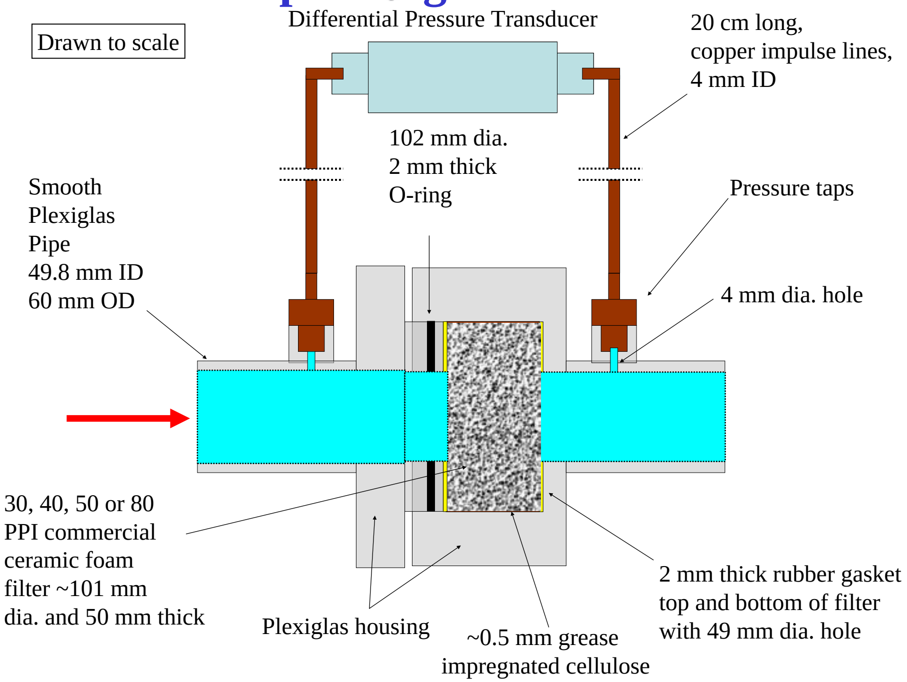
where ΔP is the pressure drop across the CFF [Pa], L the filter thickness [m], μ the fluid viscosity (which for water at 280 K is 1.382×10^{-3} [Pa·s]), V_s the fluid superficial velocity [m/s], k_1 the first order Darcy coefficient [m^2], ρ the fluid density (which for water at 280 K is ~1000 [kg/m^3]), and k_2 the non-Darcy coefficient [m].

Permeability Apparatus

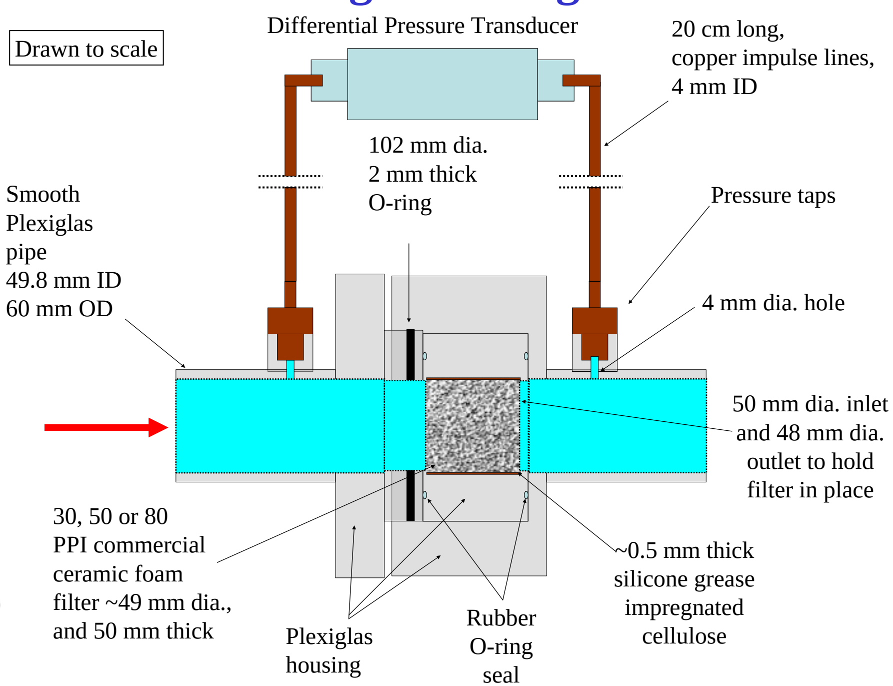
Issues:

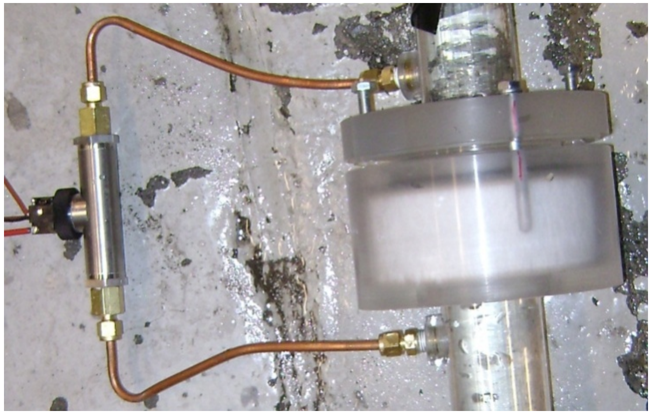
1. Inlet boundary conditions
2. Sealing
3. Flow field diameter

Expanding flow field

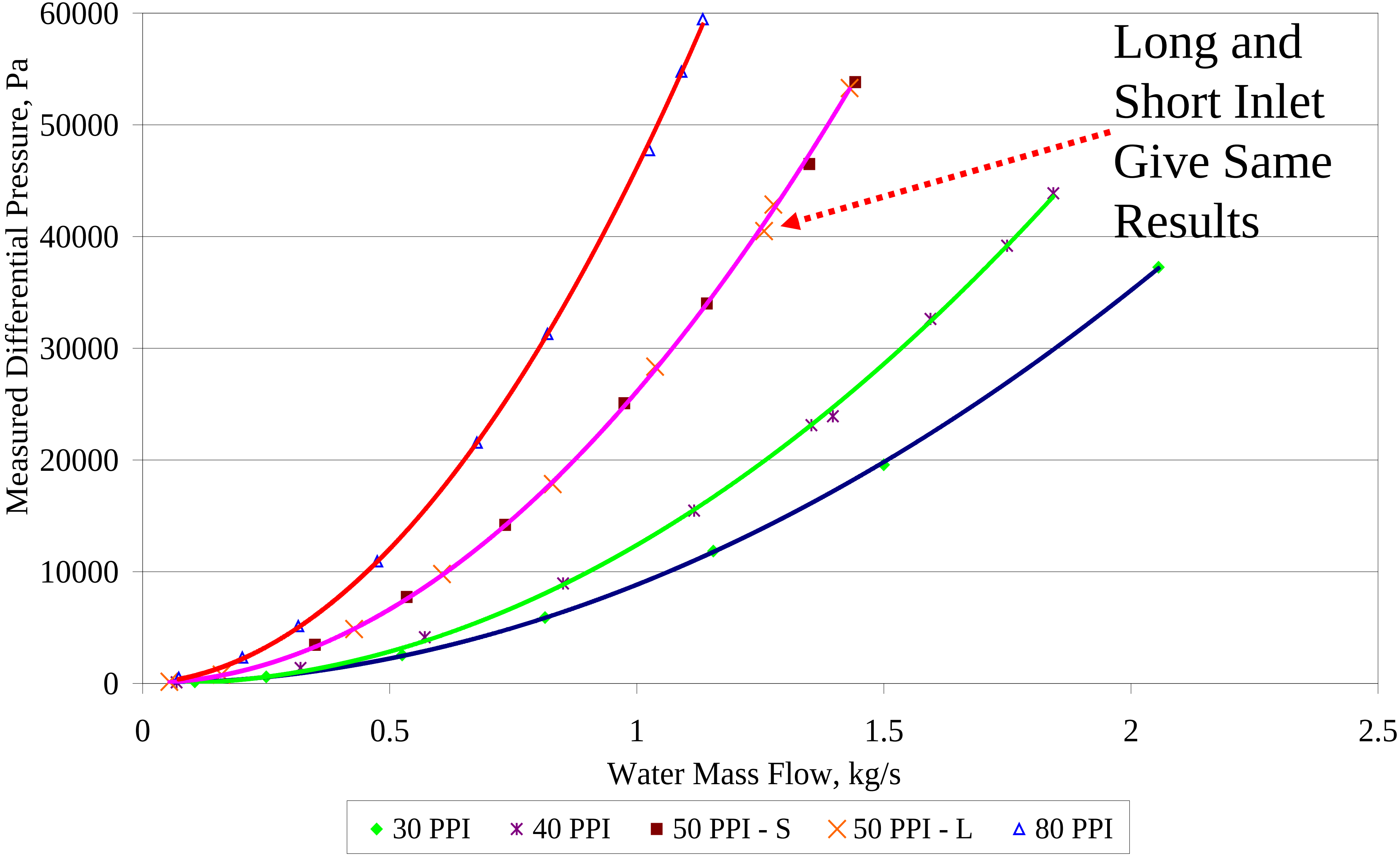


Straight Through





Measured Pressure Gradients

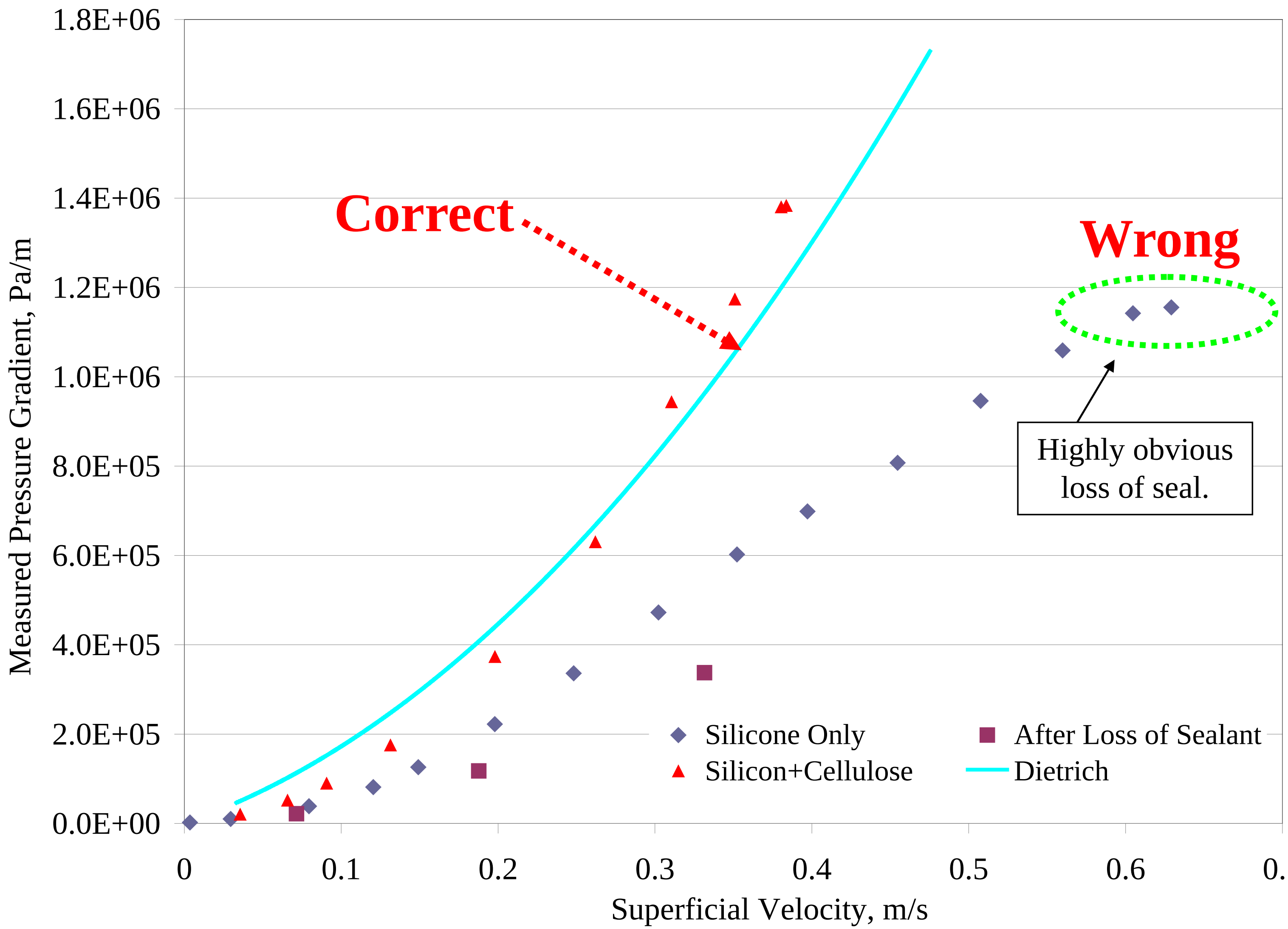


Sealing of the filters into the housing

High Viscosity
Silicone Grease

Cellulose
fibre,
i.e. paper!

How to obtain a true pressure gradient?



B. Dietrich, G. I. Garrido, P. Habisreuther, N. Zarzalis, H. Martin, M. Kind, and B. Kraushaar-Czarnetzki, *Industrial & Engineering Chemistry Research*, 48, (2009), 10395-10401

How to determine the effective Flow Field Diameter?

What diameter, which if occupied by a homogeneous fluid velocity in only the z-direction for the same total fluid flow would give the actual measured pressure gradient?

Measure: ΔP, Diameter, L, Mass Flow, Temperature (i.e. μ and ρ)

↓

Guess an effective diameter

↓

Calculate k_1 and k_2

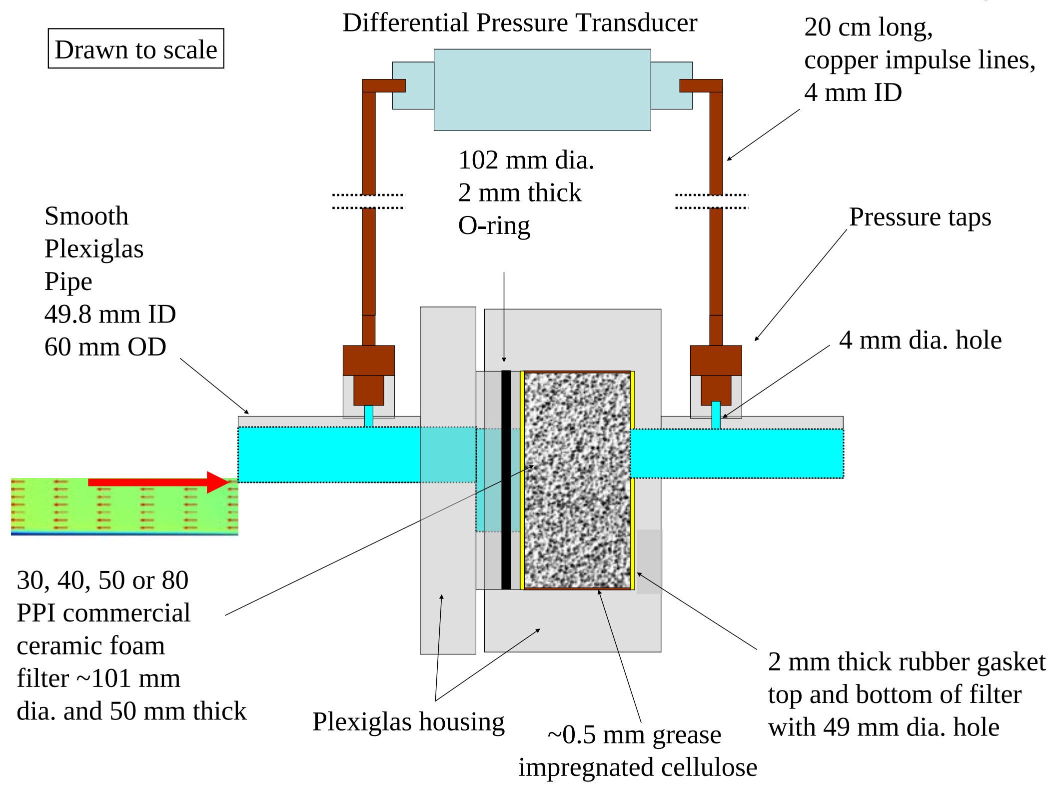
↓

CFD flow field, $\Delta P/L$ vs. V

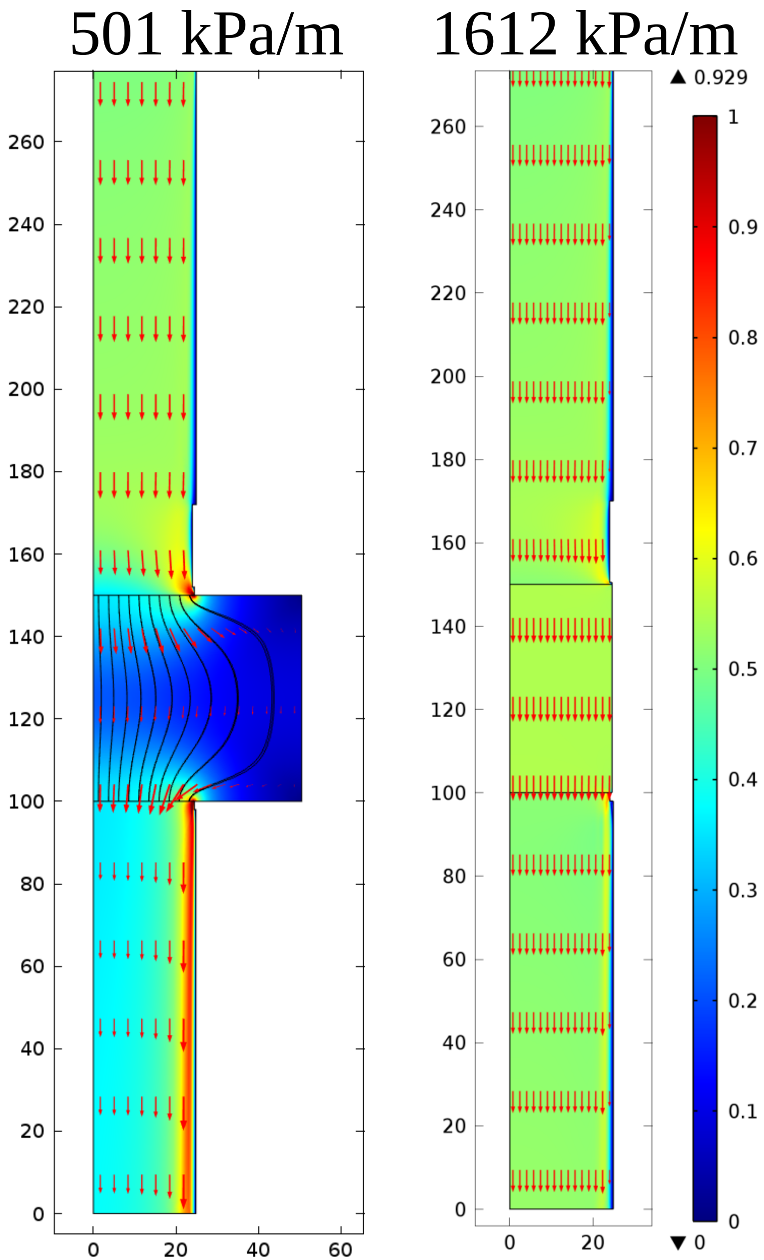
→

Same as measured?

- No → Guess a new effective diameter → Calculate k_1 and k_2
- Yes → 'Effective' diameter is correct



Comparison of Expanding Flow Field with Straight Through



0.5 m/s velocity

Expansion of the flow field has resulted in a greatly reduced pressure gradient for the same inlet velocity.

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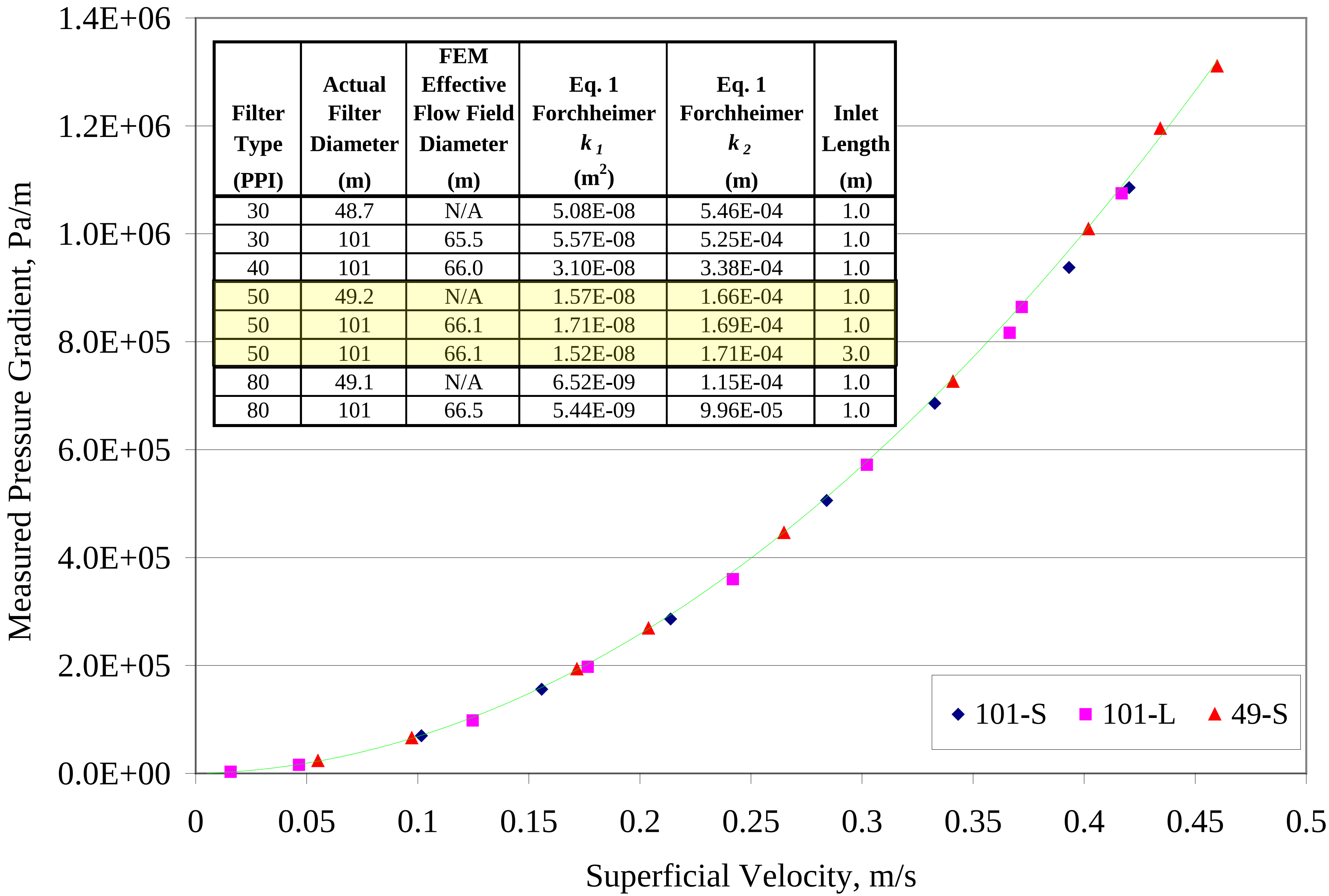
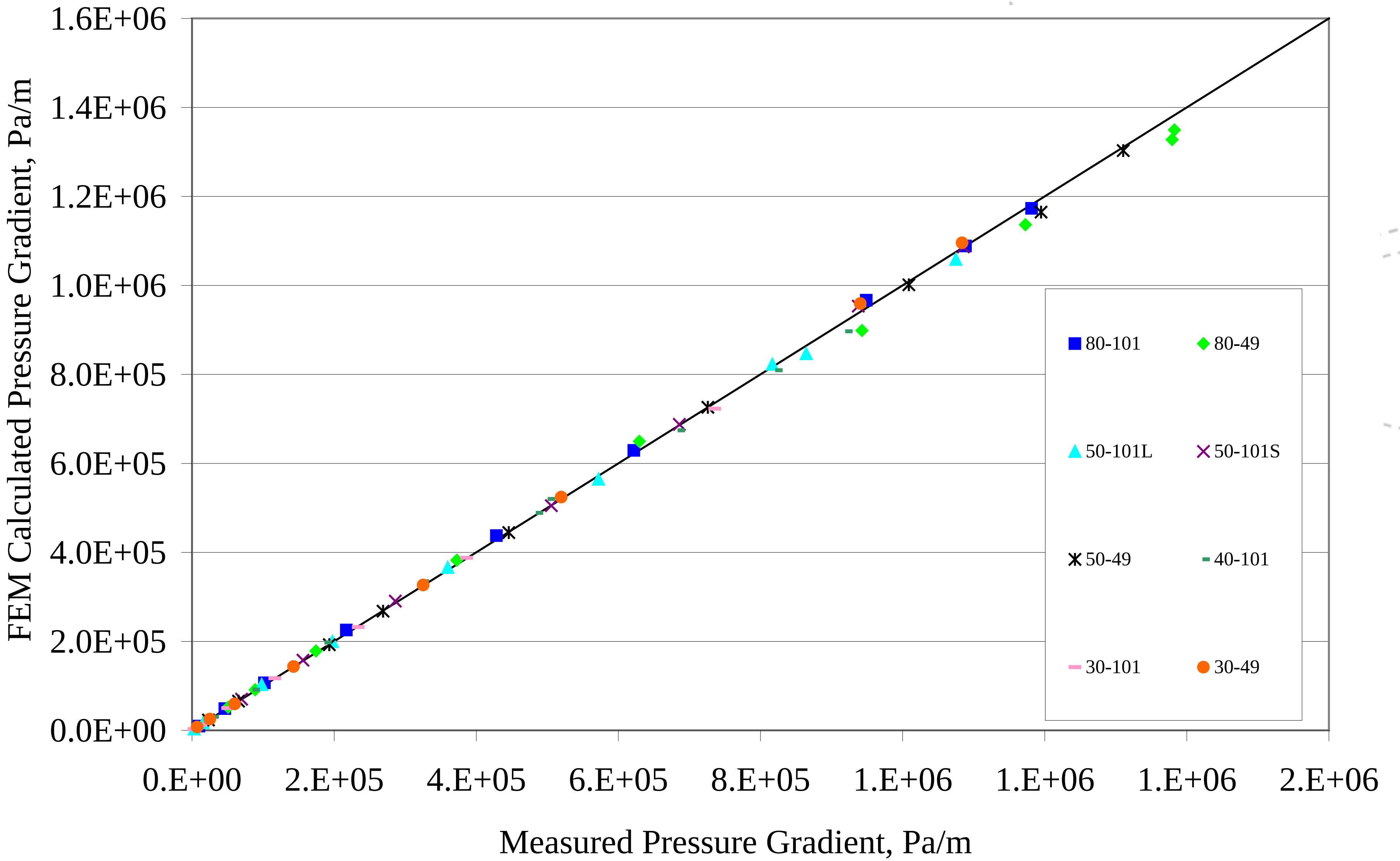
Comparison of 50 PPI, 49 mm and 101 mm L and S

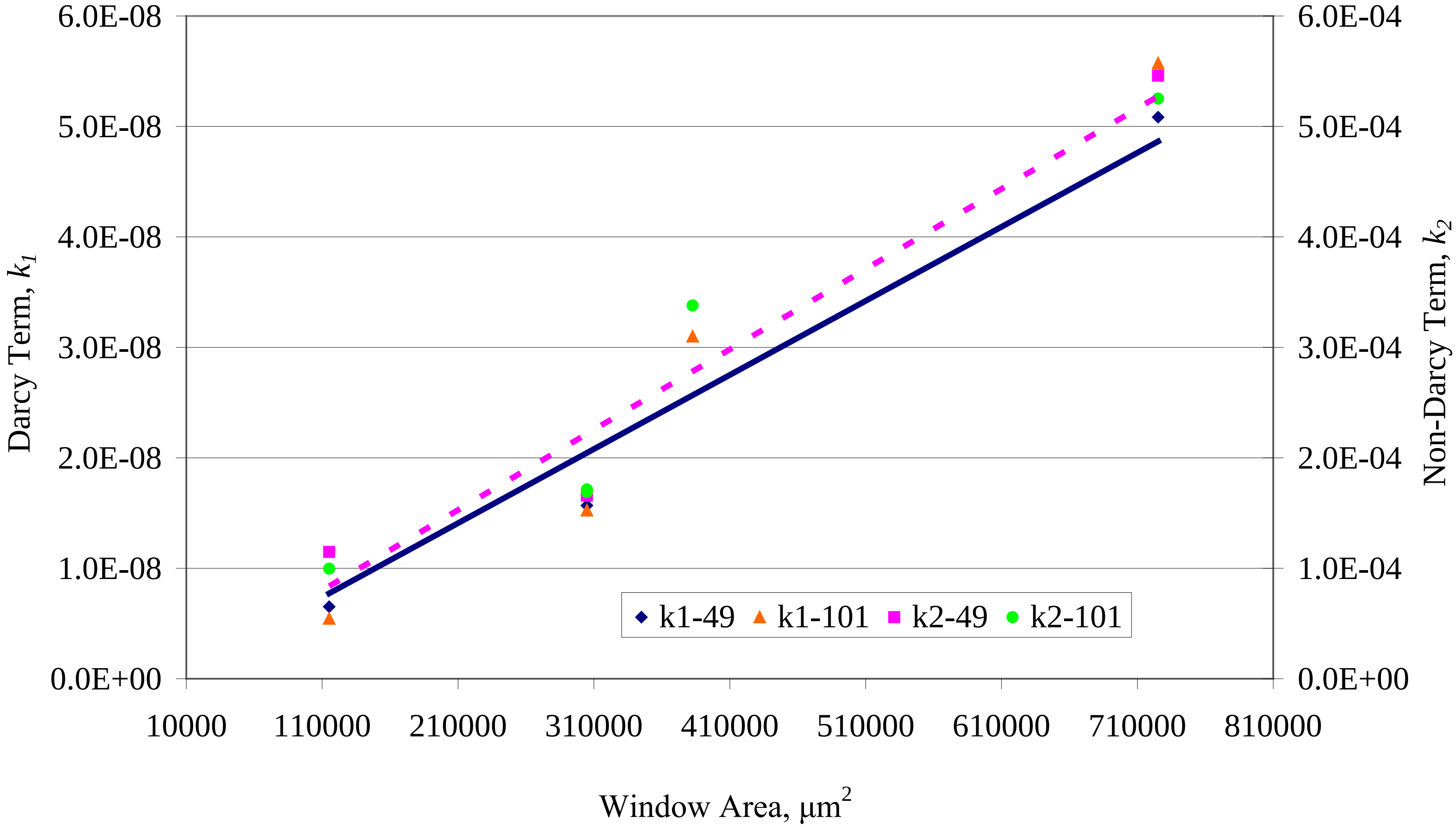


Filter Type (PPI)	Actual Filter Diameter (m)	FEM Effective Flow Field Diameter (m)	Eq. 1 Forchheimer k_1 (m^2)	Eq. 1 Forchheimer k_2 (m)	Inlet Length (m)
30	48.7	N/A	5.08E-08	5.46E-04	1.0
30	101	65.5	5.57E-08	5.25E-04	1.0
40	101	66.0	3.10E-08	3.38E-04	1.0
50	49.2	N/A	1.57E-08	1.66E-04	1.0
50	101	66.1	1.71E-08	1.69E-04	1.0
50	101	66.1	1.52E-08	1.71E-04	3.0
80	49.1	N/A	6.52E-09	1.15E-04	1.0
80	101	66.5	5.44E-09	9.96E-05	1.0

Comparison of COMSOL with Experimental



Correlation of Forchheimer Terms with Measured Window Dimensions



Conclusions

- Correct sealing of the entire side of the ceramic foam filter was required to obtain the true pressure gradients for the straight through 49 mm filter design. Sealing verified by agreement with COMSOL.

- COMSOL was required to calculated the equivalent flow field diameter and obtain the true Forchheimer coefficients for the 101 mm design.

- 49 and 101 mm results agree with each other and with COMSOL with deviations of $< \pm 7\%$.

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Thank you for your attention !

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