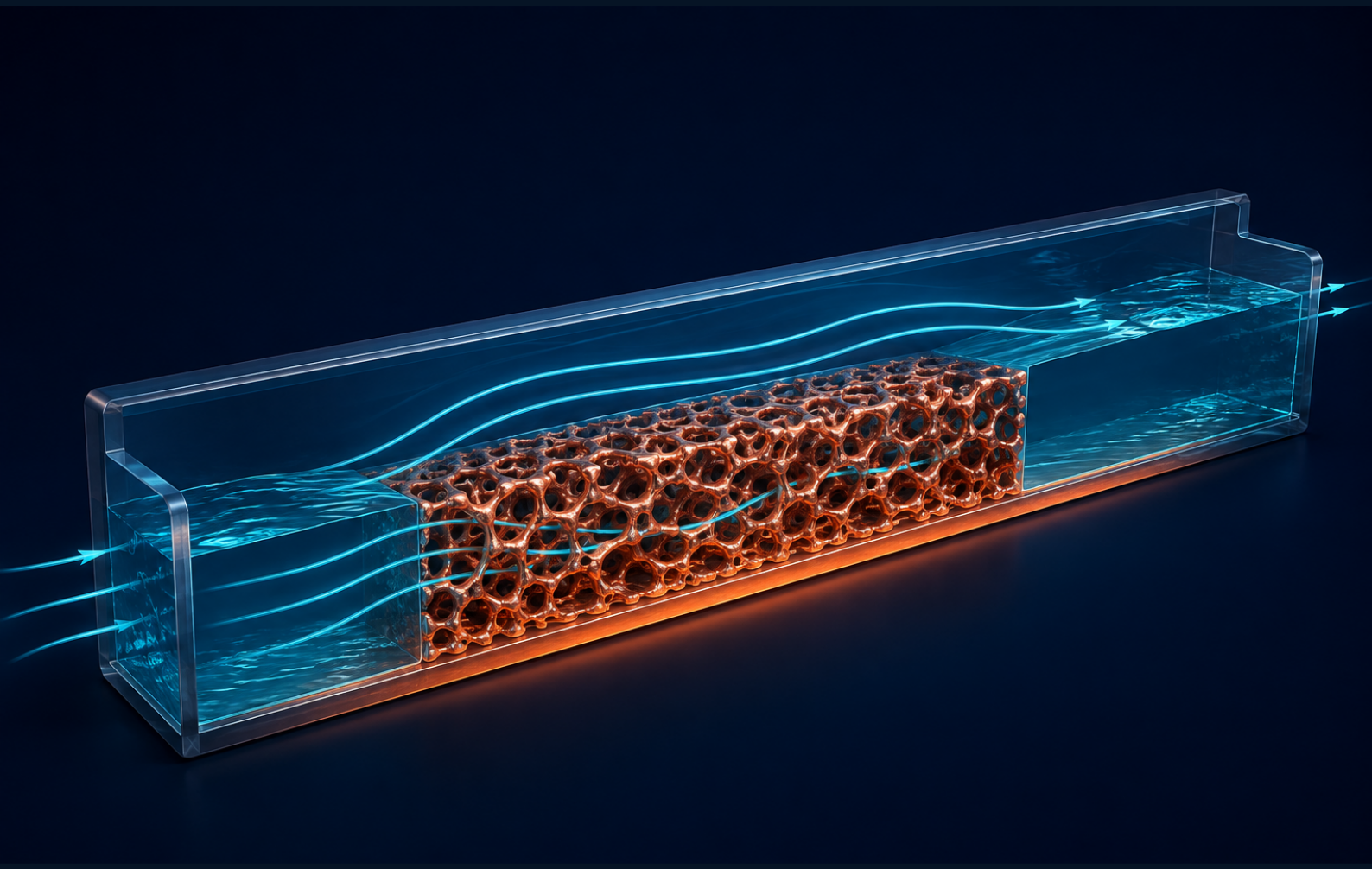
CFD + THERMAL / PORTFOLIO CASE STUDY

Porous media
in a heated channel

How insert height, permeability and flow rate reshape cooling, hotspots and pressure demand.



A lower average wall temperature can hide a hotter local peak.

A case study built from native simulation records, exported fields and independently checked comparison data.

RAMIN MASHAYEKHI

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Cover: existing AI-generated concept artwork; geometry and flow cues are illustrative.

Define the heated region

The quantitative model is a two-dimensional channel represented by a thin, one-cell extrusion.

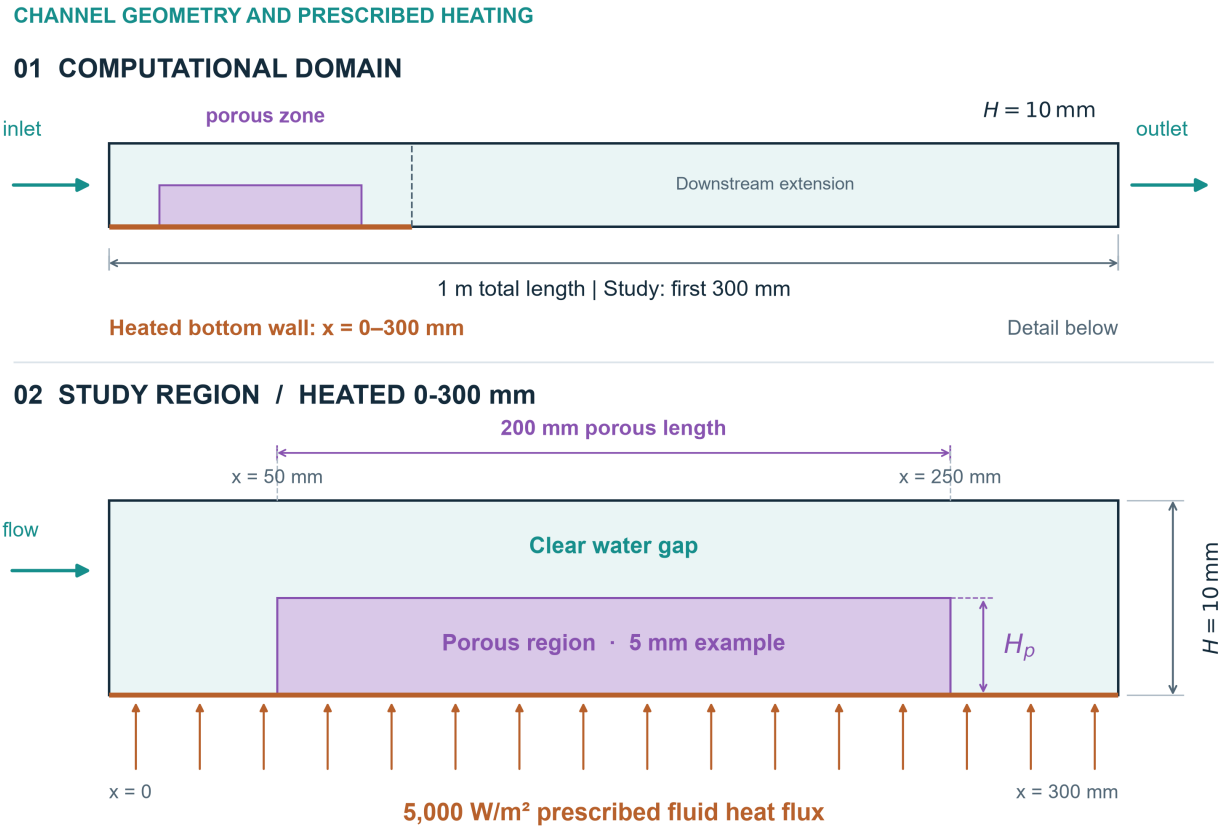


Figure 1. Original dimensioned model schematic. Vertical dimensions are enlarged. [1]

MODEL COMPONENT	SPECIFICATION
Channel / numerical width	1,000 mm long x 10 mm high / 0.1 mm
Porous region	x = 50-250 mm; H_p = 2.5, 5, 7.5 or 10 mm
Heating / inlet	Bottom x = 0-300 mm; 5,000 W/m2; water at 300 K
Boundaries	No-slip walls; unheated walls adiabatic; depth symmetry

Use the actual heat input

The empty channel receives 0.150 W. Porous cases receive 0.145 W after 0.95 porosity weighting on the heated porous-fluid boundary. Heat enters the fluid phase; the copper boundary is adiabatic.

Heat and power values refer to the 0.1 mm modeled width. This is not a specified physical device width. [2, 3]

From native cases to comparisons

Steady laminar water flow, porous momentum resistance and separate water/copper energy equations in Ansys CFX 2022 R2.

52
planned matrix cases

28
cases converged in archive

13
cases in local metric pack

The illustrated height, permeability and flow comparisons use **10 unique cases**. The 13-case metric pack adds empty-channel references at Re_H = 250, 750 and 1,000. The larger planned matrix remains incomplete.

SEQUENTIAL SOLUTION

STAGE	MODEL / CONTROL	RMS TARGET
1. Flow	Momentum + continuity; automatic timescale	1e-5
2. Energy	Frozen flow; separate water/copper temperatures	1e-12

Each of the 10 detailed cases uses **540,000 hexahedral cells**. The flow and thermal stages both reached their configured residual targets. These checks establish completion of the selected solves; they do not establish mesh independence.

KEEP THE DEFINITIONS CONSISTENT

QUANTITY	BASIS USED IN THIS REPORT
Re_H / Da_H	rho U_in H / mu and K / H2; H = 10 mm
Nusselt number	Hydraulic diameter Dh = 2H = 20 mm; water k = 0.6069 W/(m K)
Pressure / hydraulic power	Area-mean static pressure, x = 0-300 mm; P = dp x volume flow
Peak resistance	(Peak fluid-side heated-wall temperature - T_in) / actual Q

Porosity 0.95; interfacial area 9,308 m-1; interphase HTC 10,000 W/(m2 K), fixed across cases. These are declared model assumptions. [2-4]

The 1 m native model includes a downstream extension. Full-domain pressure values from older exports are excluded from the report comparisons.

Mean temperature is not hotspot control

Re_H = 500; Da_H = 1e-4 for porous cases. All temperatures below are on the fluid side of the heated wall.

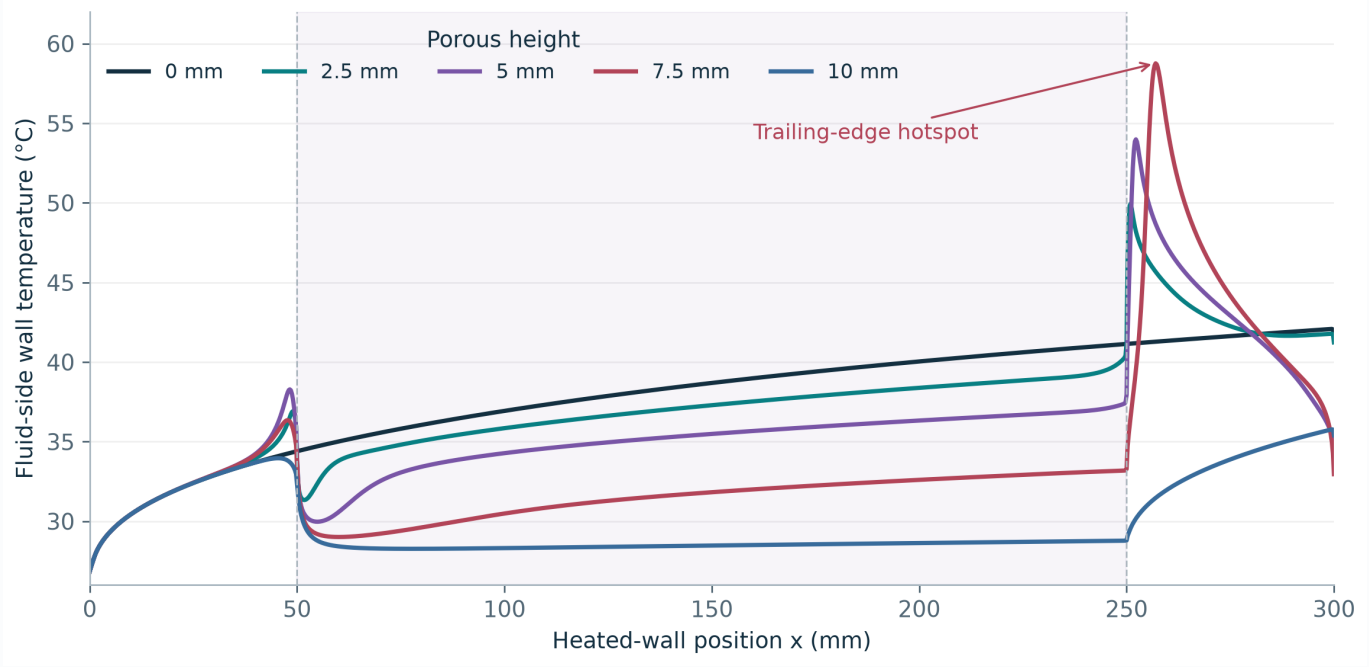


Figure 2. Native sampled wall profiles. Shading marks the porous region; table maxima are native heated-boundary evaluations. [2]

H_p (mm)	MEAN WALL (°C)	PEAK WALL (°C)	PEAK R (K/W)
0	37.88	42.08	101.53
2.5	37.23	49.98	159.49
5	35.97	54.00	187.21
7.5	33.78	58.76	220.07
10	29.94	35.78	61.56

7.5 mm insert: cooler mean, hotter maximum

Mean wall temperature falls from 37.88°C to 33.78°C, while the peak rises from 42.08°C to 58.76°C. The sampled hotspot lies near x = 257 mm, just downstream of the porous region.

The mean is weighted by geometric heated-wall area. Peak resistance uses each case's actual heat input; it refers to the modeled slice, not an explicit heater plate. [2]

The clear gap carries the bypass

A partial-height insert diverts most of the flow above the porous material. Full filling removes that bypass route.

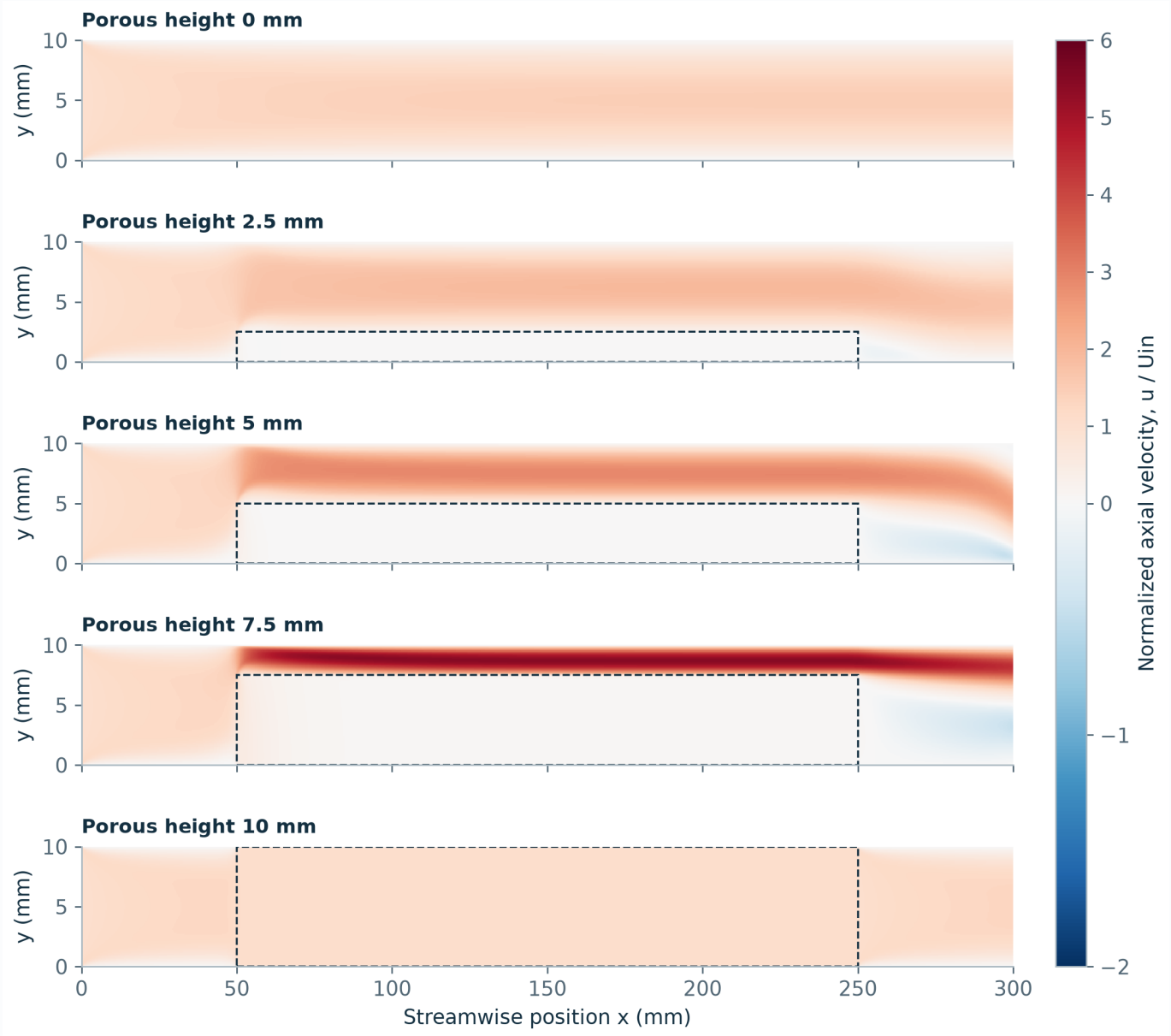


Figure 3. Native axial fluid velocity, normalized by prescribed inlet speed. Re_H = 500; Da_H = 1e-4. Dashed boundary: porous region. Vertical scale enlarged. [2]

POROUS HEIGHT (mm)	2.5	5	7.5	10
Net porous flow at x = 150 mm	0.177%	0.644%	5.134%	100%

The field evidence explains why a small average wall temperature alone is an incomplete design criterion: the flow distribution and the insert trailing edge also govern local thermal behavior.

Full filling carries a large pressure cost

At fixed Re_H = 500, the 10 mm insert improves peak resistance by 39.4%, while the study-region static pressure difference rises by 559 times.

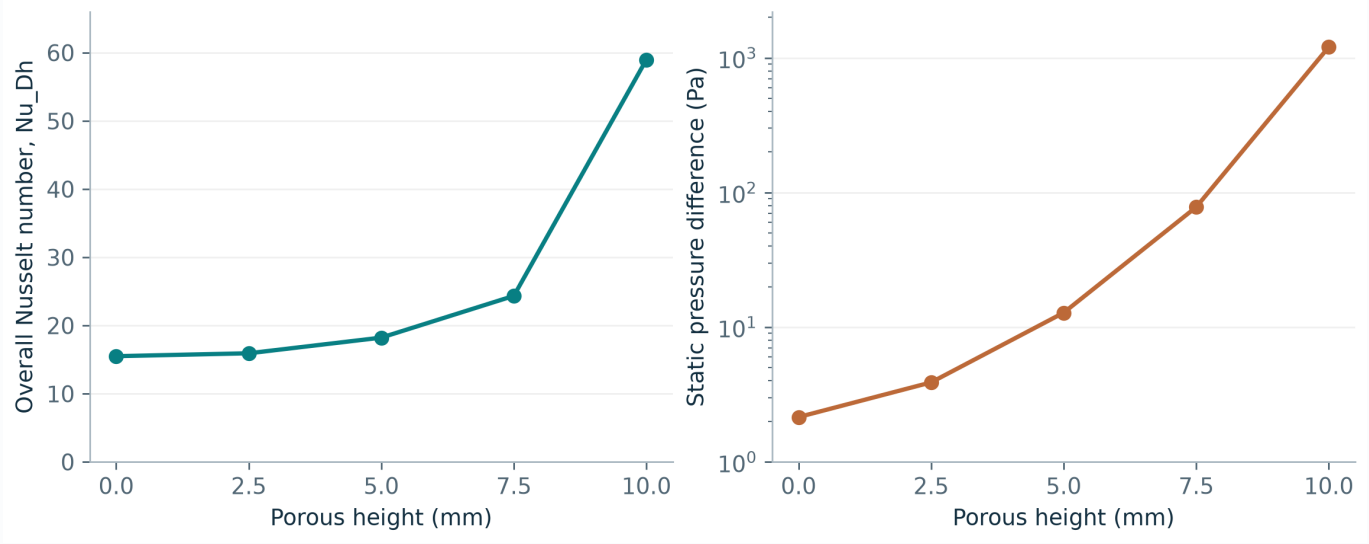


Figure 4. Overall Nu_Dh and static pressure difference over x = 0-300 mm. Pressure uses a logarithmic vertical scale. [3]

H_p (mm)	Nu overall	dp (Pa)	P / width (mW/m)	PEC overall
0	15.51	2.15	0.961	1.000
2.5	15.93	3.90	1.739	0.843
5	18.23	12.82	5.722	0.648
7.5	24.35	78.04	34.815	0.474
10	58.99	1204.00	537.168	0.462

WHAT THESE NUMBERS MEAN

Overall Nu uses the geometric heat flux and mean wall-minus-local-bulk temperature difference. **PEC** = (Nu/Nu_empty) / (f/f_empty)$^{1/3}$ is a screening index. Every porous case here is below 1 on the overall definition.

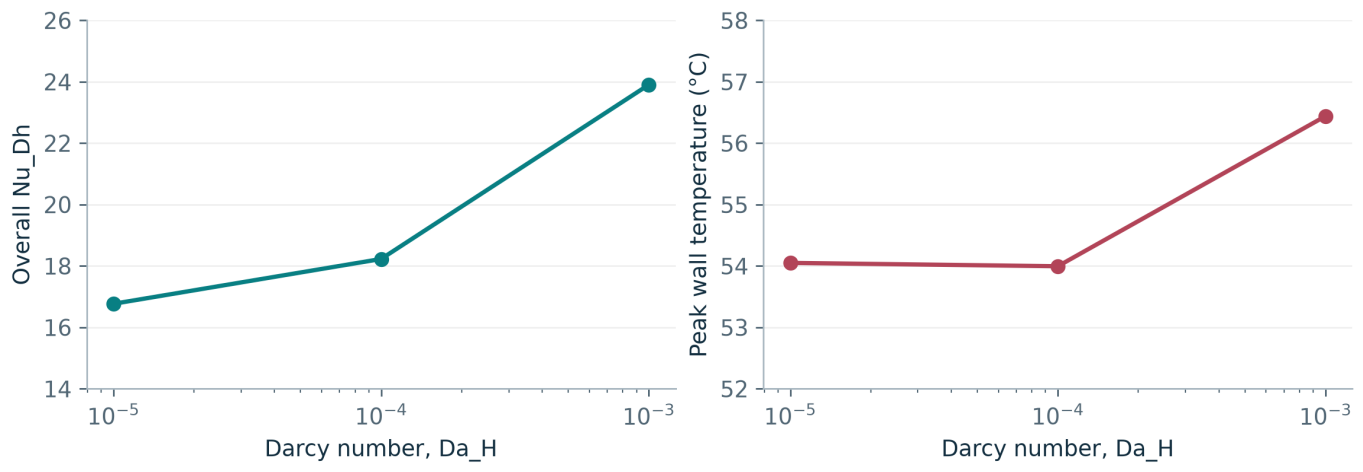
Hydraulic power is dp times volume flow. It excludes pump efficiency. The pressure-based friction factor includes porous and entrance effects; PEC is not a direct equal-pumping-power simulation.

Main thermal metric uses geometric flux: 4,750 W/m2 over the porous-fluid wall and 5,000 W/m2 elsewhere. [3]

Permeability and flow rate change the tradeoff

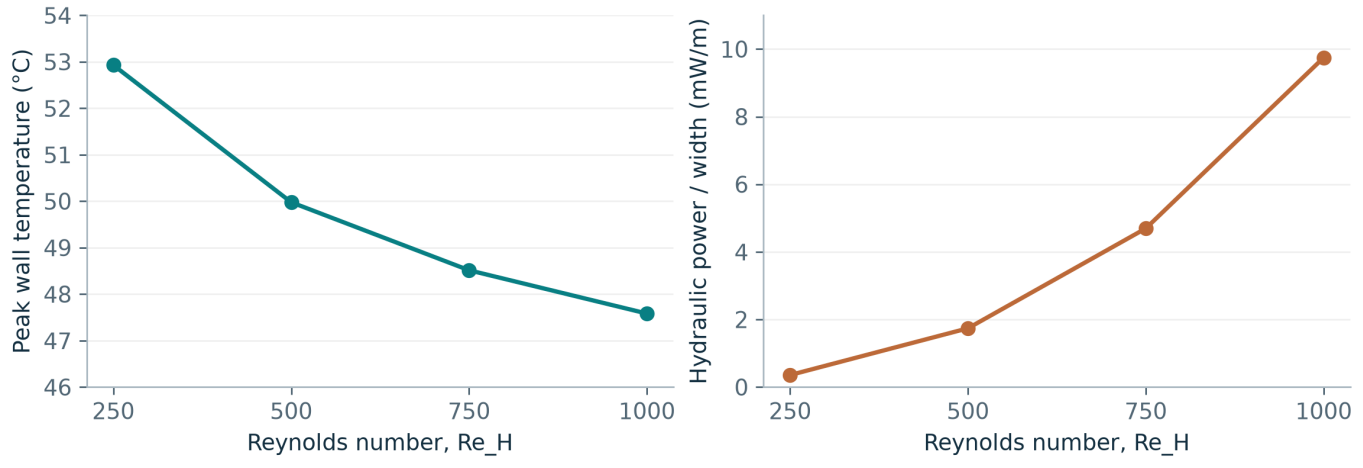
The model supports controlled comparisons, with one parameter varied at a time and the remaining selected conditions held fixed.

PERMEABILITY / Re_H = 500, H_p = 5 mm



Raising Da_H from 1e-5 to 1e-3 increases overall Nu from **16.77 to 23.90**. The peak wall temperature also rises, from **54.05°C to 56.44°C**. Better bulk heat-transfer metrics do not guarantee a cooler hotspot.

INLET FLOW / Da_H = 1e-4, H_p = 2.5 mm



Increasing Re_H from 250 to 1,000 lowers peak temperature from **52.93°C to 47.58°C**. The peak rise above the inlet falls by **20.5%**, while 0-300 mm hydraulic power rises by **27.4 times**.

Figure 5 (top): specified permeability K = 1e-9 to 1e-7 m2. Figure 6 (bottom): static hydraulic power per unit numerical width. These are computed responses under the fixed closure assumptions. [2, 3]

The Reynolds numbers use channel height H, while the reported Nusselt number uses Dh = 2H.

Separate phase temperatures, explicit limits

Local thermal non-equilibrium (LTNE) means the model solves a water temperature and a copper temperature at the same location.

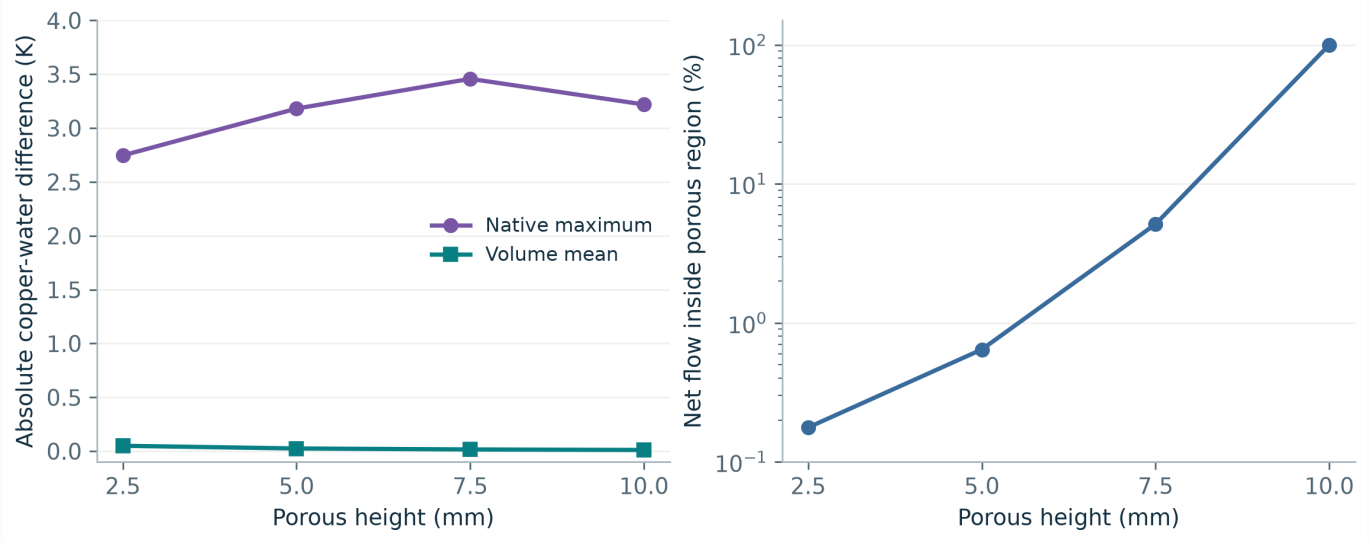


Figure 7. Native porous-domain temperature differences and net flow partition at x = 150 mm. Re_H = 500; Da_H = 1e-4. Flow fraction uses a logarithmic scale. [2]

Across the nine illustrated porous cases, maximum colocated |T_copper - T_water| is **2.58-3.46 K**, while volume means are **0.011-0.050 K**. Small domain averages can conceal localized phase differences.

WHAT HAS BEEN CHECKED

Native logs confirm target convergence for the 20 stages in the ten illustrated cases. The full-domain printed boundary enthalpy closure is within **0.48% of actual Q**. For the 13-case local metric pack, the 0-300 mm sensible-heat closure differs by up to **2.36%**. These are different checks with different boundaries.

A 120-to-1,200-point interpolation check changes mean local Nu by 1.6-11.9%, but overall Nu by less than 0.16%. This checks postprocessing sensitivity, not mesh convergence.

WHAT WOULD STRENGTHEN THE STUDY

Mesh and hotspot sensitivity. Refine the trailing edge and check the local peak.
Porous-model sensitivity. Vary the assumed interphase coupling and loss closures.
Physical validation. Compare with a measured or published benchmark before claiming performance for a particular foam or device.

This is a numerical comparison. It does not establish a globally optimal insert, calibrated commercial foam or experimental performance. [2-4]

A comparison that can be traced

All 13 cases in the local metric pack are listed below. Nu uses Dh = 20 mm; pressure spans x = 0-300 mm.

Re_H	H_p (mm)	Da_H	Nu overall	dp (Pa)	PEC overall
250	0	-	12.23	0.916	1.000
250	2.5	1e-4	12.93	1.595	0.879
500	0	-	15.51	2.154	1.000
500	2.5	1e-4	15.93	3.897	0.843
500	5	1e-5	16.77	12.517	0.601
500	5	1e-4	18.23	12.825	0.648
500	5	1e-3	23.90	11.684	0.877
500	7.5	1e-4	24.35	78.036	0.474
500	10	1e-4	58.99	1203.998	0.462
750	0	-	18.01	3.690	1.000
750	2.5	1e-4	18.03	7.015	0.808
1000	0	-	20.13	5.489	1.000
1000	2.5	1e-4	19.66	10.922	0.777

SOURCE TRAIL

[1] Geometry and illustration. Original *channel_schematic.png/.svg* and *porous_channel_hero.png*; artwork provenance retained in *Artwork_Prompt.txt*. The hero is conceptual.

[2] Native CFD exports. *porous_linkedin/results.json*, native wall/field arrays and extraction manifest, linked to source result files in the original Porous project. These supply wall, phase and flow-partition metrics.

[3] Local metrics. *porous_local_metrics/summary.csv*, raw section and wall exports, and saved CFD-Post sessions. These supply 0-300 mm pressure, power, Nu and PEC. Recalculation was checked against the exported values.

[4] Verification. Current project verification record, native solver logs and prior ten-case audit. The editable report package preserves copied data, plots, this generator and a SHA-256 manifest. No previous PDF pages were used as figures.

Prepared 28 September 2026. Numerical results are retained from the original study; the report does not represent a new solver run.