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Experimental determination of pressure drop of air flows through aluminium and nickel-chromium metallic foams

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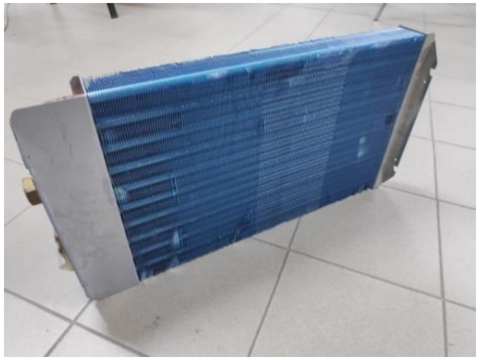
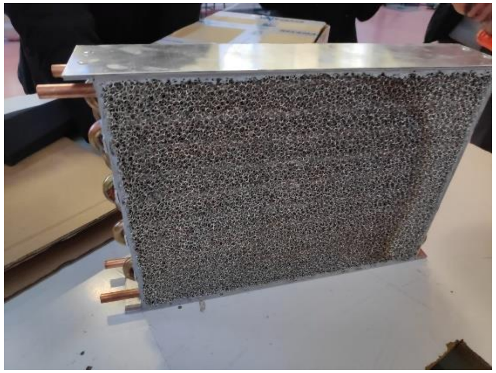


Compact finned air-water heat exchanger



Metal foam air-water heat exchanger

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OUTLINE

- Test rig description
- Analysis of the influence of the metal foam thickness on pressure drop
- Characterisation of the metal foam: evaluation of permeability (K), form drag coefficient (cf), inertia coefficient (C)
- Prediction of the differences in terms of pressure drop/air flow rate obtained by using conventional compact finned HEX and metal foam HEX coupled to the same fan-coil cabinet.

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HEAT TRANSFER

$$\underset{\Uparrow}{\boxed{q_V}} = \underset{\Uparrow}{\boxed{U \cdot a_V}} \cdot \Delta T_m$$

q_V: Thermal power per volume

U: Overall heat transfer coefficient

a_V: Surface/volume ratio

ΔT_m: Mean Logarithmic Temperature difference (air-water)

PRESSURE DROP

$$\Uparrow \boxed{-\frac{dp}{dz}} \propto \boxed{{L_c}^{-5}} \Downarrow$$

dp/dz:	axial pressure gradient	[Pa/m]
L_c:	characteristic lenght	[m]
m:	mass flow rate	[kg/s]

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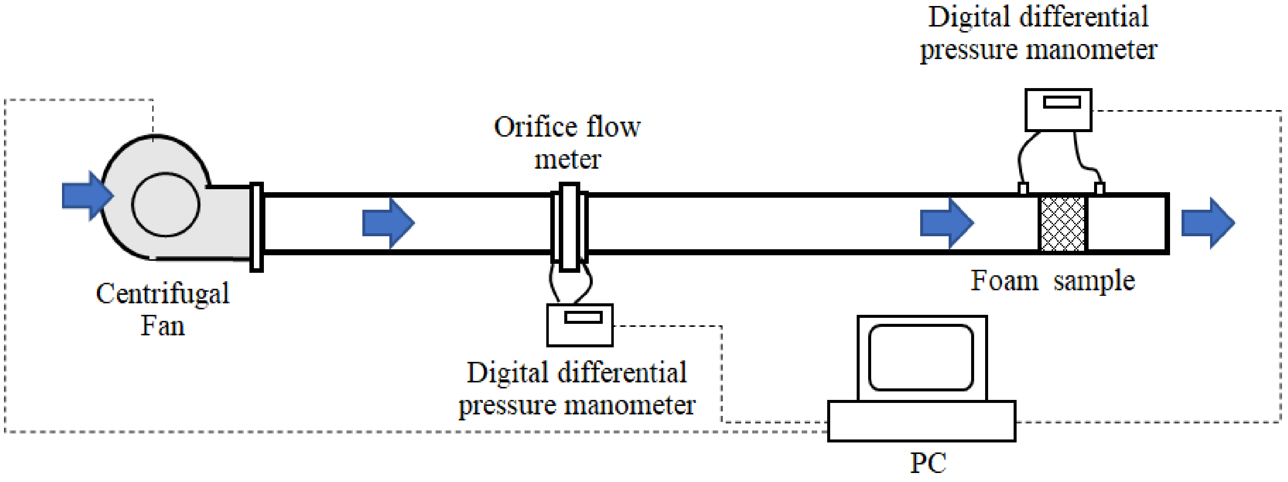
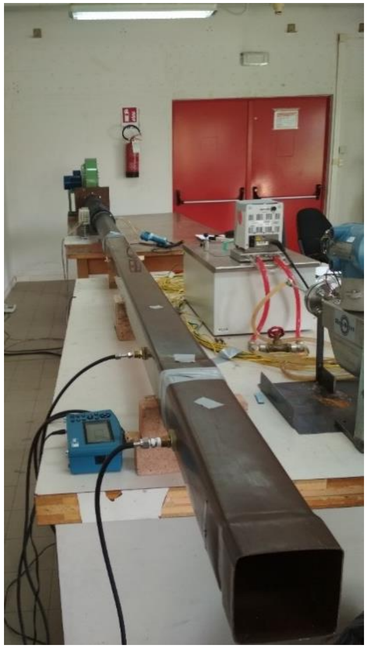
List of the metal foam samples

	Material	Sizes [mm]	Porosity φ [%] Declared/measured	PPI Declared/measured	d/t [mm]
AL-10-96(1)	Al7SiMg	100x100x20	96/96.5	10/8-11	3.1/0.47
AL-10-96(2)	Al7SiMg	100x100x20	96/96.7	10/8-11	2.80/0.47
AL-10-96(3)	Al7SiMg	100x100x20	96/96.6	10/8-11	2.59/0.47
AL-10-96(4)	Al7SiMg	100x100x20	96/96.5	10/8-11	3.17/0.47
AL-10-96(5)	Al7SiMg	100x100x20	96/96.6	10/8-11	2.60/0.47
AL-10-96(6)	Al7SiMg	100x100x20	96/96.4	10/8-11	2.82/0.47
AL-10-96(7)	Aluminium (99,7%)	100x100x20	96/96.5	10/8-11	2.19/0.47
AL-10-96(8)	Aluminium (99,7%)	100x100x20	96/96.6	10/8-11	2.61/0.47
NCX-11-92(1)	Nickel (49%) Chromium (45%)	100x100x20	92/93.9	11-16/11-16	1.4/0.6
NCX-11-92(2)	Nickel (49%) Chromium (45%)	100x100x20	92/93.3	11-16/11-16	1.4/0.6
NCX-11-92(3)	Nickel (49%) Chromium (45%)	100x100x20	92/91.8	11-16/11-16	1.4/0.6

Test rig for pressure drop measurements

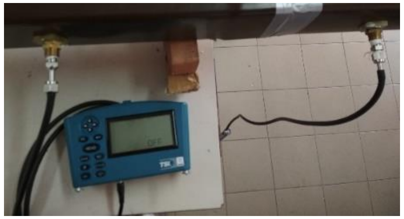




Apparatus overview

CIMME GHC 003540

TSI mod. 8386A



TSI mod. 8710

Uncertainty analysis

Characteristics and uncertainties of the measurement instruments

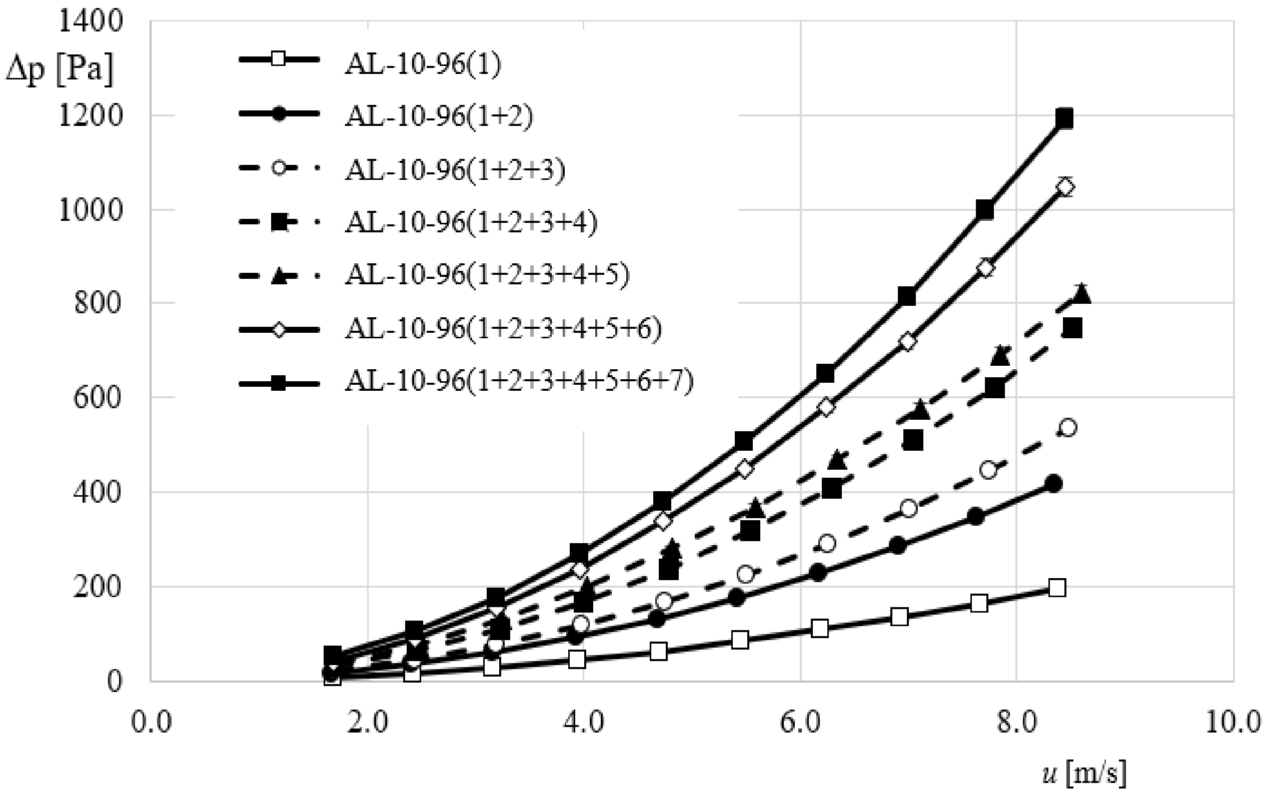
Instrument	Range	Uncertainty
TSI, VelociCalc® Plus, mod. 8386A	0-3735 Pa	±1% FS
TSI, DP-Calc™ mod. 8710	0-3735 Pa	±2% FS
Digital calibre	0-10 mm	±0.5%
Thermocouple (K-type)	0-100°C	±0.5 K

Air mass flow rate: $u_m = \pm 1\%$

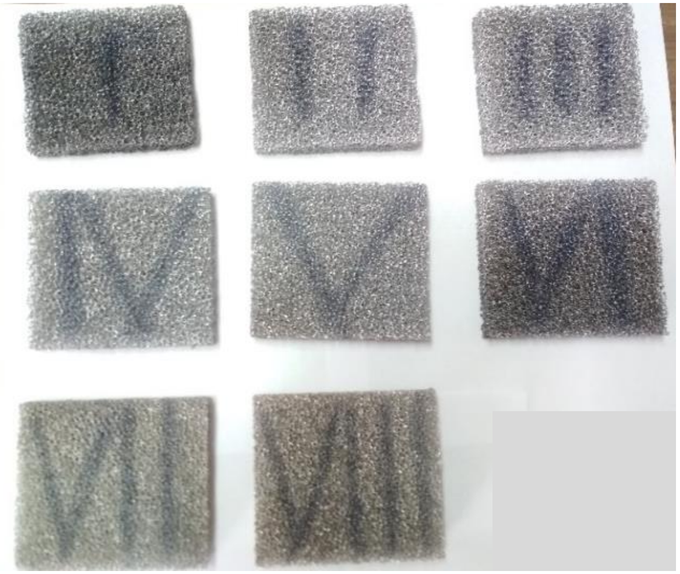
Air velocity: $u_w = \pm 1\%$

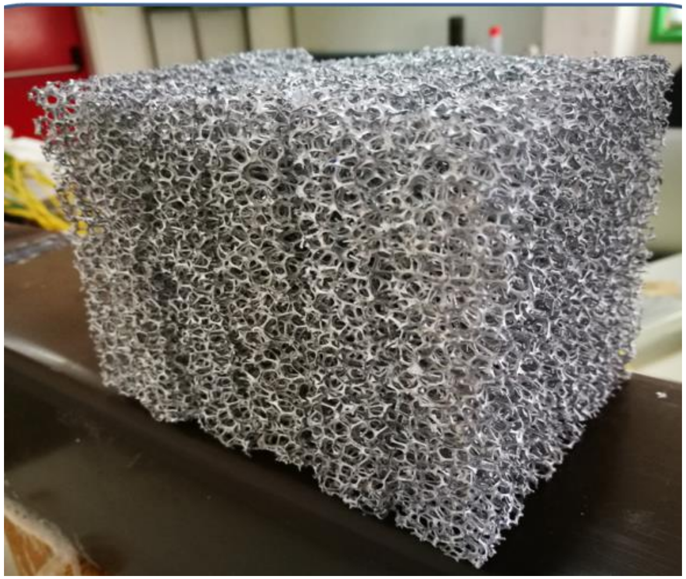
Air pressure gradient: $u_{\Delta p} = \pm 3\%$

Pressure drop vs average air velocity



Pressure drop and porous inner structure





For the assemblies of *n* samples, it has been checked if the pressure drop is influenced by:
- the order of the *n* samples
- the faces exposed at the air flow

As example, 3 samples:

(1+2+3)	(2+5+8)	(1+7+5)	No significant deviation (<3%)
(1+3+2)	(2+8+5)	(7+5+1)	
(2+3+1)	(8+5+2)	(5+1+7)	Significant deviation (>3%)

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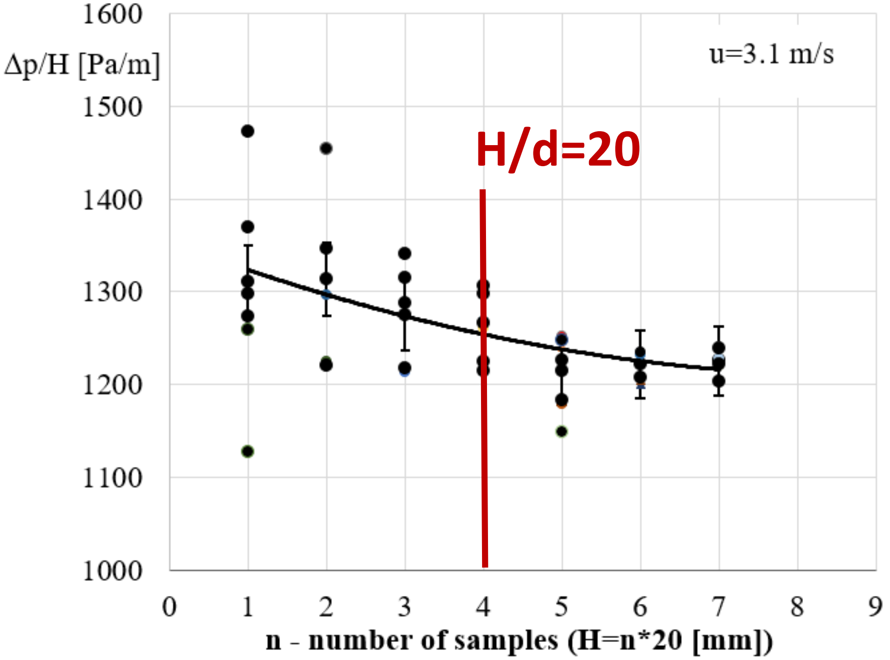
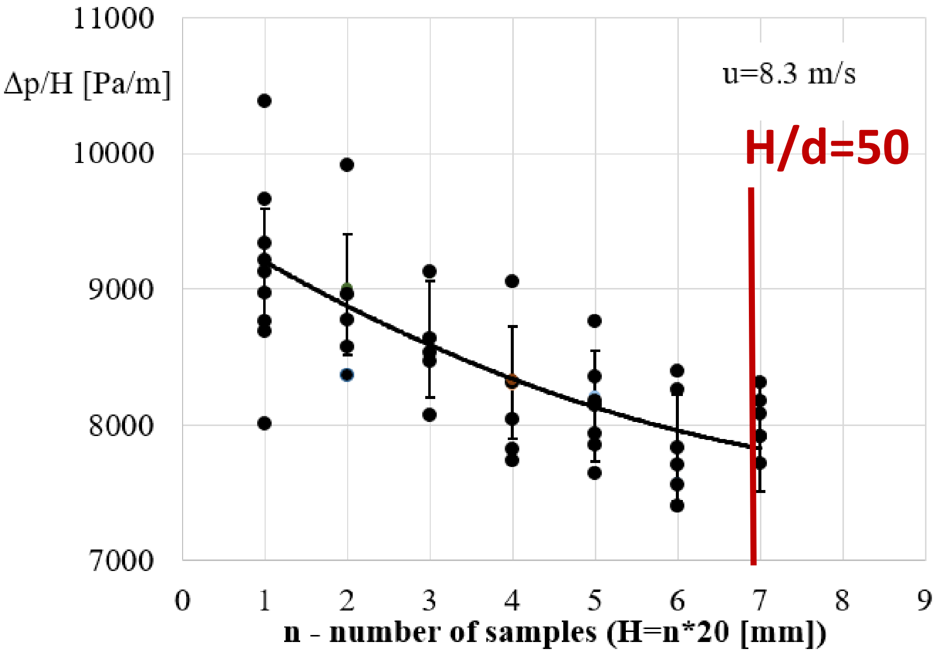
Pressure gradient vs air velocity





- **Dispersion of the results increases with the imposed average air velocity.**
- **The critical thickness increases with the air velocity**

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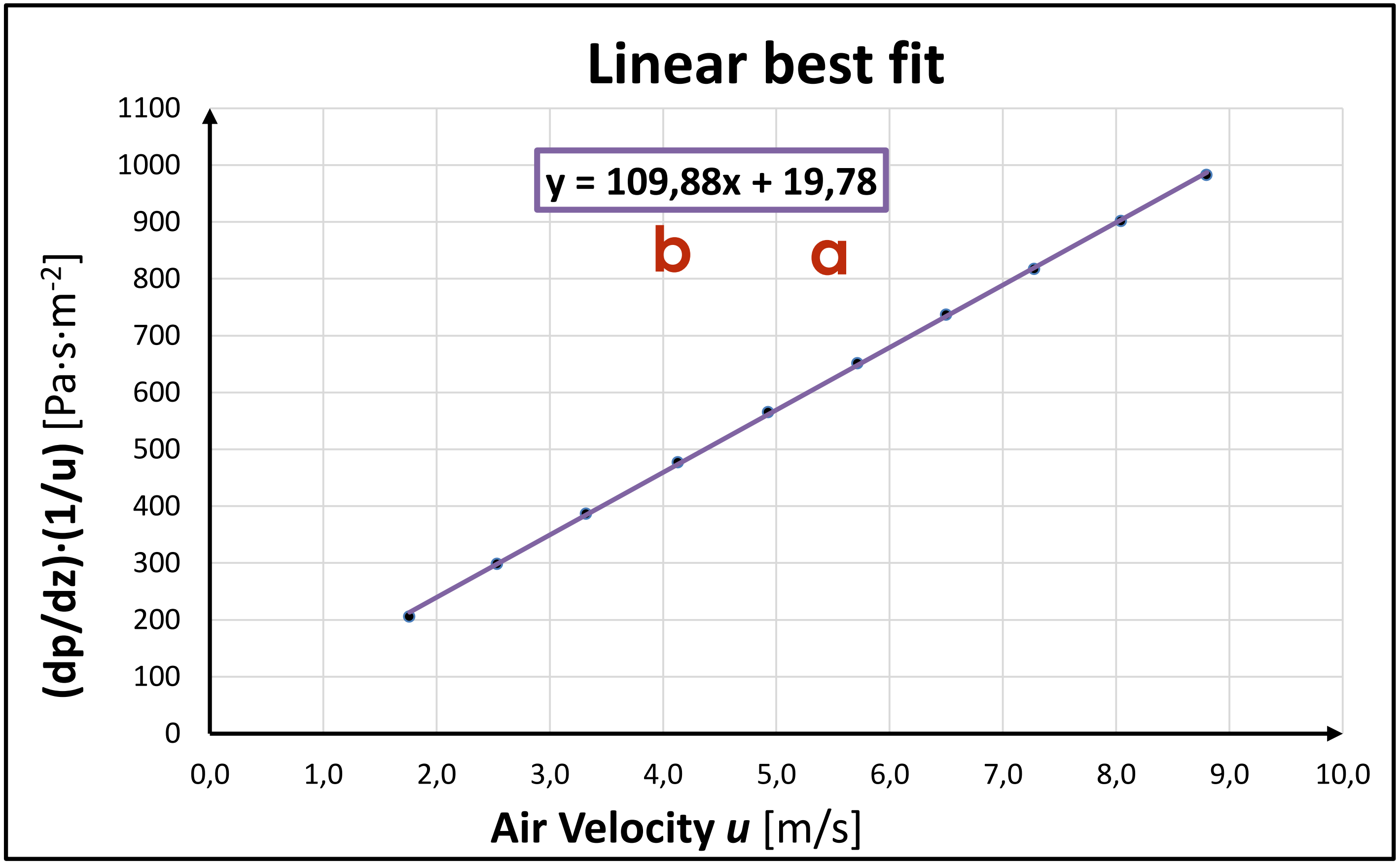
Characterization of metal foams



$$\boldsymbol{K = \frac{\mu}{a}}$$

Permeability $[m^2]$

$$\boldsymbol{c_f = \frac{b \cdot \sqrt{K}}{\rho}}$$

Form-drag coefficient $[-]$

$$\boldsymbol{C = \frac{b}{\rho}}$$

Inertia coefficient $[m^{-1}]$

$$\left(-\frac{dp}{dz}\right) \cdot \frac{1}{u} = \frac{\mu}{K} + \frac{\rho \cdot c_f \cdot u}{\sqrt{K}} = a + b \cdot u$$

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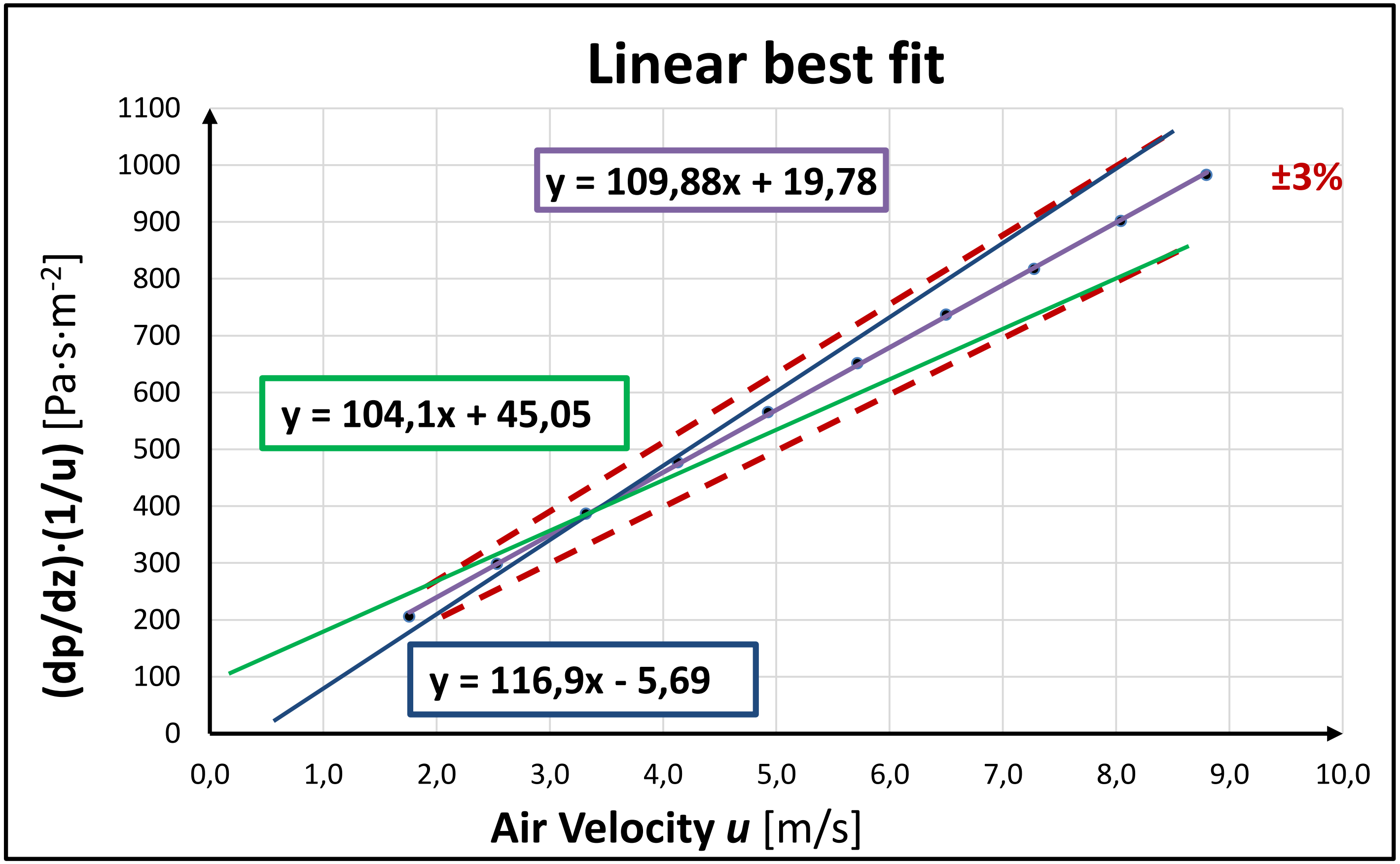
Characterization of metal foams



$$\boxed{\cancel{K = \frac{\mu}{a}}}$$

Permeability $[m^2]$

$$\boxed{\cancel{c_f = \frac{b\cdot\sqrt{K}}{\rho}}}$$

Form-drag coefficient $[-]$

$$\boxed{C = \frac{b}{\rho}}$$

Inertia coefficient $[m^{-1}]$

$$\boxed{\left(-\frac{dp}{dz}\right)\cdot\frac{1}{u} = \frac{\mu}{K} + \frac{\rho\cdot c_f\cdot u}{\sqrt{K}} = a + b\cdot u}$$

Characterization of metal foams

Experimental results obtained for two assemblies of 4 samples (H=80 mm).

Air velocity [m/s]	**AL-10-96 (2+3+4+1) Δp** [Pa]	**AL-10-96 (3+4+5+6) Δp** [Pa]	**Difference %**
2.6	64.2	67	-4.2
3.4	108	113	-4.4
4.3	168.1	177	-5.0
5.1	237.1	252	-5.9
5.9	318.2	341	-6.7
6.7	409	439.3	-6.9
7.5	511	548.3	-6.8
8.3	623.1	667.9	-6.7
9.1	750	803.5	-6.7
a [kg·m^{-3}·s^{-1}]	11,61	20,70	+78,45%
b [kg·m^{-4}]	112,8	120,0	+6,38%
K [m^2]	1,59E-06	8,86E-07	-44,28%
c_f [-]	0,121	0,095	-21,49%

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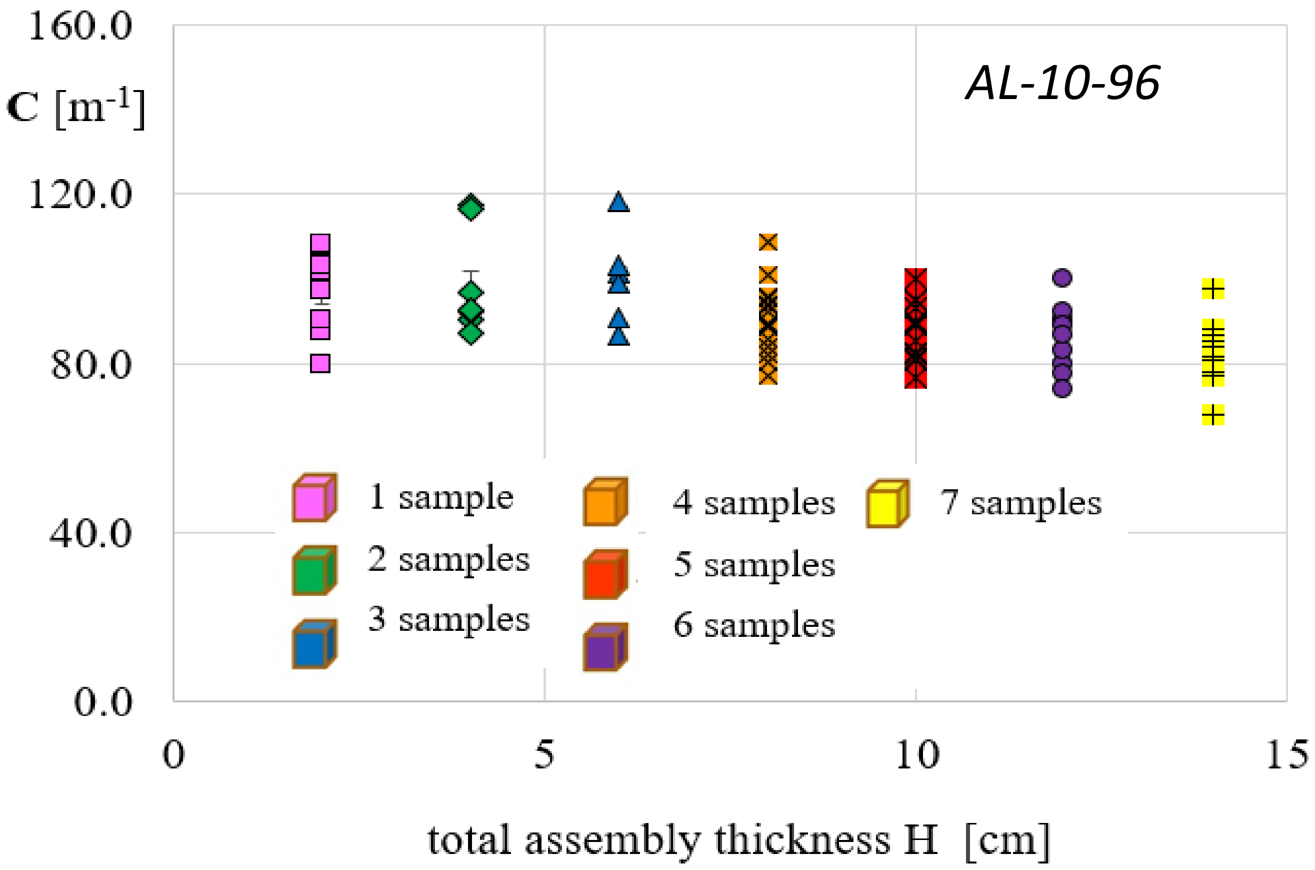
Characterization of metal foams

$$\boxed{C = \frac{b}{\rho}}$$

Inertia coefficient $[m^{-1}]$



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Characterization of metal foams

$$\boxed{C = \frac{b}{\rho}}$$

Inertia coefficient $[m^{-1}]$

Metal foam	Reference	C [m^{-1}]	C [m^{-1}] Present results
AL-10-96	Kamath et al. [11]	90÷160	68-118
	Tadrist et al. [10]	114÷128	
	Boomsma et al. [12]	110	
	De Schampheleire et al. [13]	60÷120	
	Richardson et al. [9]	123	
	Mancin et al. [14]	170-240	
NCX-11-92	Khayargoli et al. [15]	370	360-420
	Bonnet et al. [16]	381	

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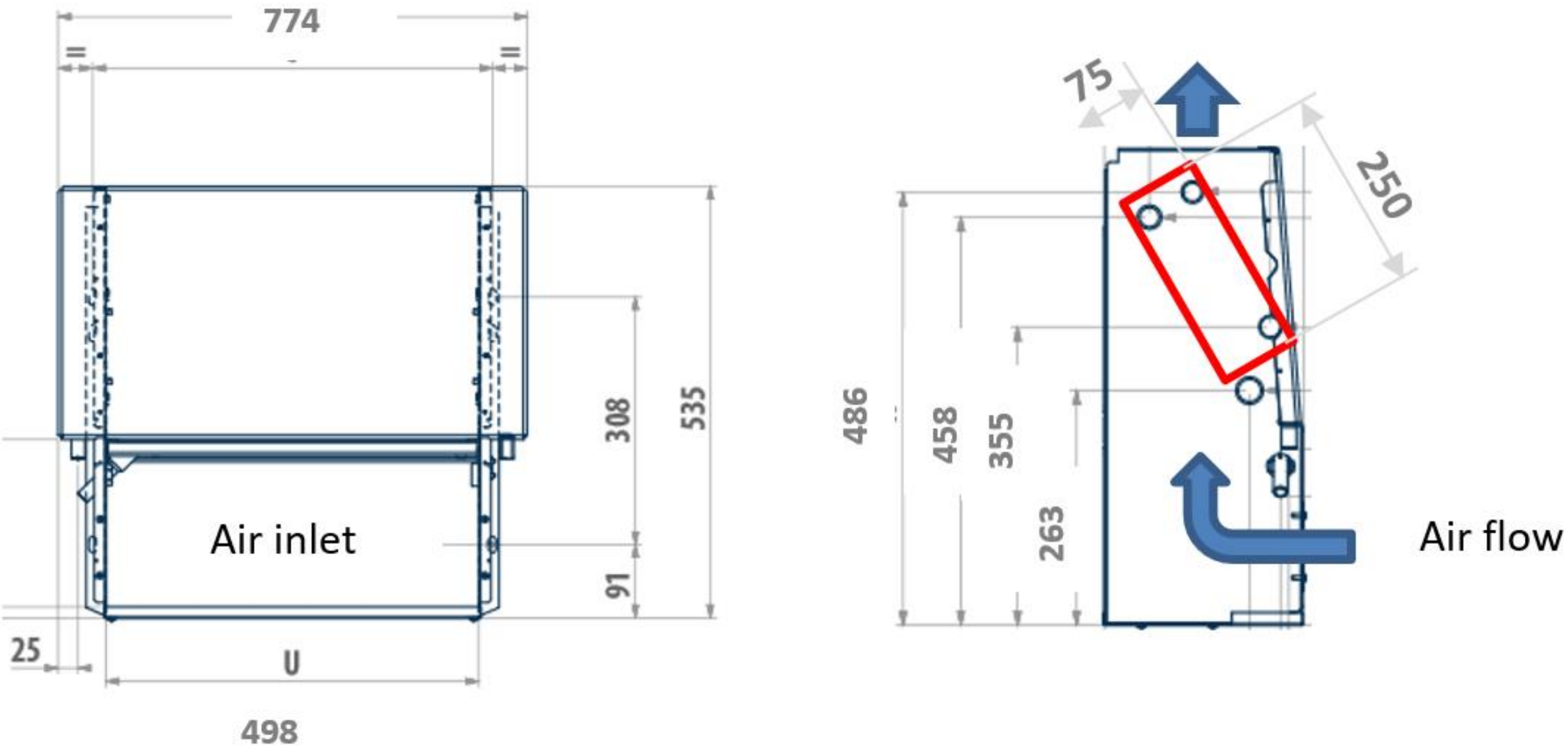
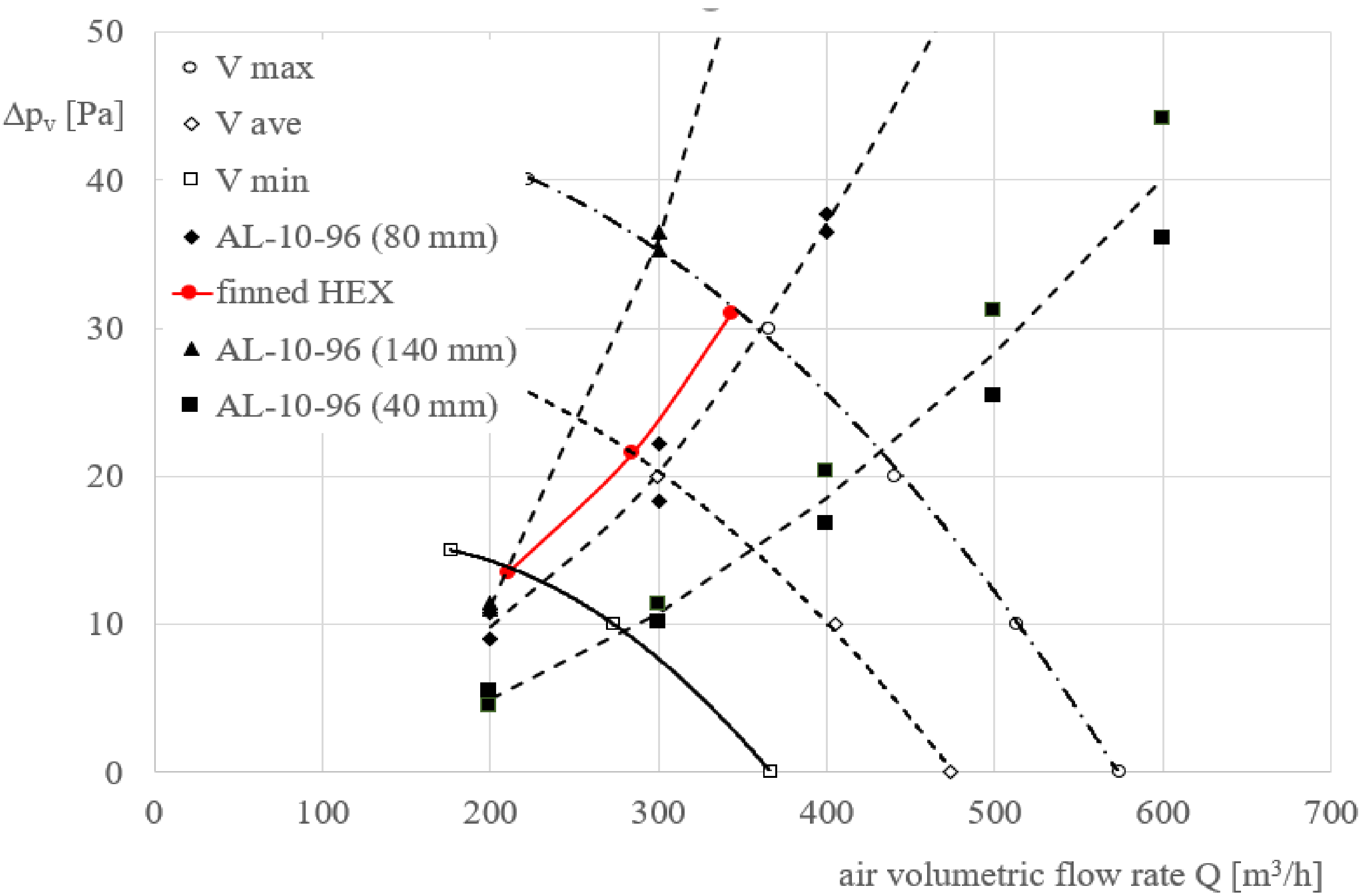
ESTRO F4



ESTRO F4 with metal foam HEX



Conclusions

- The flow regime (0.5 up to 10 m/s) is turbulent in metal foams having a porosity of 96% and 10 PPI.
- The ratio (H/d) has to be larger than a threshold value in order to obtain pressure drop values independent by the sample. This threshold value increases with the air velocity (H/d from 20 to 50).
- Permeability (K) of the metal foam derived by pressure drop data under turbulent regime can be affected by large inaccuracy.
- A HEX with metal foam (AL-96-10) with a thickness of 8 cm guarantees similar pressure drop of a conventional finned HEX in a fan-coil cabinet.

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