Heat transfer of metallic foam in thermoacoustic waves

Anne Bosma, Genie Stoffels, Theo van der Meer

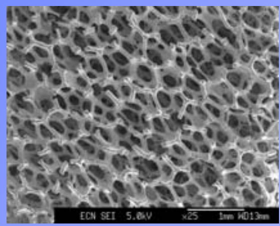
University of Twente
The Netherlands
Division of Thermal Engineering
Department of Mechanical Engineering

Introduction

- The work described on this poster is concerned with transport of heat in porous metal foam placed in an oscillating fluid in a resonance tube. In addition the fluid resistance of the foam in a steady flow is studied.
- The metal foam finds application in a thermoacoustic heat pump, which can be used for upgrading wasted heat.

Nickel Foam

- Demands of the metal foam are an excellent heat transfer and a low fluid resistance.
- Therefore the samples have a high porosity (94-97%) and a small cell size (450-550μm).
- Four non-modified foams are used. Also, one of them is modified by reducing the thickness (and thereby reducing the cell size and the porosity) by rolling the sample. Characteristics are given in the table.



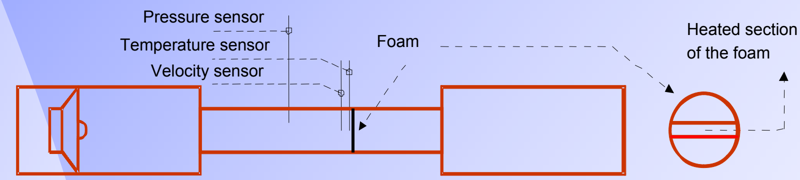
Electron microscope image of the nickel foam, 25 times enlarged. Picture from ECN.

Foam name (cellsize.porosity. thickness)	Cell -size (μm)	Porosity	Thick-ness (mm)	Frequency (Hz)
450.97.16 (ref. case)	450	0.969	1.625	20, 45 (ref. case), 85
450.96.16	450	0.959	1.650	45
550.95.16	550	0.953	1.675	45
550.97.13	550	0.971	1.350	45
450.97.14 (rolled)	394	0.962	1.375	45
450.97.13 (rolled)	366	0.961	1.325	-
450.97.12 (rolled)	338	0.958	1.225	-
450.97.11 (rolled)	309	0.956	1.175	-
450.97.10 (rolled)	281	0.950	1.025	45
450.97.08 (rolled)	225	0.941	0.875	-

Experimental details of the heat transfer measurements

- An acoustic wave is generated by a loudspeaker in a resonance tube (diameter 100 mm) in which a slice of foam is placed. Acoustic frequencies are in the order of 10 to 100 Hz.
- Velocity amplitudes are measured with a hot wire sensor and are in the range of 1 to 5 m/s.
- A rectangular part in the middle of the foam slice is heated by an electric current. The power (Q) transmitted to the foam is about 25 Watt which results in the foam reaching a temperature of around 60 degree Celsius. Foam temperature is measured by its electrical resistance.
- A volumetric heat transfer coefficient (h) is determined from:

$$h = \frac{Q}{V_{foam}\left(T_{foam} - \bar{T}_{air}\right)}$$

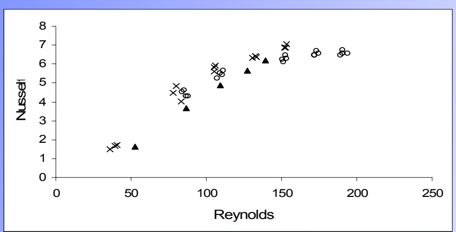


Experimental details of the fluid resistance measurements

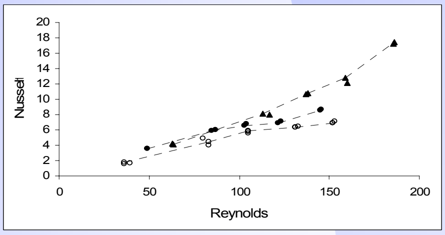
- To determine the pressure gradient in a steady flow a long small tube is used. A number of metal foam layers is placed in it and the pressure difference as a function of velocity over them is measured by a pressure transducer of the membrane type.
- To find the permeability (K) and the inertial coefficient (f) of the metal foam the experimental data are fitted to the Darcy and Forchheimer equation (e.g.: A. Bahattacharya et al., Int. J. Heat Mass Transfer 45, 1017 (2002):

$$-\frac{dp}{dx} = \frac{\mu v}{K} + \frac{\rho f}{\sqrt{K}} v^2$$

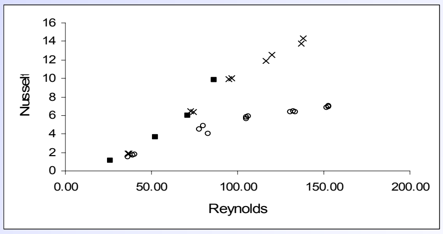
Results of the heat transfer measurements



- Effect of frequency: Nusselt number for one type of non-rolled foam (450.97.16) as a function of Rey-nolds number for three frequen-cies (○ 20; x 45; ▲ 85 Hz).

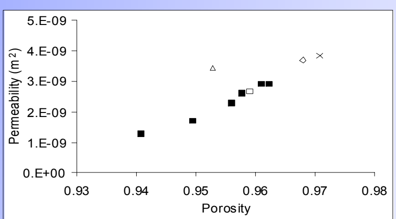


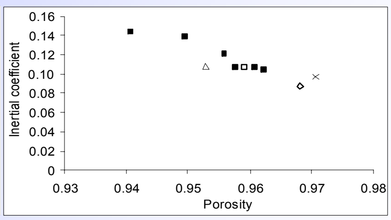
- Effect of cell size and porosity: Nusselt number for non-rolled foams as a function of Reynolds number at 45 Hz (○ 450.97.16; • 450.96.16; ▲ 550.97.16).



- Effect of rolling: Nusselt number for the rolled foams as a function of Reynolds number at 45 Hz (○ 450.97.16; x 550.97.14; ■ 450.97.10).

Results of the fluid resistance measurements





- Permeability K (left) and inertial coefficient f (right) of the foam as a function of porosity; □ 450.96.16; ◇ 450.97.16; △ 550.95.16; x 550.07.13; ■ 450.97.rolled.

This work is done in collaboration with ECN, ASTER and ETE and sponsored by Senter within the program Energy, Ecology and Technoly.

Conclusions

- Frequency does not have much influence on Nusselt.
- Only a small increase in Nusselt is found as the porosity decreases.
- Rolling the foam from 1.6 to 1.4 mm results in Nusselt increasing by a factor 2.
- A higher porosity as well as a larger cell size results in a higher permeability and a lower friction factor.
- By rolling the foam from 1.6 to 1.4 mm the pressure drop increases by a factor 1.3 only.

Address:
Department of Mechanical Engineering
Laboratory of Thermal Engineering
P.O. Box 217, 7500 AE Enschede, The Netherlands

Phone: (++31) 53 489 4094
Fax: (++31) 53 489 3663
Email: g.g.m.stoffels@ctw.utwente.nl