PRODUCTION OF CAST METAL FOAMS WITH A REGULAR INTERNAL STRUCTURE

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Abstract

The article deals with casting methods of producing of metallic foams, it is focused on materials with a regular arrangement of internal cells. Currently, there are two areas dealing with metallic foams: optimization of already used casting technologies - manufacturing of metallic foams with a regular cell structure using sand cores and the possibility of the usage of this material. Cast metallic foams have a wide range of applications such as: construction, transport, heat exchangers etc. for their outstanding properties: reduced weight sufficient strength to absorb the impact energy or the possibility of heat conduction.

Keywords: Metal foam, mechanical testing, energy absorption, 3D modelling, heat exchanger

1. INTRODUCTION

Metal foams are materials which are still in development with the wide application possibilities in many fields of human activity (eg. automotive industry, construction industry, medicine, etc.). These interesting materials contain artificially created pores in their structure. These pores then give them many exceptional characteristics such as: high rigidity at low density, high thermal conductivity, absorption of energy and others. The aim of this paper is to explore the possibility of using cast metal foam with divided inner cavity as a heat exchanger. As an instrument of the investigation the method of computer simulation was first chosen, which can compare the metal foam with classic tube exchanger [1, 2].

2. EXPERIMENTAL PART

This part of the paper is devoted to designing an experiment for the possible testing of samples made of metal foams with a regular arrangement of cells as an internal heat exchanger. Before the production of the real casting was modelled variant for flow simulation, both the metal foam and the classical tubular exchanger. Subsequently both these models are subjected to comparison and evaluation of results.

2.1. Analysis of heat transfer in metal foam

One of a possible application where the metal foams would be possible to use are a heat exchangers which need extreme heat exchange, respectively exchangers with the possibility of continuous heat distribution at the interface. A powerful tool for designing an effective and adequate heat exchanger is a mathematical simulation. Simulations will be performed in ANSYS CFX software environment [3, 4]. In the **Figures 1** and **2** are shown the initial analyzed geometries. All external dimensions are identical. **Figure 1** shows a ball cores inside the metal foam within two rows. The total number of balls is 120. On the left side of the picture is shown the internal domain of the flowing medium, on the right is displayed domain of the metal foam with input intakes for attaching hoses to entering a medium.

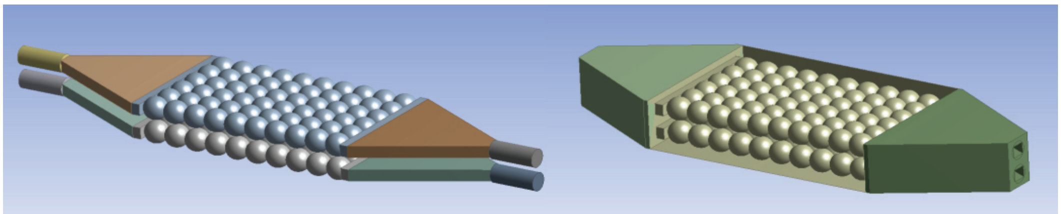

Figure 1 Analyzed geometry of the metal foam

Figure 2 shows the classic two-row tubular heat exchanger which is used in many applications. The total number of tubes is 12. The inner diameter of the pipes is equal to the diameter of balls in the metal foam.

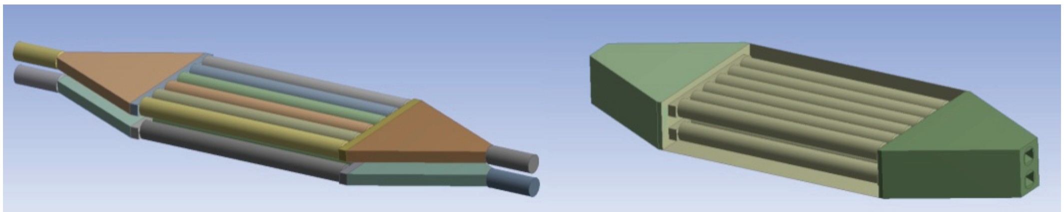

Figure 2 Analyzed geometry of the tubular heat exchanger

2.2. Mesh

Figure 3 shows mathematical meshes of both geometries. Tube heat exchanger includes a total number of 1.1 million cells. Heat exchanger created with the metal foam contains a total number of 2.1 million cells. Cell size was set at 1.5 mm in both cases. The boundary layer at the surfaces is formed by the five cells at a thickness of one millimetre.

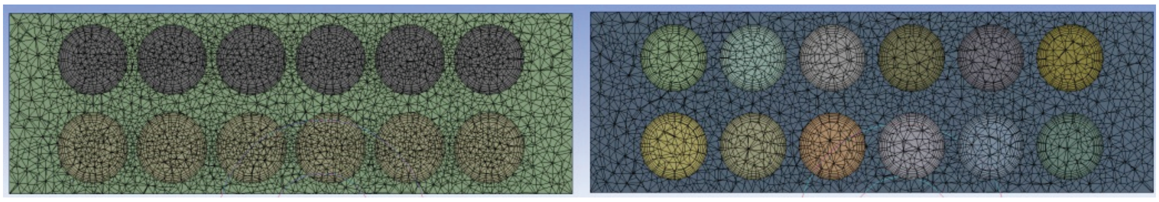

Figure 3 From left: Computing meshes of the metal foams and tube heat exchanger

2.3. Boundary conditions

Calculation both geometry was divided into two main domains. The first domain was set as a liquid representing a flowing air. The second domain was set as a solid body representing the metal exchanger. Material properties of both domains are summarized in **Table 1**. The roughness of the walls is not included in the calculation [5, 6].

Table 1 Material properties

	Domain	
	Ideal Gas	**Aluminum**
Thermal conductivity (W/m·K)	0.0261	237
Specific heat capacity (kg/J·K)	1004.4	903
Density at 20 °C (kg/m^3)	1.204	2702
Dynamic viscosity (kg/m·s)	1.831E^{-5}	-

Figure 4 shows the boundary conditions entering to the calculation. On all outer walls of solid bodies adiabatic walls were set up. Boundary conditions of the heat exchanger are defined on both floors. The following **Table 2** summarizes the initial values of the boundary conditions.

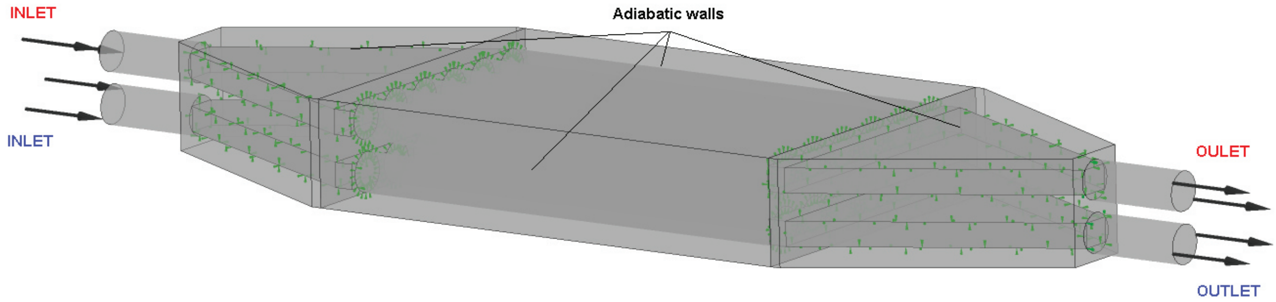

Figure 4 Boundary conditions

Table 2 Boundary conditions

Inlet		Outlet	
The temperature of the upper floor (°C)	100	Average static pressure (Pa)	0
The temperature of the bottom floor (°C)	20	Average static pressure (Pa)	0
The flow velocity in the upper floor (m/s)	1		
The velocity in the bottom floor (m/s)	1		

2.4. Results

Calculation of the tube heat exchanger ran about two hours and the accuracy of convergence is given below $1 \cdot 10^{-6}$. Calculation of the metal foam heat exchanger ran about 2.5 hours and the accuracy of convergence is given below $1 \cdot 10^{-6}$. **Table 3** summarizes the mean values of the output areas of the both heat exchangers.

Table 3 The average value of the output

	Metal foam	Pipe
Temperature (°C) - hot side	55.9	62.1
Temperature (°C) - cold side	55.5	50.2
Velocity (m/s) - hot side	0.88	0.89
Velocity (m/s) - cold side	1.12	1.1
Pressure (Pa) - hot side	$4.533 \cdot 10^{-3}$	$4.548 \cdot 10^{-3}$
Pressure (Pa) - cold side	$6.42 \cdot 10^{-3}$	$7.431 \cdot 10^{-3}$

Researched place on the warm side of the heat exchanger is highlighted by red line on a **Figure 5**, just before leaving on a media outlet. Researched place on the cold side of the heat exchanger is highlighted by blue lines. **Figures 6** and **7** show waveforms observed values dependent to coordinates.

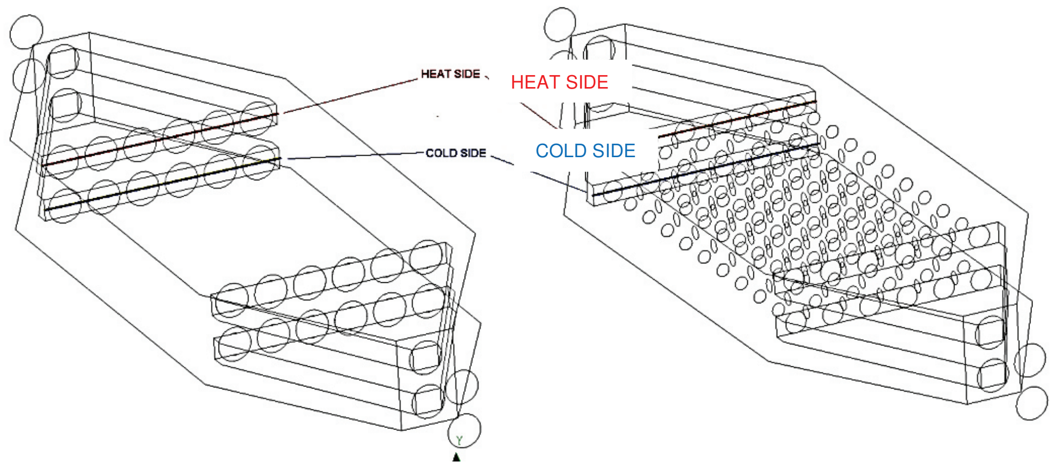

Figure 5 Highlighted researched sides of the heat exchangers

From **Figure 6** it is clear that the heat exchanger of the metal foam has a uniform distribution of the velocity field around the analysis section. Temperature variation on a conventional tubular heat exchanger has a maximum velocity in the centre of a region. Colder side heat exchangers have a higher rate of air flow over the heat side.

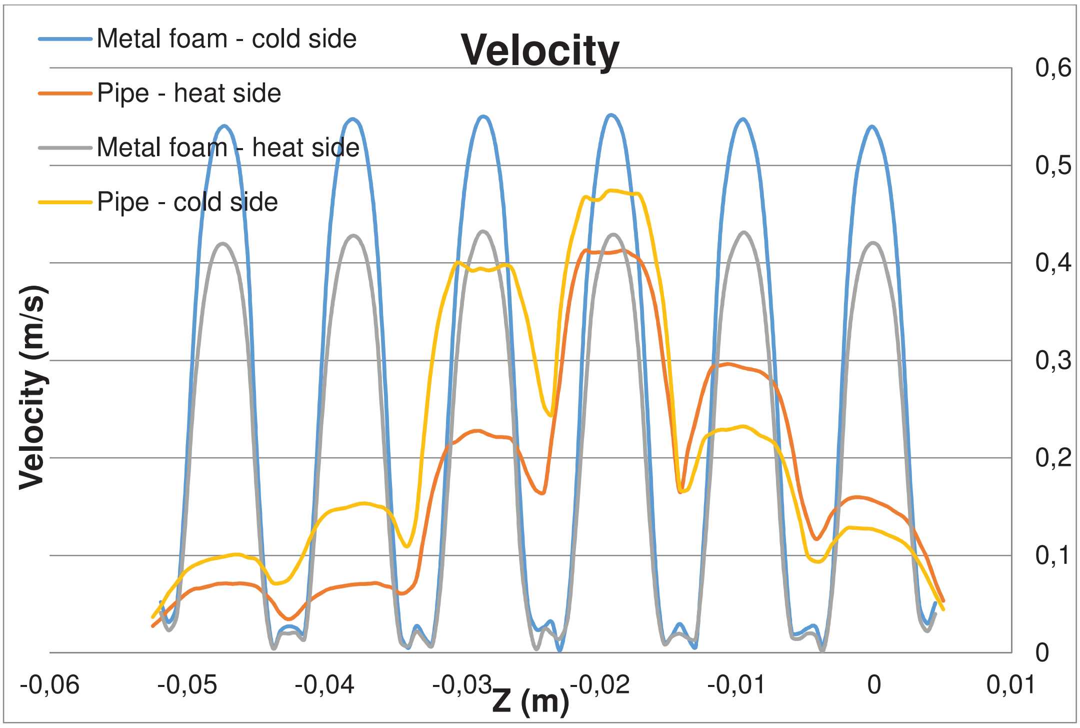

Figure 6 Velocity profile of the heat exchangers

Figure 7 shows distribution of the temperature field in the two heat exchangers. The heat exchanger formed from metal foam has a constant behaviour throughout the course of the analysis cross section on both sides. In the plane of symmetry of the heat and cold sides correspond. The maximum value achieved in a tubular heat exchanger has reached the value of about 70 °C, with a ball exchanger this value was about 55 °C. The maximum difference between the hot and cold side of the metal foam heat exchanger was approx. 1 °C, whereas classical heat exchanger had a maximum differential value of about 27 °C.

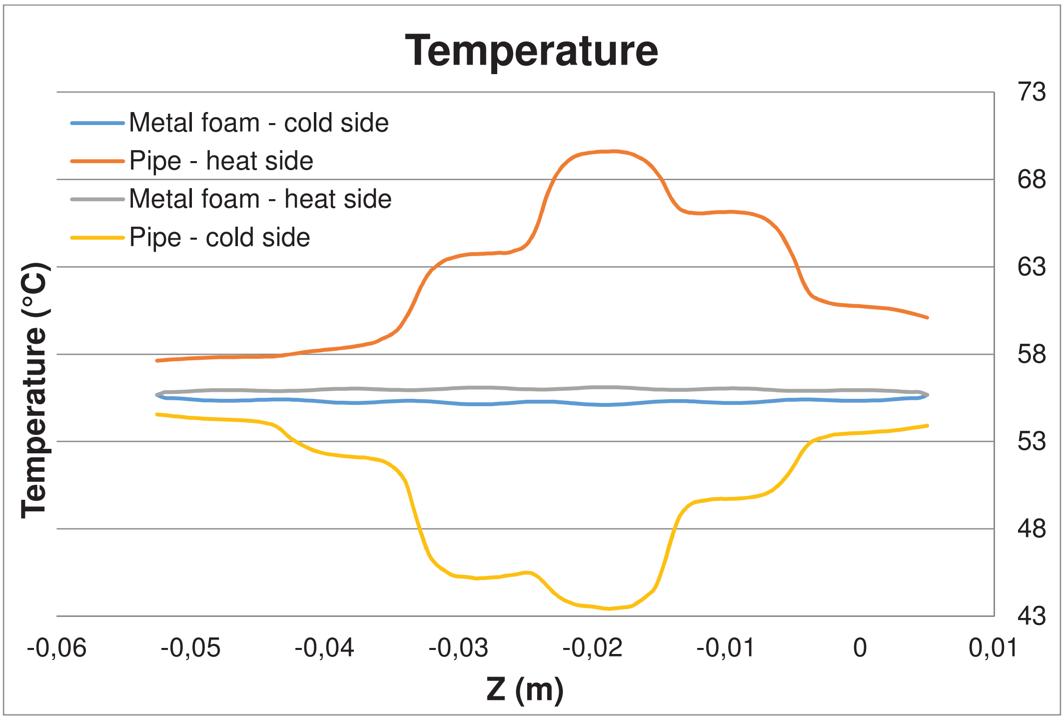

Figure 7 Heat distribution in heat exchangers

Figure 8 shows that the different geometry of the heat exchanger does not have much of a considerable importance in the pressure loss. Both heat exchangers can correspond to both affected side. A heat exchanger formed from metal foam has a sinusoidal pressure, whereas classical tubular heat exchanger has a rather constant pressure course. The maximum value of the relative pressure in ball-exchanger was 1.52 Pa. Relative pressure in the tubular heat exchanger was 1.46 Pa.

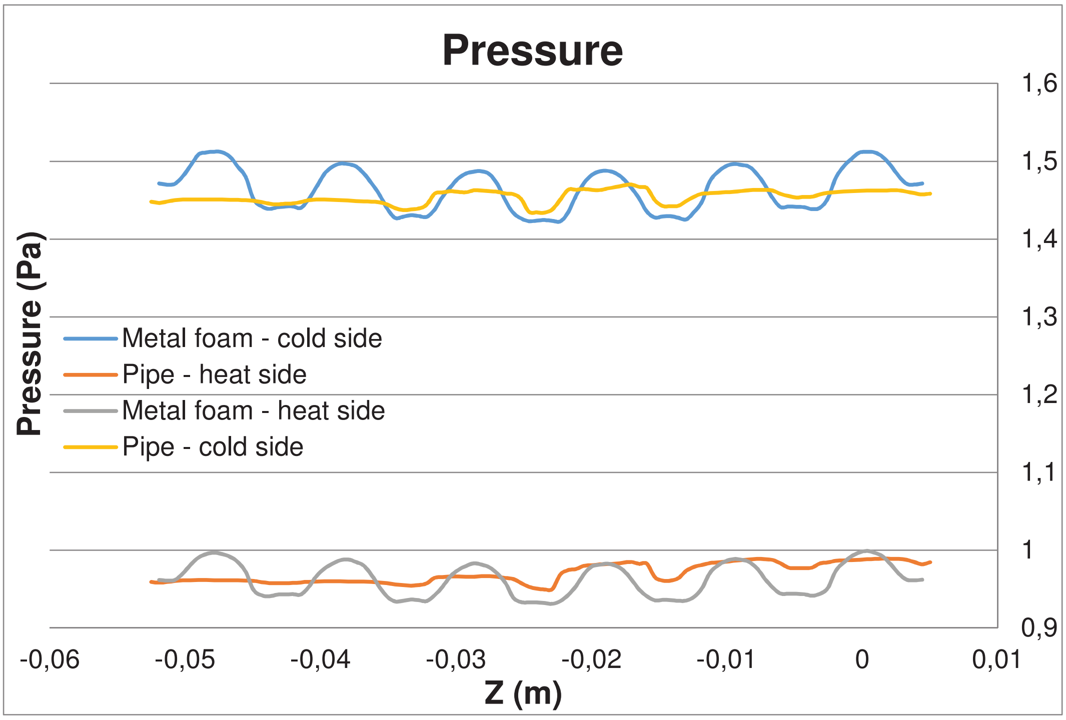

Figure 8 Pressure distribution in heat exchangers

Figures 9, 10 and **11** show the colour resolution of values examined in both heat exchangers. **Figure 9** shows the thermal field on the hot side; **Figure 10** shows the thermal field on the cold side; and **Figure 11** shows the velocity field of both heat exchangers.

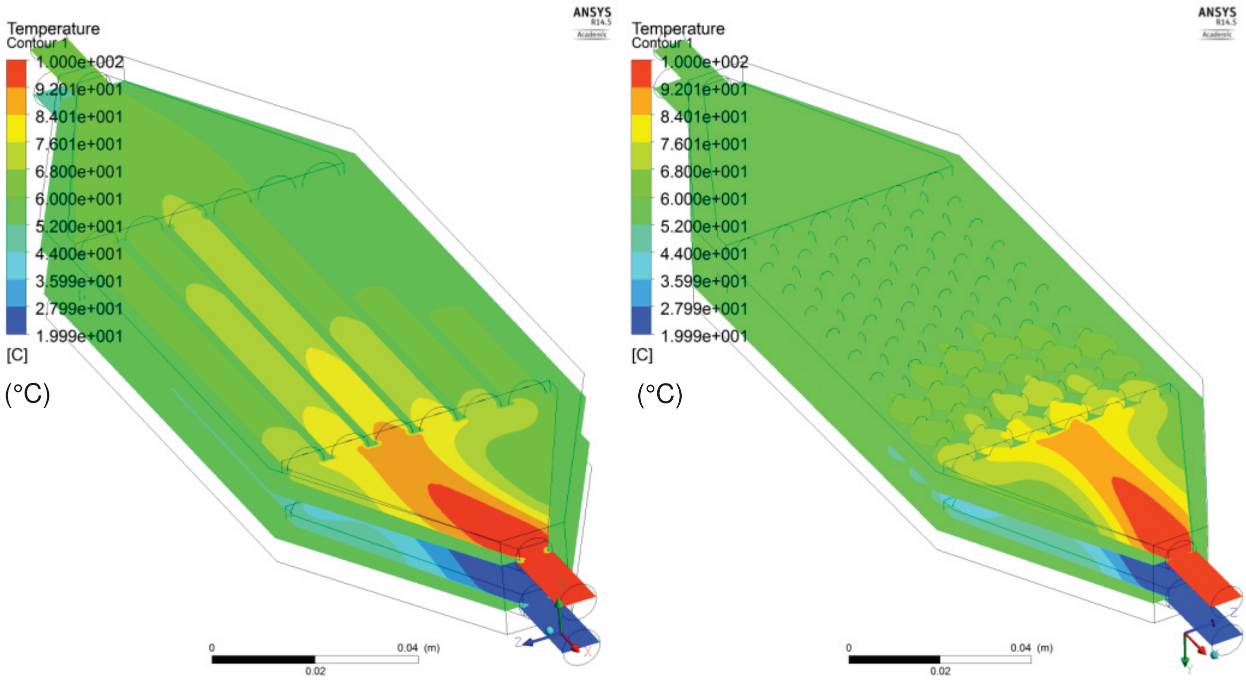

Figure 9 Heat side of the heat exchangers

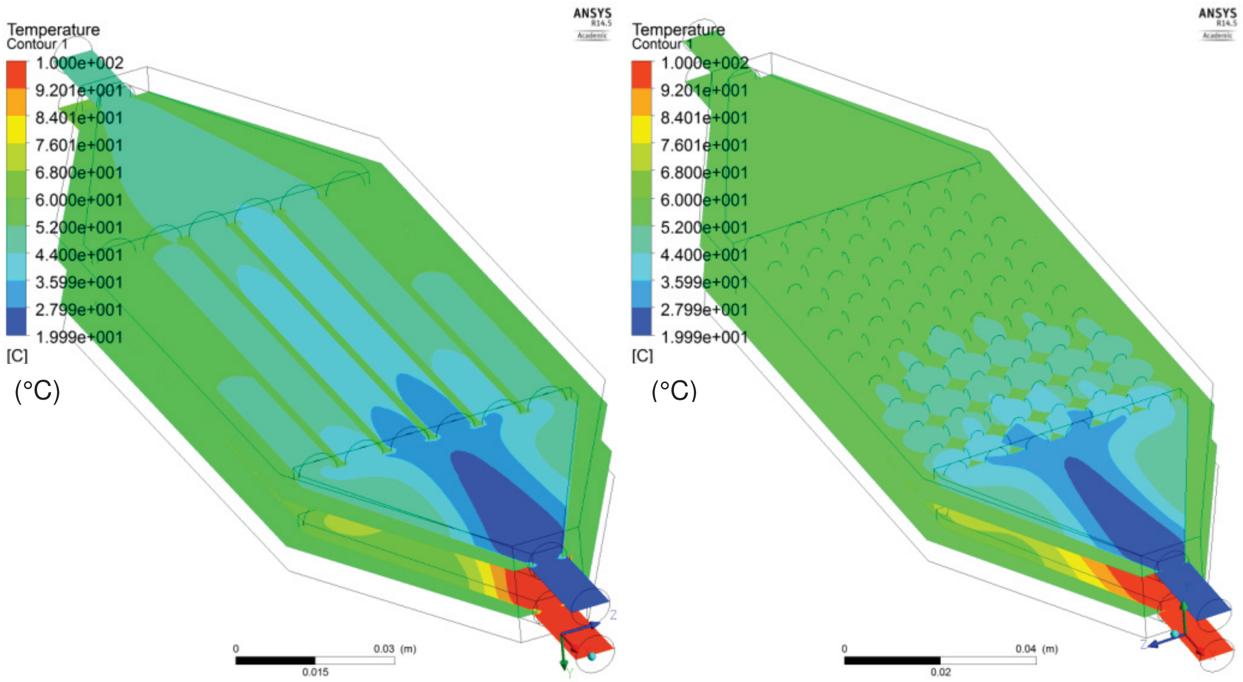

Figure 10 Cold side of the heat exchangers

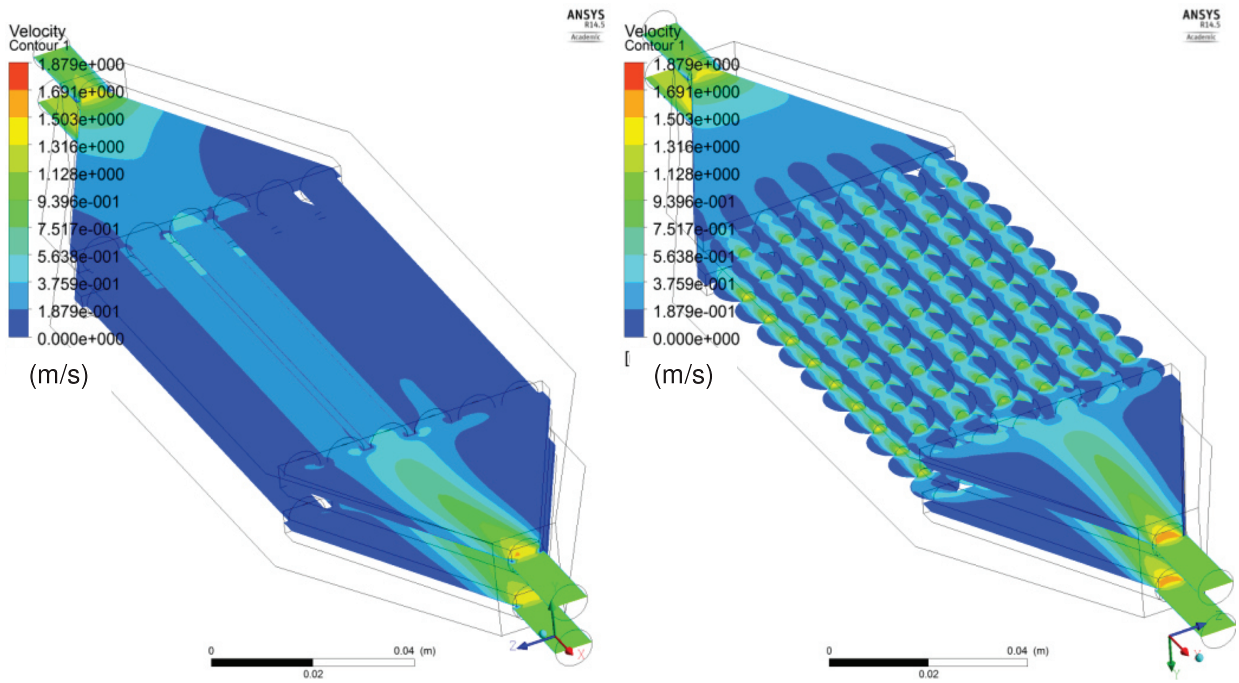

Figure 11 Velocity field of the heat exchangers

3. CONCLUSION

Thanks to the technology of an infiltration molten metal into the mould cavity filled with complex preform, which here fulfils the function of the core, we can create cast metal foam with a regular arrangement of inner cells. One of a possible application of castings with such complicated internal cavity is a heat exchanger. First for the purpose of effectiveness verification castings of the metal foams, variants for simulating the flow of gaseous media in both the metal foam and the classic tube exchanger were made by modelling.

Computational analysis showed that the heat exchangers show signs of different behaviour provided enter the same boundary conditions. The greatest differences are seen in **Figures 7** and **9**, when the newly designed heat exchanger of the metal foam exhibits stable temperature characteristics in the whole investigated cross section immediately before an outlet therefrom. Uniform distribution of heat affected overall heat transfer in the heat exchanger so that the output therefrom, the temperature was generally lower by 12 °C. The relative pressure at the outlet of both heat exchangers has corresponded.

In the next step heat exchangers with different geometries etc will be modelled. Computationally the most efficient heat exchanger will be subject to experimental measurements and compared to the reference model (tubular heat exchanger).

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