Natural convection in a Metal Foam Heat Exchanger

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Introduction: COMSOL 5.2 was used to model and optimize a metal foam heat exchanger sized 0.7x0.4x0.05m, in natural convection. Metal foams are innovative lightweight materials with unique heat dissipation properties. Both convective and radiative heat transfer processes have been implemented. The LTE - *Local Thermal Equilibrium* - hypothesis was used to validate the numerical model.

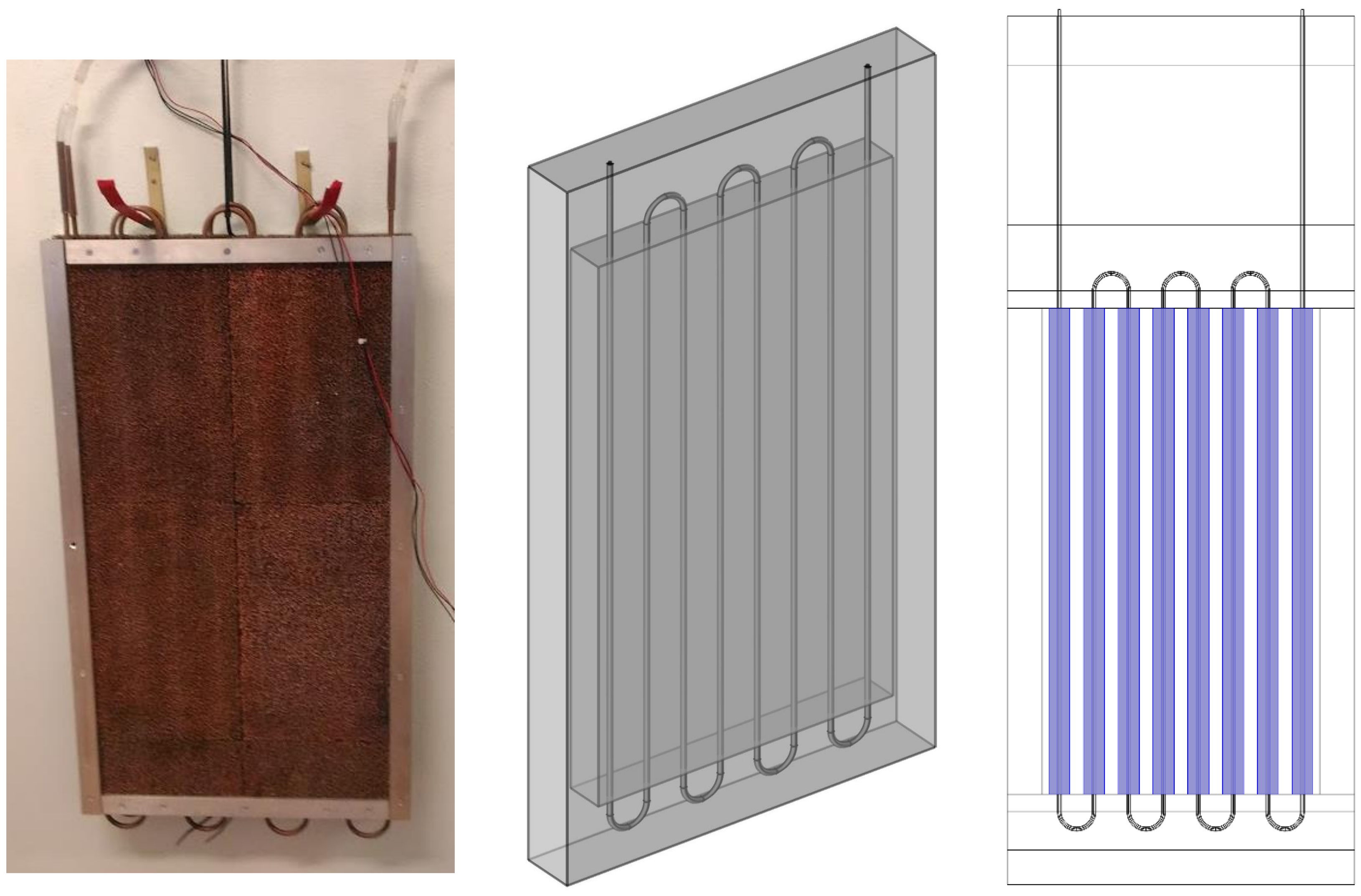

Figure 1. First prototype, initial COMSOL geometry, final configuration (foam element size 0.03x0.02x0.7m).

Computational Methods: The COMSOL model implements 3 physics and a multi physics coupling. Water flow inside the pipes, depending on Re number, is modeled with turbulence, when required, using a $k-\omega$ model. Laminar flow was modelled in the air and foam domains, using the *Brinkman Equation Interface* for the porous media. Usage of LTE equation implies that only one energy equation is needed to model the foam so temperature of aluminum and air inside the foam is the same and it is computed considered an effective conductivity.

Metal foam effective conductivity was implemented using the equation:

$$k_{\text{eff}} = A(\epsilon k_f + (1-\epsilon)k_s) + \frac{1-A}{\frac{\epsilon}{\kappa_f} + \frac{1-\epsilon}{\kappa_s}}$$

Figure 4. Metal foam sample.

Heat flux was estimated using the cooling water as reference, computing the temperature variation in the fluid, according to the same procedure that was used for the experiments, from the formula $Q[\text{W}] = \dot{m}\, C_p\, \Delta T$.

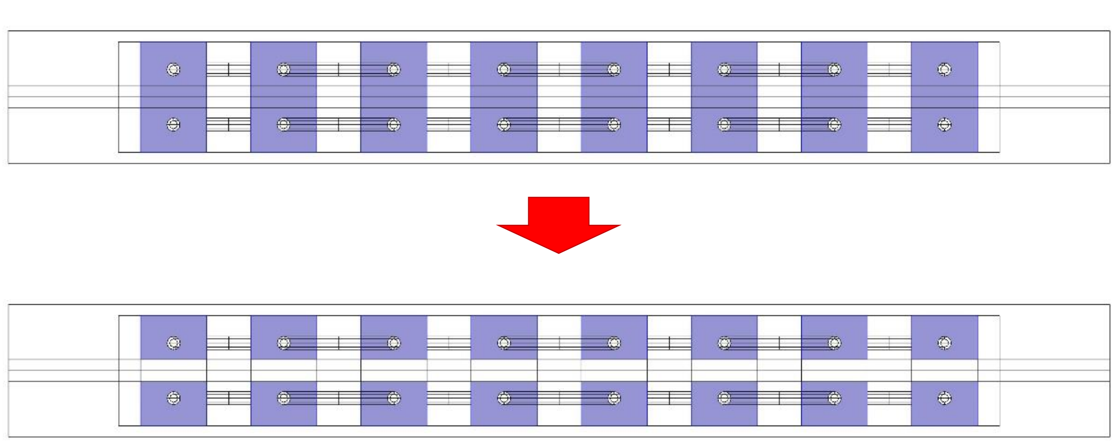

Figure 5. Geometry optimization.

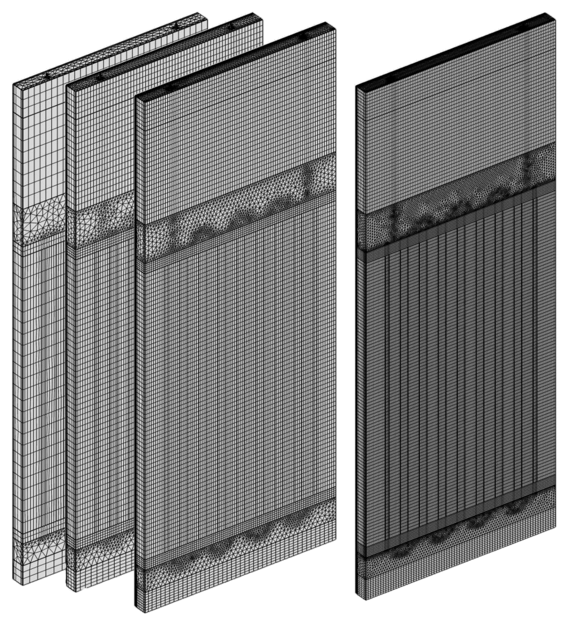

Figure 6. Meshing.

Results: After the validation of the numerical model, 4 different parametric geometries have been examined. We reached our goal to increase dissipated heat maintaining the same size.
A geometry with optimized foam shape and dimensions was obtained: 53.2% volume reduction and 53.4% surface increase.

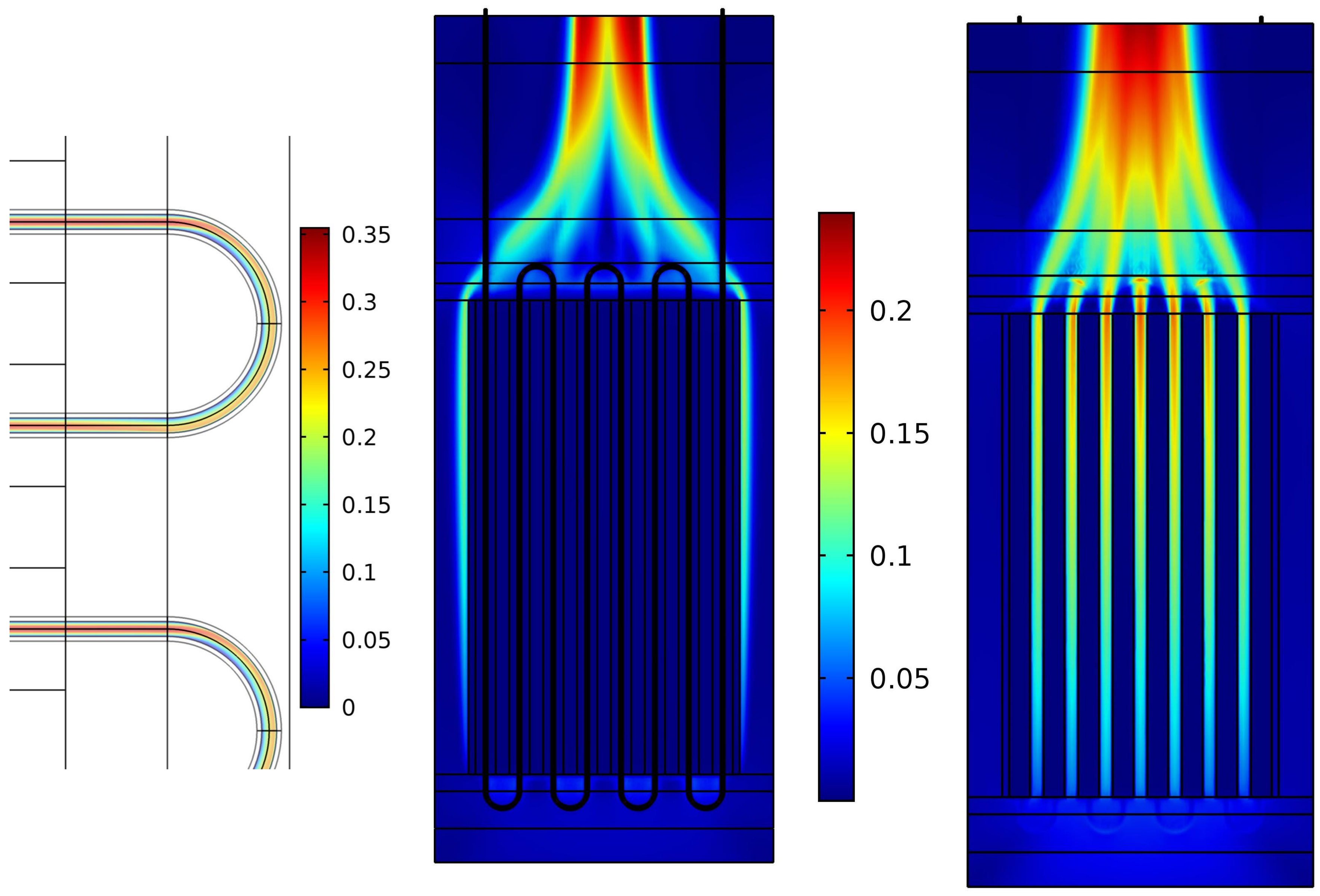

Figure 2. Water [m/s] and air [m/s] velocity fields for initial and final configurations.

Table 1. Properties of the 5PPI foam used in the study

Variable	Value	Units
Porosity	0.95	-
Permeability	2.2e-7	m^2
Emissivity	0.55	-
Conductivity	2.65	W/(mK)
$\Delta T_{\text{in water - amb}}$	5	°C

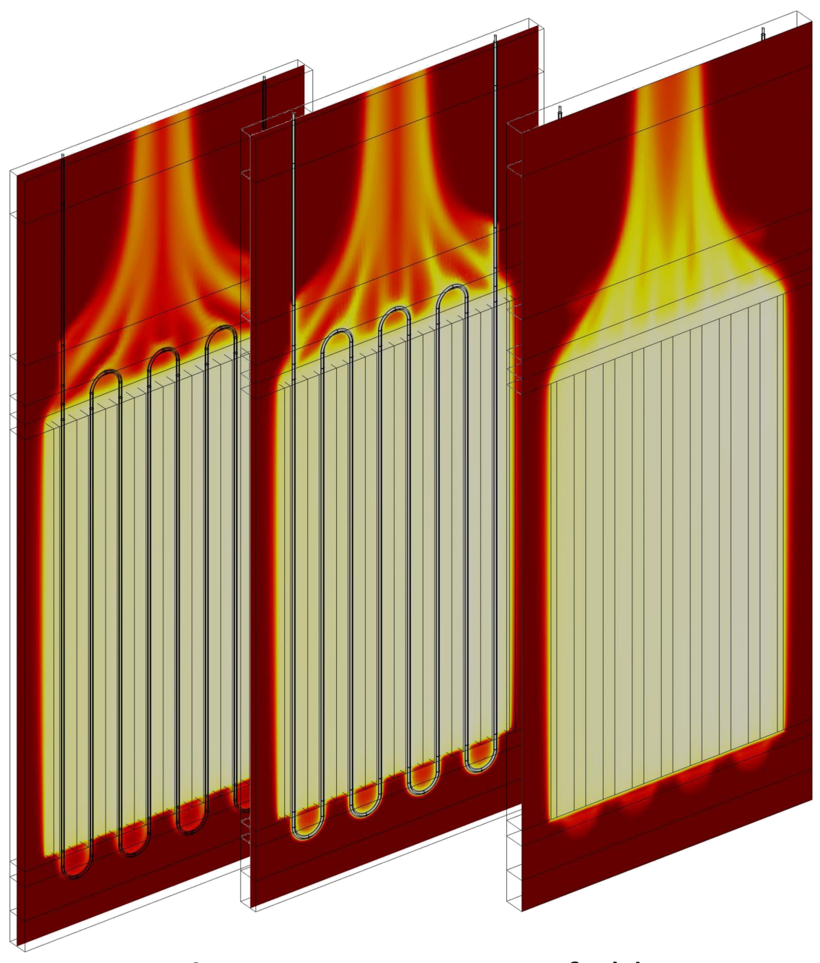

Figure7. Temperature field.

Conclusions: Using COMSOL, it was possible to validate and optimize the geometry of the radiator, obtaining a 30% increase in the heat flux. A new optimized prototype of the radiator is going to be built for further experimental testing.

Future work may include implementation of Local Thermal Non Equilibrium, forced convection applications and more advanced geometries for the foam.

References:

1. *Bhattacharya, Calmidi, Mahajan* - Thermophysical properties of high porosity metal foams - *International Journal of Heat and Mass Transfer, 2002, vol 45.*
2. *Lu,Zhao,Hodson* - Thermal radiation in ultralight metal foams with open cells - *International Journal of Heat and Mass Transfer, 2004, vol 47.*
3. *Phanikumar, Mahajan* - Non-Darcy natural convection in high porosity metal foams - *International Journal of Heat and Mass Transfer, 2002, vol 45.*

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