

# Numerical Simulation of Forced Convection through Metallic foam (HVAC Heating Coil Application)

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## Abstract

The hydraulic and thermal performance of a porous medium generating of heat, considered as a HVAC heating coil, has been established using a numerical simulation. The used metallic foam is made from Copper and Aluminum with a porosity of 0.93. The channel has a rectangular shape with an establishment length equal to 5 times of the height. The thermal equilibrium in the porous medium is considered between the fluid and solid, and the flow regime found is the Darcy regime for input speeds between 0.1 and 3 m / s. The Aluminum metal foam has the higher temperature inside the porous medium compared to copper one, under the same conditions of velocity and heat flux.

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*Index terms*— HVAC, metallic foam, forced convection, heat transfer.

## 1 I. Introduction

The Heat transfer under convective boundary condition is common in heat exchangers [1]. The metal-foam-filled channels are proposed to increase the heat transfer area between hot and cold flows in plate heat exchangers [2]. The metallic foam is more and more used in thermal applications due to its convenient hydrodynamic and mechanic properties: porosity (in general ? 90%), high permeability and strength.

Pei-Xue et al. [3] report that the local heat transfer increase with increasing in flow rate and it decrease along the channel. Their numerical results show that there is a difference between the fluid particle temperature and the solid one which demonstrate the importance of non-equilibrium model. Z.G. Qu., et al. [4] found that the flow resistance maybe decreases with high porosities, density of pores and the metallic foam thickness report. The optimal porosity correspond the T maximum Nusselt number; the latter increases with decreasing in fluid-solid conductivity report. The results of Degan. G et al. [5] show that the permeability K has a significant influence on the convective heat transfer, where the heat transfer is best with high permeability values. Jeng, Tzer-Ming [6] present an experimental study of heat cooling of metallic foam blocs, they found that the Nusselt number may be intensified with factor varying between 3 and 5 compared to the smooth channel. Brahim MADANI et al. [7] indicate that the three-dimensional cellular structure of the foam acts as a mixing promoter. They report that the dispersion of the results obtained on similar metallic foams shows that the control and the understanding of the phenomena of flow in such media must pass through a thorough and precise analysis of their structures. The results of Hamadouche et al. [8] demonstrate that the insertion of metallic foam in turbulent flow participates in the enhancement of heat transfer with factor of 300% compared to the smooth channel. Kouidri et al. [9] characterized three metallic foam, with different surface roughness, their results show that the pressure drop increase from the smooth to the rough one, they report also that the permeability changes from type of flow to another.

The present work consists to studying the thermal and hydrodynamic performances of an HVAC Heating coil situated in air treatment station. The latter is considered as a porous medium (metal foam) generating of heat. The physical problem is simplified to a flow between two adiabatic plates, through a porous medium, generating of heat. The tested metallic foams are made from Copper and Aluminum.

44 **2 II. Problem Description**

45 We consider an air flow between two horizontal plates. The channel is divided into three parts: inlet, outlet  
 46 and the porous medium generating of heat (Fig ??). The first zone (inlet) has an establishment length L1 equal  
 47 to 5H. The second zone, which has a length L2-L1, is considered as HVAC heating coil with a porous medium.  
 48 The third zone (outlet) has an establishment length of 5H. We noted that the height H is equal to 1cm and the  
 49 thickness of metallic foam is equal to cm. The upper and lower walls are assumed to be adiabatic. Keywords:  
 50 HVAC, metallic foam, forced convection, heat transfer.

51 **3 III. Mathematical Formulations and Modeling**

52 The used method to derive the discretization equations is the finite volume with the SIMPLE algorithm. The  
 53 structural mesh is adopted with 25000 nodes after studying the sensibility of mesh.

54 The conservation equations for a twodimensional stationary laminar flow, considering the thermal equilibrium,  
 55 taken from the reference [10] are presented in the equations: 1, 2, 3 and 4. The used metallic foam was  
 56 characterized by Kouidri et al. [9]. The Aluminum foam has the same geometric characteristics to the copper  
 57 one. Figure ?? : Physical problem and computational domain. The permeability is used as a characteristic length  
 58 in Reynolds equation (Eq. 5):

59 **4 Mass conservation equation**

60 **5 Momentum conservation equation**

61  $\rho \frac{\partial u}{\partial x} + \rho \frac{\partial v}{\partial y} = 0$  (Channel inlet)  $T = T_0, u = U_0, v = 0$   $\rho \frac{\partial u}{\partial x} + \rho \frac{\partial v}{\partial y} = 0$  (Channel outlet)  $\frac{\partial T}{\partial x} = 0, \frac{\partial T}{\partial y} = 0$   $\rho \frac{\partial u}{\partial x} + \rho \frac{\partial v}{\partial y} = 0$   $\rho \frac{\partial u}{\partial x} + \rho \frac{\partial v}{\partial y} = 0$   $\rho \frac{\partial u}{\partial x} + \rho \frac{\partial v}{\partial y} = 0$  (4)

63 The same for the friction factor f which is calculate on basis of permeability (Eq.6)

64 The efficiency of the HVAC heating coil is given by the Eq. 7:

65 Where Qgen represents the heat flux generated in the porous medium (Heating coil), it equals to 5000000  
 66 W/m3. And Qabs represents the heat flux absorbed by the fluid between the inlet and outlet of the porous  
 67 medium. It is calculate on basis of Eq. 8:

68 **6 IV. Results**

69 **7 a) Velocity profile**

70 Figure 3 (a) shows the velocity profile at the inlet of the channel, which is established before reaching the entrance  
 71 of the porous medium, where the maximum velocity is at the center of the Y axis. We noted that the length of  
 72 the channel at the inlet is 5 times greater than its height, which is sufficient for the establishment of a laminar  
 73 regime. An explicative scheme of the boundary conditions is represented in Fig. 2.

74 **8  $\Delta P = \mu \frac{L}{k} u$**

75  $\Delta P = \mu \frac{L}{k} u$  (7) (5) (??) Figure ?? shows the pressure drop, along the porous medium, for  
 76 Aluminum and copper metallic foam. It is obvious that the two metallic foam samples present the same pressure  
 77 drop because they have the same geometric characteristics. The pressure drop vary linearly with the velocity.  
 78 Using a linear regression, the correlation between the pressure drop and the velocity may be writing following  
 79 Eq. 9:  $Q_{abs} = \mu \frac{L}{k} u$  (8)

80 The form of this equation is similar to the one given by Darcy [11] (Eq. 10), which demonstrate that the flow  
 81 regime is Darcian.

82 In the present simulations, the constant ( $\mu/k$ ) is equal to 2773.5 as is shown in Fig. ?? Figure 6 shows a  
 83 comparison between the present simulations and the data given by the literature [9,12], for different material  
 84 of metallic foam, the results are closed to those given by Kouidri et al. [9], this is due to the fact that the  
 85 same geometric characteristics were introduced in the present simulations. Figure 7 presents the temperature  
 86 distribution along the porous media, averaged on the Y axis, It is obvious that the evolution is logarithmic along  
 87 the porous medium, for the two metallic foam samples.

88 In the same flow conditions, velocity and heat flux, the Aluminum sample gives the highest temperature; it can  
 89 be interpreted by its calorific capacity which is more important compared to the copper one. This characteristic  
 90 of Aluminum metallic foam is very important in HVAC heating coil, because it permits to have an important  
 91 blowing temperature with minimum of dissipate energy. Copper [9] NiFeCrAl [9] Aluminum [11] Simulation  
 92 Copper

93 **9 Simulation Aluminum e) HVAC heating coil efficiency**

94 The HVAC heating coil is calculated on basis of Eq. 7, presented in previous paragraph.

95 Figure 8 depicts the HVAC heating coil (made from porous media) efficiency, we remark that the efficiency in  
 96 the case of Aluminum foam increase from 40% to 50% depending on the inlet velocity. The latter is constant for  
 97 the velocity  $> 1.5$  m/s.

98 On other hand, the Aluminum foam gives an efficiency 5 times more important compared to the copper one, this is due certainly to its important calorific capacity.<sup>1</sup>

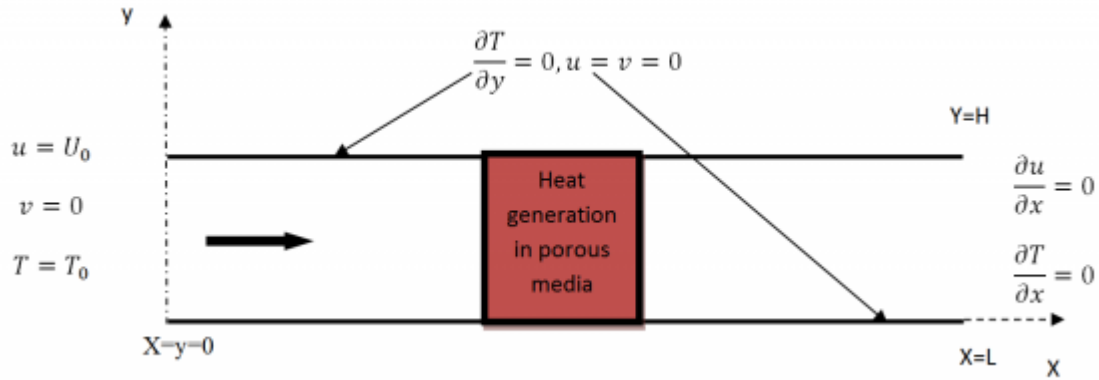
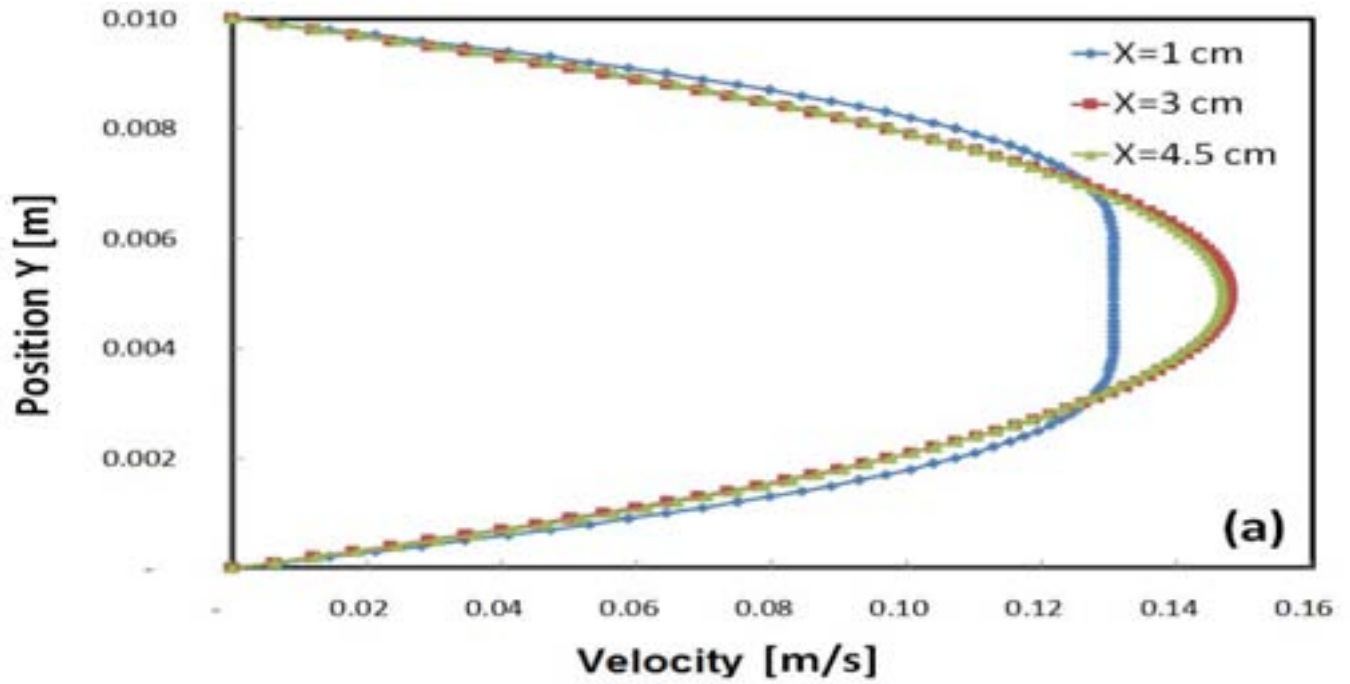


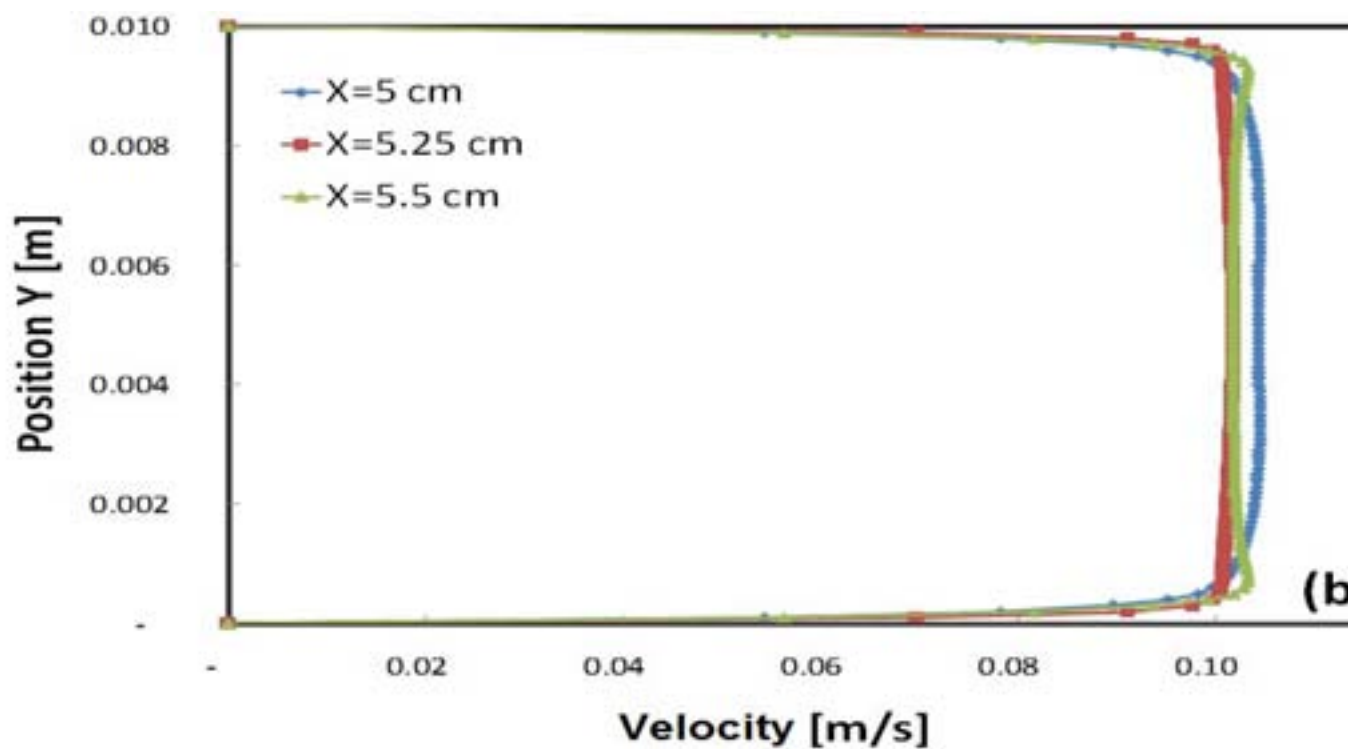
Figure 1:



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Figure 2: Figure 2 :

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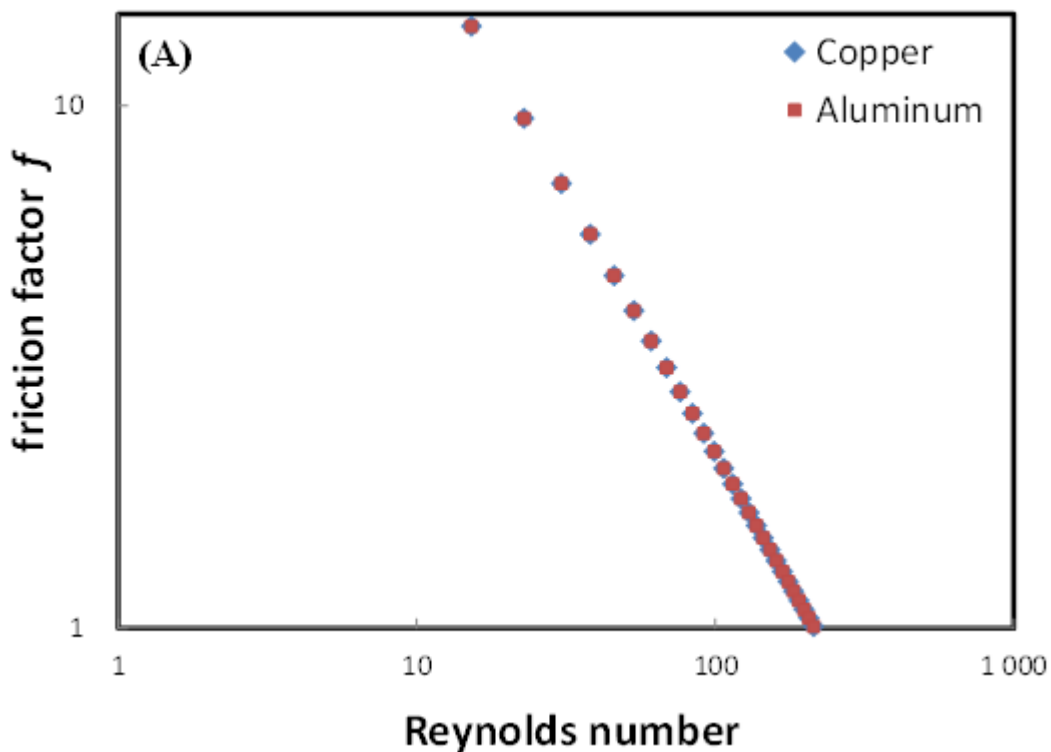


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Figure 3: Figure 3 (?????? 2

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Figure 4: Figure 3 :

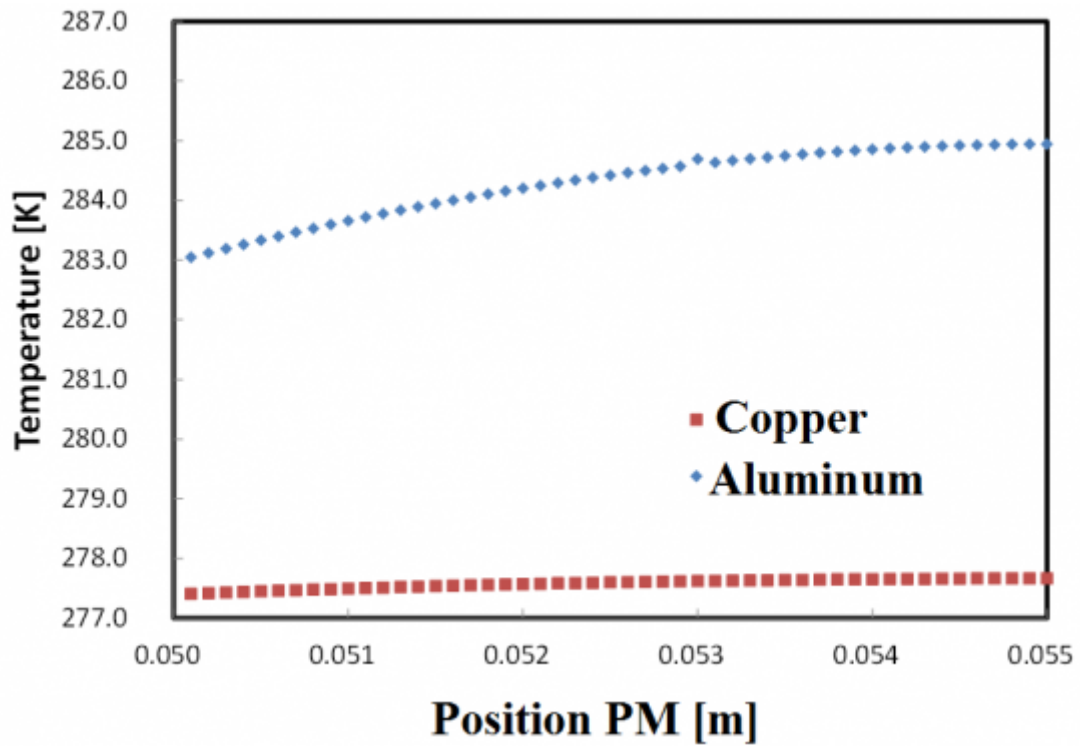


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Figure 5: Figure 4 :Figure 5 :A

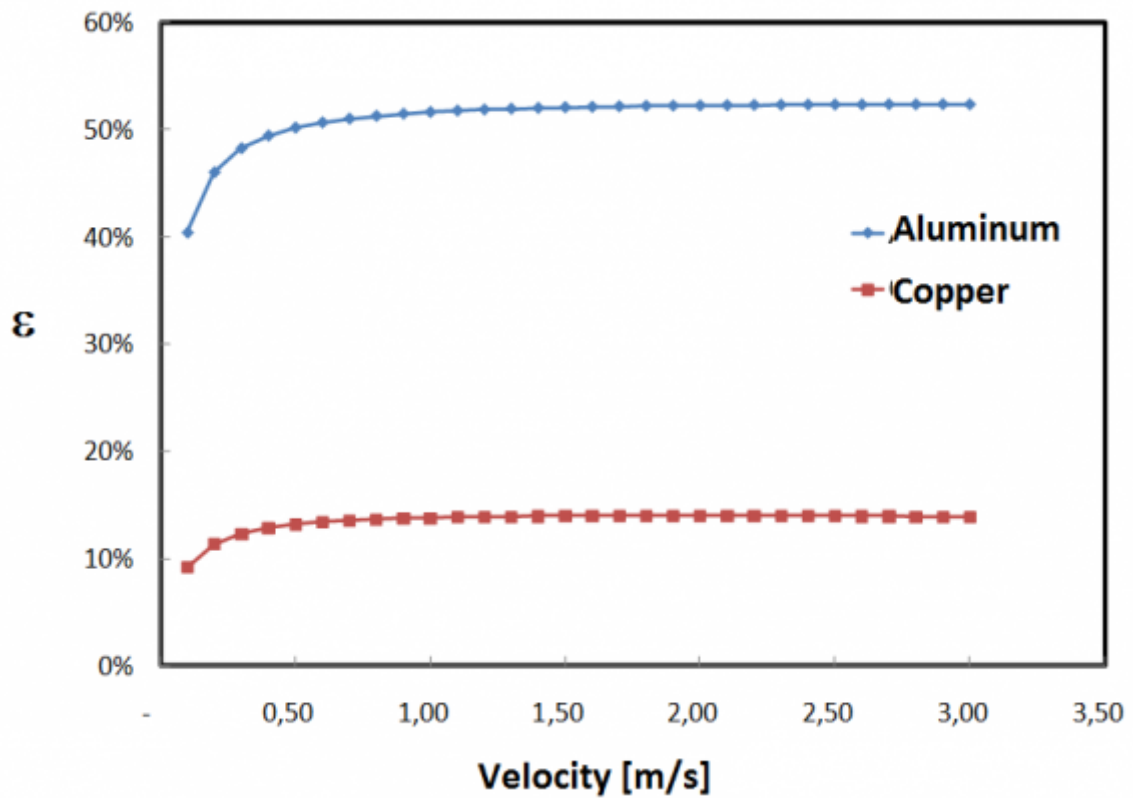
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Figure 6: Figure 6 :



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Figure 7: Figure 7 :



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Figure 8: Figure 8 :

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D (mm)	p	D lig (mm)	Ligament type	Porosity (%)	PPI	Permeability
Copper 1.2		0.187	Triangular	93	18	6.40E-09

Figure 9: Table 1 :

## .1 Global

for the same flow conditions. This can be interpreted by the large calorific capacity it has, compared to that of copper. Since the study is conducted on HVAC heating coil, this feature of Aluminum is interesting and saves energy. Moreover, the Aluminum foam gives an efficiency 5 times more important compared to the copper one, this is due certainly to its important calorific capacity.

It should be noted that the efficiency of the porous heating coil, for both materials, remains unchanged beyond a velocity of 1.5 m/s.

## .2 NOMENCLATURE

## .3 V. Conclusions

The aim of this study is to present the hydrodynamic and thermal performances of HVAC heating coil. The latter is simulated by a porous medium, generating of heat. The metallic foam, made from Aluminium and copper, is used as porous medium.

The two metallic foam samples, Aluminium and copper, present the same hydrodynamic performance because they have a same geometric characteristics.

The metallic foam made from Aluminium permits to reach a blowing temperature significantly higher, compared to that given by the copper sample, Year 2017

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