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Fabrication and Characterization of an Innovative Heat Exchanger with Open Cell Aluminum Foams

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Abstract

The present study deals with the design, the fabrication and the characterization of an innovative heat exchanger manufactured by using open cell aluminum foams. The cooling performances of the heat exchanger, working in low temperature difference were measured. Open cells aluminum foams, produced via polymeric foam replication method, have been assembled to manufacture the cooling elements. The wettability of the aluminum foam surface was improved through a surface treatment, in order to enhance the joining between the pipes and the metal foam. In a first phase, preliminary experimental tests on aluminum metal foam samples were used for an estimation of the overall cooling performance. The experimental test was also aimed to understand the basic mechanisms involved in the heat transfer process. In a second phase, the full heat exchanger was assembled, and an experimental setup was designed in order to determine the performance of the heat exchanger. The heat exchanger revealed its high potentiality in terms of thermal performance, showing also a remarkable behavior in terms of energy saving, assembly and endurance.

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Keywords: Aluminium Foams, Heat exchanger, Cooling, Energy efficiency

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1. Introduction

Recently, metal foams, due to their unique structural and functional properties have been stimulating interest in many research and technological domains [1-3]. The mechanical characteristics of such class of materials are function of pore size, distribution and density [4-7]. One of the advantages, in using metal foams, is the possibility to combine interesting mechanical properties and lightness to functional properties [4-5].

The metal foams can be produced with different morphologies and may have structures with open or closed cells. This last feature will inevitably define the field of application [1], [8]. In particular metal foams with closed cells are produced with several common used methods like powder compact melting method [1], [6] or dissolution and sintering process [8]. The replication processes, casting or coating processes etc., can be used for the production of open-cell cellular material [1]. The cost linked with the production of cellular materials is still too high, due to process complexity and hazard although all the efforts to develop a cheaper procedure [1], [3] and [5]. Moreover, in many production approaches several problems of replicability of the final product are highlighted [1], [6-7]. Some researchers to solve the replicability problems of the process adopted with satisfactory results the neural networks, [8-9]. Open cells metal foams present structures randomly oriented and mostly homogeneous in size and shape. They are distinguished mainly for their attractive functional properties. The particular inner structure of these foams permits the application of these materials in many technologies domains like heat exchangers, cryogenics, combustion chambers, cladding on buildings, strain isolation, geothermal operations, petroleum reservoirs, catalytic beds, compact heat exchangers for airborne equipment, air-cooled condensers for air conditioning and refrigeration systems, and compact heat sinks for power electronics [10-13]. Most commercially available foams are produced in different metals such as aluminum, copper, nickel and metal alloys. One of the critical constructive aspects which restrict the use of these materials is related to the difficulty in joining them with other components, limiting the ability in heat transfer from the bulk to the foam [14-16]. In the past years, many researchers have investigated on the thermal transport in metal foams for practical applications. Calmidi et al. experimentally investigated the effective thermal conductivity of high-porosity fibrous metal foams [17]. Hsieh et al. carried out an experimental study to characterize the heat transfer behavior of several heat sinks made of aluminum metal foams with different porosity (0,87-0,96) and PPI (10-40) [18]. Boomsma and Poulikakos developed a one-dimensional heat conduction model for use with open-cell metal foams, based on idealized three-dimensional cell geometry of the foam. Only open-cell metal foams appear to have interesting future in constructing heat exchangers [19]. Bhattacharya et al. proposed an analytical and experimental investigation for the determination of the effective thermal conductivity, the permeability and inertial coefficient of high porosity metal foams [20]. Lu et al. analyzed the forced convection problem in a tube filled with a porous medium subjected to constant wall heat flux [21]. K. Nawaz and Guarino et al. studied the fluids flow inside the open-cell metal foams and stated the these materials have high specific surface area, relatively high thermal conductivity, and a tortuous flow path to promote mixing [22-23].

Many studies related to the thermal characterization of metal foams were made, but much less on their actual application in industrial or domestic components. In particular, the information that can be used to evaluate a real application of metal foams in heat exchangers, are currently scanty in the scientific literature. In this context, in this paper, the authors have designed, manufactured and characterized a metal foam heat exchangers The performance of a heat exchanger, working in low temperature difference, is evaluated. The novel heat exchanger was assembled and used for experimental tests aimed at understanding the basic mechanisms involved in the heat transfer process and to establish the thermal performance.

2. Materials and methods

The 10 pore per inch Aluminum foams used for the heat exchanger (Hex) manufacturing, and provided by M-PORE (Germany), were produced via the replication method of polymeric pattern. The aluminum foams were cut in the dimension of (350x400x12.5) mm^3 and assembled to obtain panels with dimension (700 x 400 x 12.5) mm^3 (mid HEx), fig. 1a. Subsequently two panels were milled in order to obtain the seat of the coil. In order to obtain a good joining between the aluminum foam and copper pipes, the wettability of the aluminum foam surface was improved through a thin copper coating (about 10 μm) by electro-deposition process. The copper coating allowed the use of commercial and low cost brazing media (tin-based). The electro-deposition was carried out in an electrolytic cell at