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Properties of plain weave metallic wire mesh screens

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ABSTRACT

Porous structures made of metallic wire mesh screens are receiving renewed interests from researchers due to their large potential for enhancing heat transfer. Accurate estimation of key porous parameters undoubtedly helps understand heat transfer mechanisms inside those porous structures. This study presents a new methodology for calculating volumetric porosity, specific surface area, and in-plane thermal conductivity for porous structures made of square-shaped and diamond-shaped wire screens. Analytical models were developed accordingly. Affecting factors including mesh number, wire diameter, compactness factor, and stacking patterns were systematically studied. This work, for the first time, considers the cases when the wire mesh screens are cold compressed. The models developed in this study are compared with typical existing models. Satisfactory agreement was shown.

1. Introduction

Metallic plain weave wire mesh screens, commercially available in many different materials, weave styles and mesh sizes, have long been used in applications including filtering, food processing, chemical reaction, heat pipes, solar energy collector, thermal insulation, etc. Structures or laminates made of wire screens are generally highly porous, possessing large specific surface area (defined as total wetted surface area per volume) and a large number of pores. If deployed in heat transfer applications, they can serve as lightweight, rigid heat transfer inhibitors or enhancers. An example using mesh screens as a thermal insulation structure is reported by Kim et al. [1]. One early reference to enhancing boiling heat transfer by coating the heat transfer surface with a mesh screen is found in [2]. In recent years, much interest has been directed to the study of heat transfer enhancement utilizing structured porous surfaces [3,4] or fins [5] made of wire mesh screens. The macro effects of parameters, such as porosity, mesh size, and wick thickness on heat transfer performance were explored [3–5]. However, the enhancement mechanism of heat transfer inside those porous structures has not been fully investigated. We believe a lack of accurate knowledge of physical properties of those wick structures, including porosity, specific surface area, effective thermal conductivity (in-plane and cross-plane), pore hydraulic diameter, etc. contributes to this lack of understanding.

Direct measurement of the porosity of a porous structure is occasionally feasible, but it is generally a challenging task to obtain the value for the wetted surface area. Therefore, reliable models are needed. Research efforts made in this area have resulted in several typical models for calculating volumetric porosity [6,7] and effective thermal conductivity in the directions of in-plane (along the wire length direction) [6,8,9] and cross-plane (perpendicular to the screen plane) [4,9,10].

However, in general, those models lack completeness: models developed by different researchers only focus on one or two parameters that are of particular interest to the developers themselves. When models of different origins are combined to calculate a third property, large uncertainty may occur. In addition, there are no models for uniformly compressed wire screens, which have been studied more and more due to strong thermal contact between wires and layers [3–5]. Except for the work done by Xu and Wirtz [8], which studied the properties of diamond-shaped wire mesh screens, most other work only focused on a very special type of wire mesh—plain weave square-shaped wire screens and, thus, fall short of generality.

In this study, analytical models are developed for calculating volumetric porosity, specific surface area, and in-plane thermal conductivity of plain weave wire mesh in different packing patterns, with the screens un-compressed and compressed. Initially, the widely used square-shaped plain weave wire mesh screens are examined. Following, the models are extended to diamond-shaped

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Nomenclature

C, C_1, C_2	multiplication factor [–]
cf	compactness factor [–]
d	wire diameter [m]
d_h	pore hydraulic diameter [m]
l	arc length [m]
M	mesh number [m^{-1}]
N	number of wire screen layers [–]
k	thermal conductivity [W/mK]
R	thermal resistance [K/W]
S	surface area [m^2]
t_N	thickness of N layer wire screens [m]
V	volume [m^3]
w	width [m]
α	transformation factor [–]
β	specific surface area [m^{-1}]
ϵ	volumetric porosity [–]
θ	angle [°]

Subscripts

D	plain diamond mesh
eff	effective
es	ratio of effective to solid
f	fluid
fs	ratio of fluid to solid
I, II	associated geometry
S	plain square mesh
s	solid
tot	total
x	In the x direction
y	In the y direction

plain weave wire screens. The trends displayed by models are briefly discussed. In addition, the models are compared with existing models in the literature.

2. Physical models

The plain weave wire mesh screen is the most commonly used weave type, in which each warp wire and shute wire pass over a wire and under an adjacent wire, as depicted in Fig. 1. Wires are crimped in the weaving operation. Two of the most important wire parameters are the wire diameter, d and the mesh number (also called mesh count), M. Mesh number is defined as number of openings in a linear inch measured from the center of one wire to the center of a parallel wire in the direction parallel to the center of the other group of wires. More terminologies concerning wire mesh screen can be found in [11].

Fig. 1(c) shows a unit cell of a arbitrary plain weave wire screen, in which the wire diameter, mesh number and intersection angle vary in different directions. Depending on the parameter configuration, the opening area of a plain weave wire mesh screen can be square, as shown in Fig. 1(a) when ($\theta_1 = \theta_2 = 45°$, $M_1 = M_2 = M$, $d_1 = d_2 = d$), rectangular when ($\theta_1 + \theta_2 = 90°$), diamond-shaped, as shown in Fig. 1(b) when ($M_1 = M_2 = M, d_1 = d_2 = d$), or parallelogram. The square-shaped plain weave wire screen has identical physical properties in both shute wire and warp wire directions, while the diamond shaped mesh may display anisotropy. That said, the square-shaped screen is by far the most popular woven wire mesh that has been used or investigated, while the diamond mesh can be useful in special applications.

Multiple layers of wire meshes are often used to form a structured-porous laminate of different thicknesses. Two of the extreme packing patterns, namely in-line stacked and staggered stacked, are shown in Fig. 2. An in-line stacked wire mesh screen laminate shows periodic characteristics in its structure; it has the same porosity and effective in-plane thermal conductivity as that of a single layer mesh screen, while the specific surface area of an in-line stacked screen laminate may not be the same as for a single layer.

Xu and Wirtz [6] defined "compression factor", cf, as in Eq. (1), to describe the thickness decrease due to different packing pattern. If the wire mesh screens are not compressed, for a single layer or multiple layers of in-line stacked screen laminate, the compression factor equals one; for staggered stacked wire mesh screens, the compression factor is less than one. Apparently, "compression factor" does not truly describe compression, so it is misleading by its literal meaning. We suggest "compactness factor" being used to include those two cases, and specifying "compressed" if wire screens are uniformly compressed, or "uncompressed" if wire screens are not compressed. By definition, cf is generally not bigger than one.

$$cf = \frac{t_N}{N(d_x + d_y)} \tag{1}$$

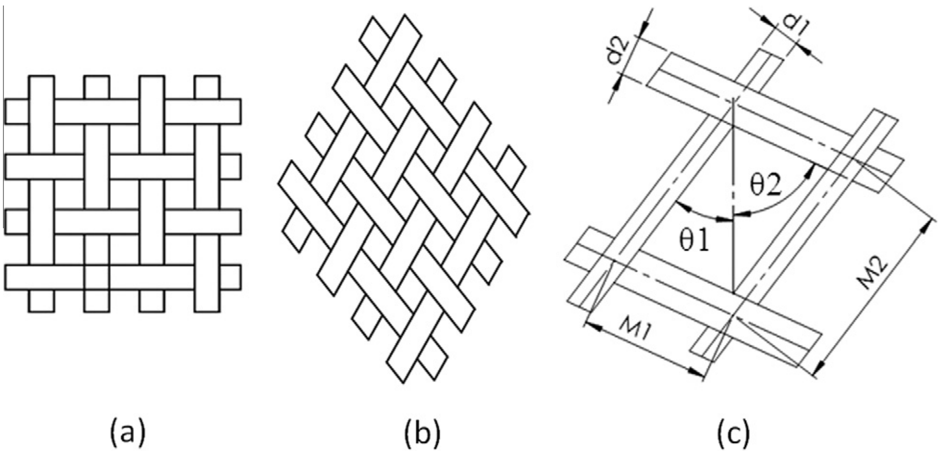

Fig. 1. Plain weave wire mesh screen (a) square screen; (b) diamond screen; (c) arbitrary.