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Review of convection heat transfer and fluid flow in porous media with nanofluid

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ABSTRACT

There are two advantages of using porous media. First, its dissipation area is greater than the conventional fins that enhances the heat convection. Second is the irregular motion of the fluid flow around the individual beads which mixes the fluid more effectively. Nanofluids result from the mixtures of base fluid with nanoparticles having dimensions of (1–100) nm, with very high thermal conductivities; as a result, it would be the best convection heat transfer by using two applications together: porous media and nanofluids. This article aims to summarize the published articles in respect to porosity, permeability (K) and inertia coefficient (C_f) and effective thermal conductivity (k_{eff}) for porous media, also on the thermophysical properties of nanofluid and the studies on convection heat transfer in porous media with nanofluid.

Contents

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Nomenclature

A	cross section area (m^2)
C	shape factor ≈ 150 (Blake–Kozeny), 180 (Carman–Kozeny)
Cf	Forchheimer coefficient
Cp	specific heat capacity, (J/kg K)
Da	Darcy number
D_h	hydraulic diameter, (m)
D_p	mean particle diameter, (m)
Gr	Grashof number
h	heat transfer coefficient, (W/m^2 K)
K	permeability for porous media, (m^2)
k	thermal conductivity, (W/mK)
Le	Lewis number
M	molecular weight of the base fluid
N	Avogadro number
Nu	Nusselt number
Pe	Péclet number
Pr	Prandtl number
Ra	Rayleigh number
Re	Reynolds number
Ri	Richardson number
Sh	Sherwood number
V	volume

Greek symbols

Δp	pressure drop
ε	porosity
μ	dynamic viscosity, (kg/ms)
ρ	density, (kg/m^3)
ρ_{fo}	mass density of the base fluid calculated at temperature $T=293^\circ$ K
α	thermal diffusivity, (m^2/s)
φ	nanoparticle volume fraction

Subscripts

b	base fluid
f	fluid
nf	nanofluid
p	particle
r	radial direction
s	solid
eff	effective
$p.m$	porous media

1. Introduction

In thermal devices, improvement of convection heat transfer becomes an important factor in industries like electronic equipment and heat exchangers. Heat exchangers may be classified according to transfer process, construction, flow arrangement, surface compactness, number of fluids, and heat transfer mechanisms as shown in Fig. 1. Some of these classifications have been dealt in [1–8].

In industrial processes, another method for improving the convection heat transfer characteristics is using porous medium (any material which consists of solid matrix with an interconnected void is called porous media such as rocks and open-cell aluminum foams [9]) and nanofluid. Therefore, porous media technique has been the subject of many studies and has received a considerable observation. This attention is due to the fact that this kind of structure is encountered in many engineering applications, such as filtration, thermal insulation, ground water, oil flow and all types of heat exchangers.

Convection heat transfer and fluid flow with porous medium occur in power stations of many engineering applications where cooling or heating is required such as cooling turbine blades, cooling electronic equipment and combustion systems. The mixing of the low and high energy fluids which occur in these applications significantly affects the performance of these devices [10]. One of the ways to increase heat transfer is to employ porous medium with nanofluid.

2. Fluid flow in porous media

Fluid flow through a porous medium depends on Darcy's law (1856), where fluid flow discharge rate in the porous media is proportional to the pressure drop and the viscosity of the fluid over a given distance [11] as shown in Fig. 2.

$$\nabla p = -\frac{\mu}{K}\vec{v} \tag{1}$$

Darcy's law was later found to be limited in accuracy and only valid for low velocity flows that are incompressible and isothermal. Further research brought forth the Dupuit–Forchheimer extension to Darcy's law which is represented in Eq. (2). This addition to Darcy's law defines the form drags effect on the flow, which is represented by the inertial resistance coefficient (C_f). The relationship of inertial resistance is non-linear and affects higher velocity flows, but it varies with respect to pore size, internal structure, and porosity [9].

$$-\nabla p = \underbrace{\frac{\mu}{K}\vec{v}}_{\text{Darcy term}} + \underbrace{\frac{\rho c_f}{\sqrt{K}}|v|v_j}_{\text{Forchheimer term}} \tag{2}$$

where C_f is the Forchheimer coefficient (inertia coefficient).

Flows in porous media are defined as being in one of three ranges, which are determined from the Reynolds number of the flow. They are laminar, non-linear laminar (the transition between the Darcy regime, where viscous effects dominate, to the Forchheimer regime, where inertial effects dominate) and turbulent ranges [9]. Several methods for calculating the Reynolds number for flows in porous media have been proposed. Oosthuizen et al. [12] and Boomsma and Poulikakos [13] used square root of permeability to calculate the Reynolds number value in porous medium as show in Eq. (3); this use is best acceptable with low porous medium porosity. Non-linear laminar flow occurs in the Re_K range 1–10 [9]. For this relation and condition, Bonnet et al. [14] elaborated that it was valid for laminar flow only. Boomsma and Poulikakos [15] and Bonnet et al. [14] used mean pore diameter to calculate the Reynolds number in porous medium as show in Eq. (4). Using the pore size as the length scale has been found to be more accurate, since permeability and inertial resistance are dependent on pore size [16].

$$Re_K = \frac{\rho u\sqrt{K}}{\mu} \tag{3}$$

$$Re_{D_p} = \frac{\rho u D_p}{\mu} \tag{4}$$