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Pressure loss and forced convective heat transfer in an annulus filled with aluminum foam ☆

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Abstract

This experimental study investigates non-Darcy flow and heat transfer in an annulus with high porosity aluminum foams to attain the miniaturization of thermal systems. The local wall temperature distribution, inlet and outlet pressures, and temperatures and heat transfer coefficient were measured for heat flux of 13.6–31.4 kW/m^2. The results show that aluminum foam enhances heat transfer from a surface compared with that of laminar flow in a clear annulus. Correlations for the friction factor and the Nusselt number are proposed and used for design of thermal applications.

Keywords: Aluminum foam; Inertia effect; Annulus; Non-Darcy flow

1. Introduction

The trend in heat exchanger design continues to be in the direction of higher heat transfer rates per unit volume. In the usual commercial fluid-to-fluid heat exchangers, there is an obvious economic incentive to reduce equipment size. This is accomplished by introducing more surface area or augmenting heat transfer coefficients. Many ideas for cooling methods have been proposed. Porous media have large contact surfaces with fluids, which enhance heat transfer performance; hence, there are wide investigations of heat transfer and transport phenomena in the porous media for many industrial applications such as heat exchangers, the packed-sphere bed, electronic cooling, chemical catalytic reactors, drying processes and heat pipe technology. From this idea, an experimental investigation has been conducted to examine the feasibility of using a high conductivity porous channel as a heat sink for high performance forced cooling in heat exchangers. One drawback of a packed bed is that it incurs a large pressure drop. As a whole, the packed bed is a dense material of porosity, ε, which implies a void fraction in the material in the range of 0.3–0.6. Thus, to solve this shortcoming, foam material with high permeability has been developed. Aluminum-based foam material is a highly permeable porous medium with high porosity, typically $\varepsilon > 0.9$, which enables considerably reduced pressure drop for the flow.

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Koh and Colony modeled the microstructures as a porous medium using Darcy's law to describe the flow. But they did not account for various important effects such as conduction through the fluid phase, dispersion and non-Darcian effects [1]. Hwang and Chao carried out the measurement for packed bronze beads in a channel [2]. They showed that the high conductivity porous channel enhances the local heat transfer rate and the maximum wall temperature could be reduced drastically. Kim et al. performed an experimental investigation on the flow and convective heat transfer characteristics for the aluminum foam in an asymmetrically heated channel [3]. They showed that the friction factor is much higher at the lower permeable aluminum foams while the significant enhancement in Nu is obtained.

However, previous studies for the flow characteristics of the porous media appear to be confined to the Darcy flow regime wherein the flow is laminar and inertial forces are negligible and to two basic duct geometries of parallel plates and a circular pipe. Whereas, the effects of a solid boundary or the inertia forces are expected to become more significant near the boundary and in high porosity media, causing the application of Darcy's law to be invalid. However, relatively little attention has been given to the study of these effects.

The present investigation is concerned with the general case of flow through a high porosity medium, with the emphasis on the non-Darcy flow regime. Since the geometry in practical applications would be generally concentric cylinder of annulus, the heat transfer and friction factor measurements in an annulus with porous heat sink were performed for water flow.

2. Experimental apparatus and test procedure

The apparatus employed to study the flow and heat characteristics of porous media is shown in Fig. 1. As shown in the figure, it was composed of four major parts: (a) working fluid supply, (b) test section, (c) porous medium and (d) data acquisition system. The working fluid flows in a closed loop that encompasses the upstream reservoir, test section

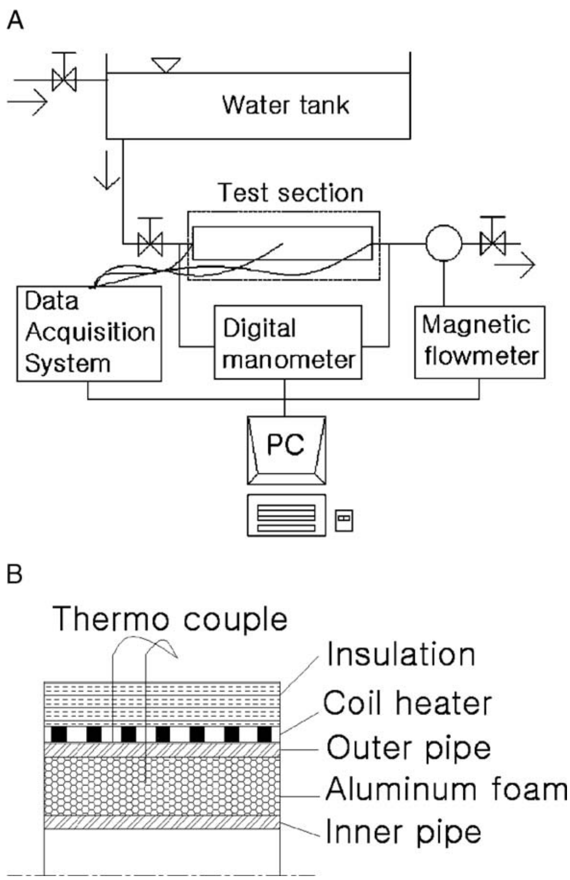

Fig. 1. Schematic of experimental apparatus. (A) Experimental setup. (B) Detail of test section part.