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Hydrodynamic and thermal interaction of a periodically oscillating fluid with a porous medium lying over a thick solid plate

Shohel Mahmud [a,*], Syeda Humaira Tasnim [b], Roydon Andrew Fraser [b], Ioan Pop [c]

[a] Mechanical Engineering Program, School of Engineering, University of Guelph, Guelph, ON N1G2W1, Canada
[b] Department of Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, ON N2L3G1, Canada
[c] Faculty of Mathematics, University of Cluj, R-3400 Cluj, CP 253, Romania

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ABSTRACT

In this paper, the hydrodynamic and thermal interaction of a periodically oscillating compressible fluid with a layer of porous medium is analytically investigated. The velocity amplitude of the oscillating fluid is considered to be small when compared to the thermal penetration depth (a transverse length scale) of the thermal energy transport inside the porous layer. The solid wall adjacent to the bottom of the porous layer is considered to be thick and the conduction heat transfer inside that wall is included in this model. The entire problem is treated as a *conjugate heat transfer thermoacoustic* like problem. The governing momentum and energy equations are simplified and linearized by using a first order perturbation analysis. Such an analysis is usually used to solve the linear thermoacoustic problem in the low Mach number limit and available in the thermoacoustic literature. Analytical expressions for oscillating velocity, temperatures in the porous layer and in the solid wall, heat transfer from the solid wall to the porous medium, and the entropy generation rate are calculated and graphically presented.

1. Introduction

Heat and mass transfer studies through a saturated porous medium are an important development and a rapid growing area in the contemporary heat transfer research [1] because of its importance to a variety of small to large scale applications (e.g., electronic cooling, industrial heat exchanger, lighter cooling device, special cooling/refrigeration, filtering, etc.). Although the mechanics of fluid flow through porous media has preoccupied engineers and physicists for more than a century, the study of heat transfer has reached the status of a separate field of research during the last three decades [2–8].

A recent potential application of convection processes in porous media is found in the standing wave thermoacoustic prime movers and refrigerators [4]. The analysis presented in this article is applicable to the stacks of standing wave thermoacoustic prime movers and refrigerators. The cross-sectional diagram of a similar standing wave thermoacoustic refrigerator is available in Poese et al. [9]. Thermoacoustic devices typically consist of three elements placed in a resonance tube; a porous structure (usually called stack) and two heat exchangers. The stack is the structural heart of a thermoacoustic device that supports a longitudinal temperature gradient and is the element in which the desired interchange between thermal and acoustic energies takes place. Stacks are finely subdivided into many parallel channels or pores in order to maintain moderate (standing-wave) thermal contact between the working gas and the stack across large cross-sectional areas. The surface of the stack material should be large enough so that most of the entrained gas lies within the thermal penetration depth, and yet not significantly impede the oscillating sound wave. Therefore, the stack is no more than a means for increasing the total amount of contact area for gas in which heat pumping effects can occur. Stacks are available in different sizes and shapes; honeycombs, spiral rolls, parallel plates, circular pores, and pin arrays are examples of stacks commonly used in thermoacoustic engines and refrigerators [4]. Installation of heat exchangers near the extremities of the stack either supply or remove heat from the stack. Thus a thermoacoustic refrigerator can be used to cool the other systems which are connected to the cold heat exchanger. The approximations that are made in the analysis (such as linear thermoacoustic theory, short stack, low amplitude etc.) are good according to Swift [4] at the operating conditions of the practical standing wave thermoacoustic devices. Several models of energy transport processes in the stacks that employed those approximations are available in the existing thermoacoustic literature [4] and achieved

* Corresponding author. Tel.: +1 519 722 7587.
E-mail addresses: smahmud@uoguelph.ca, smahmud@engmail.uwaterloo.ca, shohel_mah@yahoo.ca (S. Mahmud).

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