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Layered porous media architecture for maximal cooling

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Abstract

In this paper, we address the fundamental problem of how to arrange fluid flow and solid material for minimal thermal resistance. A heat-generating board is cooled by a stack of porous layers through which a coolant flows. The stream is generated by a fixed pressure drop. The problem consists in determining the optimal porosity and material of each layer for minimizing the hot spot temperature (thermal resistance), under global mass and cost constraints. We combine a genetic algorithms (GA) toolbox with a finite volume program to optimize the design. The shape and structure of the system emerge from the global optimization, under global constraints. The optimal material to use in each layer is determined by the GA – not assumed – and is chosen from a database of four materials. The GA eliminates layers that do not contribute to the overall performance and therefore optimizes the size of the stacking. The results indicate that more solid material should be used closer to the hot plate (non-uniform distribution). Several nearly optimal configurations are found in the design space.

Keywords: Cooling of electronics; Heat sink; Cold plate; Layered structure; Genetic algorithms; Porous media

1. Introduction

The cooling of every heat-generating device (e.g., engine, electronics) is essential for maintaining its temperature in the acceptable range where the integrity and performance of the device are not jeopardized. The designer of a cooling system has to provide "thermal pathways" by which the heat current can be discharged in an external reservoir (e.g., ambient air) either by conduction, convection or radiation. The removal of heat by a coolant that sweeps or bathes a warm surface is one of the most encountered cooling strategies in engineering systems. Extended surfaces, or fins, are then used to increase the surface of exchange and maximize the heat transfer rate. Designing a fin system is equivalent to distributing a high thermal conductivity material within the flow or equivalently, distributing the flow within the high thermal conductivity material.

In this paper, we examine the opportunities for optimizing the performance of a cooling system made of a stack of porous layers, like the one shown in Fig. 1a. The coolant circulates in the network of pores and transports the heat outside of the system. The solid phase of the porous media is made of high thermal conductivity material in order to increase the surface of exchange and minimize the global thermal resistance of the stacking. Porous media, such as metallic foams and sponges, are used for improving the thermal performance of various systems [1–6]. One of the current challenges is the characterization of the porous material properties, such as the equivalent thermal conductivity and permeability [7–10].

Our approach is in line with the constructal point of view: the internal structure of the cooling system has to emerge as a result of the optimization, under global constraints [11]. Previous work on optimized internal structures in heat transfer systems led to the idea of 'designed porous media' [12,13]. A network of pores can be optimized for maximal heat removal or minimal pumping power requirement [14–19].

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Nomenclature

Be	Bejan number
c_p	heat capacity, J kg^{-1} K^{-1}
c	cost per unit of mass, \$ kg^{-1}
C	cost per unit of length, \$ m^{-1}
D	diameter of the pipes
k	thermal conductivity, W m^{-1} K^{-1}
K	permeability, m^2
L	length, m
H	height, m
M'	mass per unit of length, kg m^{-1}
N	number of layers in the y-direction
P	pressure, Pa
q''	heat flux, W m^{-2}
S	number of cells in the x-direction
T	temperature, K
u	velocity, m s^{-1}
x, y	Cartesian coordinates, m

Greek symbols

α	thermal diffusivity, m^2 s^{-1}
ϕ	porosity
γ	penalty coefficient
μ	viscosity, kg m^{-1} s^{-1}
ρ	density, kg m^{-3}

Subscripts

f	fluid
j	layer index
s	solid
0	constraint value

Superscript

$\sim$	dimensionless quantity

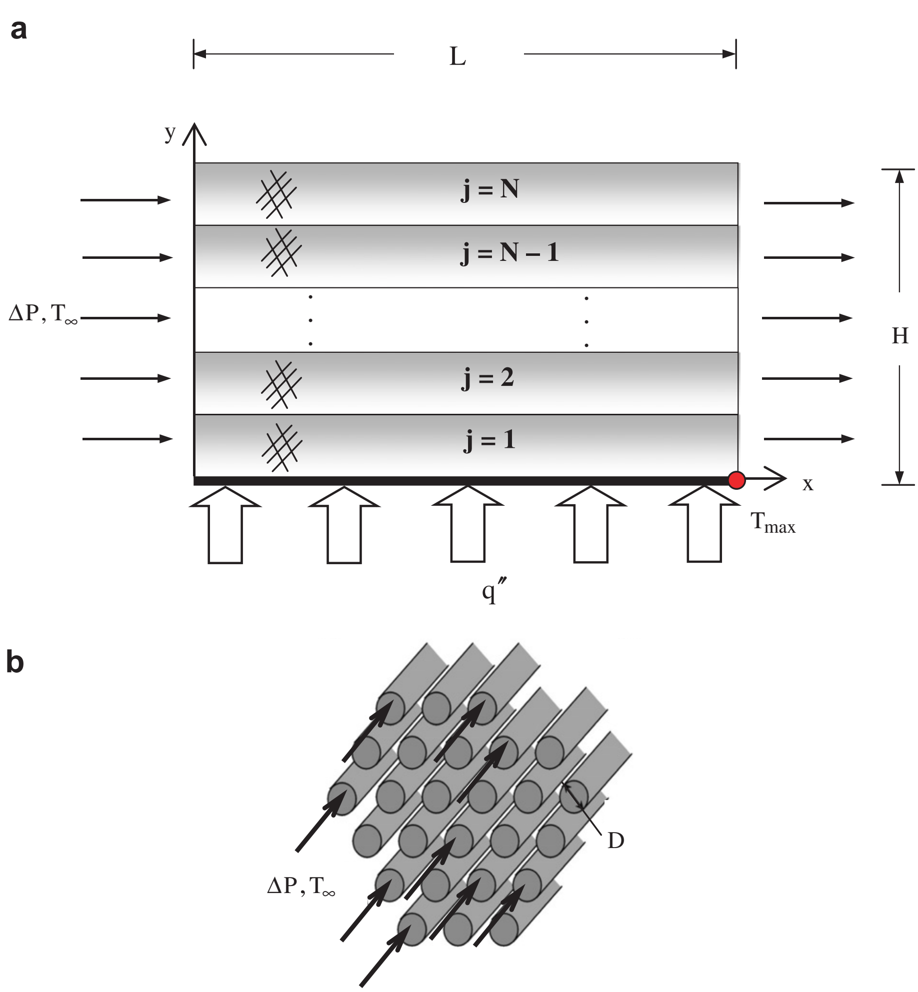

Fig. 1. Physical representation of (a) a stacking of porous layers and (b) the porous structure.