International Communications in Heat and Mass Transfer 38 (2011) 1354–1359

Contents lists available at SciVerse ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Maximum heat transfer density rate enhancement from cylinders rotating in natural convection ☆

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ARTICLE INFO

Available online 26 October 2011

Keywords:
Natural convection
Rotating cylinders
Heat transfer density rate
Counter-rotation
Optimal packing

ABSTRACT

In this paper we investigate the thermal behaviour of an assembly of consecutive cylinders in a counter-rotating configuration cooled by natural convection with the objective of maximizing the heat transfer density rate (heat transfer rate per unit volume). A numerical model is used to solve the governing equations that describe the temperature and flow fields. The spacing between the consecutive cylinders is optimised for each flow regime (Rayleigh number) and cylinder rotation speed. It was found that the optimized spacing decreases as the Rayleigh number increases and the heat transfer density rate increases, for the optimized structure, as the cylinder rotation speed is increased. Results further shows that there is an increase in the heat transfer density rate of the rotating cylinders over stationary cylinders.

1. Introduction

Efficiency is a key aspect in design, which has become prevalent in the design of heat transfer devices such as heat sinks and pin fins. Research has been and is still being conducted on this subject with the aim of extracting more and more heat from a given space through the maximizing of the packing of heat-generating material per unit volume. This drive to augment heat transfer devices has become reinforced by modern electronic systems which produce high amounts of heat due to the ever increasing power-to-volume ratio employed in such systems.

The strive for greater heat transfer density rates has been the driving force behind many of the miniaturization efforts, augmentations and unconventional ways of designing heat transfer devices. This has lead researchers to study the optimized configurations for various architectures such as: the optimal spacing of parallel plates in forced convection, natural convection and mixed convection [1–4]; the optimal spacing of cylinders in forced convection and natural convection [5,6]; and various optimized multi-scale structures [7–12], etc.

The heat transfer and fluid flow around a single rotating cylinder has been studied previously. Badr and Dennis [13] considered the problem of laminar forced convective heat transfer from an isothermal circular cylinder rotating about its own axis located in a uniform stream. The authors reported that the temperature fields are strongly influenced by the rotational speed of the cylinder and contradictory to expectation they found that the overall heat transfer coefficient tends to decrease as the rotational of the cylinder increases. They attributed this to the presences of a rotating fluid layer around the cylinder that separates the cylinder from the main flow stream. Chiou and Lee [14] considered a problem of forced convection on a rotating cylinder cooled with an air jet. The results confirmed that the overall heat transfer is enhanced at lower rotational speeds and at higher rotational speeds the effect became reversed. They attributed this to the presences of a layer of dead air around the cylinder. Panda and Chhabra [15] considered a problem of forced convection heat transfer from a heated cylinder rotating in streaming power-law fluids. The results show a similar behaviour of the heat transfer rate: for moderate rotational velocities at low Reynolds numbers the heat transfer rate is enhanced and there is an envelope of conditions (Reynolds number, rotation speed and power-law index) in which rotation has a negative effect on the heat transfer rate. Similar research includes the works of Gshwendtner [16], Mohanty et al. [17], Oesterle et al. [18], Ozerdem [19], Paramane and Sharma [20,21], Yan and Zu [22] and Nobari et al. [23].

Further studies have been conducted with a row of heat-generating rotating cylinders in forced convection by Joucaviel et al. [24]. Here the authors report that a counter-rotation configuration increases the heat transfer more efficiently when compared to a co-rotation configuration. Ogunronbi et al. [25] then built onto this work as well as prior research by Bello-Ochende and Bejan [10] by considering a multi-scale constructal design. The study presented in this paper builds onto prior research by Bello-Ochende and Bejan [12], in which the authors optimized the cylinder-to-cylinder spacings in a multi-scale constructal design of heat-generating cylinders (without cylinder rotation) cooled by natural convection for one and two degrees of freedom. These classical results will be used as a reference (benchmark) for the results reported in this paper. It is the purpose of this paper to maximize the heat transfer density

☆ Communicated by W.J. Minkowycz.

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0735-1933/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2011.08.010