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A review of studies on forced, natural and mixed heat transfer to fluid and nanofluid flow in an annular passage

Hussein Togun [a,b,*], Tuqa Abdulrazzaq [c], S.N. Kazi [a,**], A. Badarudin [a], A.A.H. Kadhum [d], E. Sadeghinezhad [a]

[a] *Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[b] *Department of Mechanical Engineering, University of Thi-Qar, 64001 Nassiriya, Iraq*
[c] *Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 Selangor, Malaysia*
[d] *Department of Chemical and Process Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia*

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ABSTRACT

The enhancement of the thermal performance of heat exchanging equipment transport energy at low financial cost by various techniques is presented in this review. Various annular passage configurations have been used in the reviewed studies, namely circular, ellipse, rectangular, square, triangular, and rhombic annular channels with different fluid and boundary conditions. The effect of eccentricity in both horizontal and vertical directions on heat transfer rate in most numerical and experimental investigations for horizontal and vertical annular passages is studied. The effects of heater length, as well as the Darcy, Prandtl, Reynolds, Grashof and Rayleigh numbers on heat transfer in concentric and eccentric annular passages are also investigated. In case of rotating the inner, outer or both cylinders of the annular cylinder arrangement, the generated secondary flow influences the heat transfer to fluid flow in an annular passage. The effect of nanofluid on the increased enhancement of heat transfer in an annular channel is presented. Related studies on curved, covered annular channels showed augmented heat transfer rate in comparison with straight annular channels. In this review, a good agreement is evident between experimental and numerical data, which could help researchers design thermal systems supported by annular passages with the goal of retarding energy consumption by equipment and machineries in applications that could ultimately contribute to appeasing the global energy crisis.

Contents

* Corresponding author at: Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.
** Corresponding author.
E-mail addresses: htokan_2004@yahoo.com (H. Togun), salimnewaz@um.edu.my (S.N. Kazi).

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1. Introduction

Environmental and economic sustainability have drawn the attention of researchers and prompted them to seek alternative methods that offer maximum energy at low cost. Thermal system channel configuration and heat transfer fluid type are significant to providing the greatest required energy transport.

Investigating forced, natural and mixed heat transfer to fluid flow in an annular passage is among the most important heat transfer studies, owing to its presence in several applications from heat exchangers, to reactors, packed beds, gas turbines, chemical industries, etc. There are numerous published investigations that were initiated decades ago, comprising experimental and numerical explorations that deal with different types of fluid and boundary conditions.

Rohsenow et al. [1] distinguished four fundamental thermal boundary conditions with the potential to be applied in annular passages, as follows:

First kind: Uniform temperature at one wall (different from the incoming fluid temperature), while the other wall is at uniform entering fluid temperature.
Second kind: Uniform heat flux at one wall (i.e., adiabatic with zero heat flux) and the other wall is insulated.
Third kind: Uniform temperature at one wall (unlike the entering fluid temperature) and the other wall is insulated.
Fourth kind: Uniform heat flux at one wall, and the other wall maintains entering fluid temperature.

There are also other types of boundary conditions represented by varying and non-zero uniform heat flux at both walls of an annular passage.

In the last decade, the demand for energy has increased due to global development. Techniques used for saving energy and cost are provided by changing the flow channel configurations besides introducing high thermal conductivity fluid, such as nanofluid, which enhances thermal performance.

Throughout the present review, the subject matters of interest are investigated systematically, such as temperature distribution, thermal stresses, thermal length, heat transfer coefficient, pressure drop, and velocity profile. Some studies have also addressed the effect of a rotating inner and/or outer pipe and the effect of eccentricity on heat transfer processes in an annular passage.

The geometry of annular passages in engineering applications is available in various configurations, including circular, rectangular, elliptical, conical, polygonal, rhombic, triangular, square, and non-uniform, as found in concentric and eccentric configurations. A number of researchers have employed a concentric annular passage, meaning that the center line of the inner pipe has the same coordinates as that of the outer pipe, while others have used an eccentric annular passage whereby the inner pipe's center line does not have the same coordinates as that of the outer pipe. More recently investigations have been conducted on the accuracy of the heat transfer process in annular passages, and a good agreement is identified relative to other studies, as referred to in the present paper.

The purpose of this review paper is to clarify the economic value of achieving highly efficient energy transport at reduced cost via different approaches, including change in the structural configuration of thermal systems and employing high thermal conductivity fluids.

Due to an affluent number of available investigations on concentric and eccentric annular passages, this review is subdivided into two groups.

2. Heat transfer and fluid flow in concentric annular passage

Earlier studies with focus on forced, natural and mixed heat transfer to fluid flow in an annular passage were pioneered by Taylor [2], Dufinescz and Marcus [3], Zerban [4], Foust and Christian [5], Jakob and Rees [6], TEMA [7], Monrad and Pelton [8], Davis [9], Lorenzo and Anderson [10], Chen et al. [11], McMillan and Larson [12], Carpenter et al. [13], Bailey [14], Migushiva [15], Trefethen [16], MacLeod [17], Barrow [18], and Murakawa [19,20].

They have adopted numerical and experimental forms of investigating forced, natural and mixed heat transfer to fluid flow with vertical or horizontal annular passages and rotating or non-rotating flow for varying boundary condition, e.g., uniform heat flux or a wall with uniform temperature either for the inner pipe, outer pipe or both. The researchers have also applied various types of fluid in their studies. Diverse results were obtained, including on the effect of step ratio between inner and outer pipe, eccentricity, surface roughness, type of fluid, and fluid velocity in an annular passage on the heat transfer processes, temperature profiles of fully developed flow, thermal stresses and thermal length. Prior studies have contributed better insight into current research works, some of which are mentioned in this review paper. Generally, the obtained results indicate enhanced heat transfer rate due to effective flow channel shape and fluid type, which yield greater energy harvest at lower expense.

2.1. Heat transfer and fluid flow in horizontal concentric annular passage

Experimental and numerical studies have been carried out that investigate two-dimensional natural and mixed convection heat transfer in horizontal, concentric annular channels for circular cylinders. The effect outcomes of cylinder curvature, Prandtl number, Rayleigh number and ratio of the radius between inner and outer cylinders on heat transfer have been reported by Grigull and Hauf [21], Mack and Bishop [22], Powe et al. [23,24], Kuehn and Goldstein [25], Caltagirone [26], Custer and Shaughnessy [27], Burns and Tien [28], Kuehn and Goldstein [29], Vasseur et al. [30], Date [31], Glakpe et al. [32], Kolesnikov and Bubnovich [33], Kumar [34], Himasekhar and Bau [35], Yoo et al. [36], Mota and Saatdjian [37,38], Yoo [39], Labonia and Gui [40], Charrier-Mojatabi and Mojtabi [41],