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Heat transfer augmentation using nanofluids in an elliptic annulus with constant heat flux boundary condition

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A B S T R A C T

This work reports numerical simulation for three dimensional laminar mixed convective heat transfers at different nanofluids flow in an elliptic annulus with constant heat flux. A numerical model is carried out by solving the governing equations of continuity, momentum and energy using the finite volume method (FVM) with the assistance of SIMPLE algorithm. Four different types of nanofluids Al_2O_3, CuO, SiO_2 and ZnO, with different nanoparticles size 20, 40, 60 and 80 nm, and different volume fractions ranged from 0% to 4% using water as a base fluid were used. This investigation covers a Reynolds number in the range of 200 to 1000. The results revealed that SiO_2–Water nanofluid has the highest Nusselt number, followed by Al_2O_3–Water, ZnO–Water, CuO–Water, and lastly pure water. The Nusselt number increased as the nanoparticle volume fraction and Reynolds number increased; however, it decreased as the nanoparticle diameter increased. It is found that the glycerine–SiO_2 shows the best heat transfer enhancement compared with other tested base fluids.

1. Introduction

The heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy and heat between physical systems. Heat transfer is classified into various mechanisms, such as conduction, convection, and radiation. Convection is one of the major modes of heat transfer that can be qualified in terms of being natural, forced, gravitational, granular, or thermomagnetic. A combined model of natural and forced convection heat transfer can be classified as mixed convection heat transfer. Mixed convection heat transfer exists when natural convection currents are the same order of magnitude as forced flow velocities. The term “Combined Convection” is also used, and the flows may be internal or external to a bounding surface [1].

Mixed convection heat transfer and fluid flow in an annulus is a significant phenomenon in engineering systems as it is a common and essential geometry for fluid flow and heat transfer devices. It has a lot of engineering applications such as in double pipe heat exchanger, gas turbines, nuclear reactors, turbo machinery, thermal storage systems, aircraft fuselage insulation to underground electrical transmission cables, solar energy systems, boilers, cooling of electronic devices, compact heat exchangers, cooling core of nuclear reactors, cooling systems, gas-cooled electrical cables, thermal insulation,

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electrical gas insulated transmission lines ventilation and air conditioning system [2]. The heat transfer enhancement technology has been improved and widely used in the heat exchanger applications. One of the widely used heat transfer enhancement technique is inserting different shaped elements with different geometries in channel flow [3].

The main technical applications of the problem in the mixed convection heat transfer in closed canals are in the design and analysis of heat exchangers, mechanical, electrical, electronics, and many others practical's have taken a new revolution as it ventures into the period. For example, a heat exchanger problem which mainly concerns with food or chemical industries, when products to be treated may exhibit complex rheological behaviour, such as concentrated fruit purees, fruit juices, emulsions and polymeric melts, which present high apparent viscosity. The tubular heat exchangers are one of the commonest types of heat exchangers in the food industry and their typical areas of application are in the sterilization and pasteurization. On the other hand, the concentric and eccentric annular geometry is widely employed in the field of heat exchangers, as it is used in numerous heat transfers and fluid flow devices involving two fluids. One fluid flows through the inner tube while the other flows through the annular passage between the two tubes. For example, gas-cooled electrical cables, heat exchangers designed for chemical processes require the consideration of mixed convection in an annular flow. Cooling of nuclear fuel rods is another example where the results for the buoyancy-influenced convection in an annulus are useful [4].

Several attempts in this field have been completed to formulate appropriate effective thermal conductivity and dynamic viscosity of nanofluid [5]. Teng et al. [6] have measured the effects of temperature, nanoparticles size and weight fraction on the thermal conductivity of Al_2O_3–Water nanofluid. They compared their results with numerical results and proposed a significant correlation for thermal conductivity, which depends on temperature, nanoparticles size and weight fraction. Das et al. [7] have investigated a water–Al_2O_3 mixture experimentally and found that increasing temperature increases the effective thermal conductivity remarkably while the dynamic viscosity decreases. Yu et al. [8] measured that the thermal conductivity of ZnO-EG nanofluid. They establish that the enhanced value of 5.0 vol% ZnO-EG nanofluid is 26.5%, well beyond the values given by the existing classical models for the solid liquid mixture, and it is consistent with the prediction values by the combination of the aggregation mechanism with the Maxwell and Bruggeman models.

The single phase approach is simpler and requires less computational time, which assumes that the fluid phase and particles are in thermal equilibrium and move with the same velocity. But using appropriate expressions which calculate the properties of single phase nanofluid are beneficial and notable. However, the single phase approach has been used in many theoretical studies of convective heat transfer with nanofluids [9]. Hence, the properties of nanofluids are not completely specified, and there are not good expressions for predicting nanofluid mixture, generally the single phase numerical prediction are in good agreement with the experimental results.

Some researchers have considered the application of nanofluids in an annulus [10,11]. Abu-Nada [10] has studied single phase Al_2O_3–water nanofluid flow in an annulus. Different viscosity and thermal conductivity models are used to evaluate heat transfer enhancement in the annulus by his work. Izadi et al. [11] have also investigated laminar forced convection of a nanofluid consisting of Al_2O_3 and water numerically in a two dimensional annulus with single phase approach. The tubes of elliptic cross section have drawn particular attention since they were found to create less resistance to the cooling fluid which results in less pumping power [12]. Velusamy and Garg [13] have studied mixed and forced convection fluid flow in ducts with elliptic and circular cross sections. They found that irrespective of the value of the Rayleigh number, the ratio of friction factor during mixed convection to the corresponding value during forced convection is low in elliptical ducts compared to that in a circular duct as well as the ratio of Nusselt number to friction factor is higher for elliptic ducts compared to that for a circular duct. Despite the fact that these secondary flow in elliptical ducts is very small compared to the stream wise bulk flow, secondary motions play a significant role by cross-stream transferring momentum, heat and mass. On the other hand, the main advantage of using elliptic ducts than circular ducts is the increase of heat transfer coefficient [14]. Hence, heat transfer enhancement in these devices is essential, nanofluids usage can be play effective roles to increase heat transfer coefficient.

It is obvious from the above literature review that the heat transfer augmentation of laminar mixed convection flow using nanofluids in an elliptic annulus with constant heat flux seems not to have been investigated in the past, and this has motivated the current work. In addition, most of the previous research on elliptic annulus involved conventional fluids (not nanofluids) and there is a very little work reported in the open literature that involved nanofluids in an elliptic annulus. However, there is no previous research involved the usage of nanofluid in an elliptic annulus. The present study examines 3D laminar mixed convective heat transfer in an elliptic annulus with uniform heat flux by using different types of nanofluids, different nanoparticle volume fractions, and different nanoparticle diameters are dispersed in different base fluids (water, glycerine, engine oil and ethylene glycol). This investigation covers Reynolds number in the range of 200 to 1000 and particle diameters range from 20 to 80 nm. Different types of nanofluids and different volume fractions ranged from 0% to 4%. Results of interests such as Nusselt number, velocity profile and temperature contours for laminar mixed convection heat transfer in an elliptic annulus are reported to illustrate the effect of nanofluids on these parameters.

2. Mathematical modeling

2.1. Physical model

The physical model of the test section mainly consists of two concentric horizontal cylinders are used to form an annular space ranging from an elliptical tube placed at the center of a circular cylinder. The outer cylinder was made from