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Turbulent heat transfer to separation nanofluid flow in annular concentric pipe

Hussein Togun [a], [*], S.N. Kazi [b], A. Badarudin [b]

[a] Head of Biomedical Engineering Department, University of Thi-Qar, 64001 Nassiriya, Iraq
[b] Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

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ABSTRACT

Turbulent heat transfer to separation nanofluid flow in annular concentric pipe were studied numerically and experimentally. In the numerical study, finite volume method with standard k-ε turbulence model in three dimensional domains was selected. Three different types of water based (Al_2O_3, CuO, TiO_2) nanofluids were employed in this simulation. The adopted boundary conditions were, expansion ratio (ER = 1.25, 1.67, and 2), Reynolds number ranging from 20,000 to 50,000, water based nanofluids used Al_2O_3, CuO, TiO_2 with volume fractions varied between 0 and 2% at different heat fluxes, varied from 4000 W/m^2 to 16,000 W/m^2. For experimental study, Al_2O_3 water based nanofluid was used to validate the numerical results. The results show that the volume fraction of nanofluid and Reynolds number significantly affect the surface heat transfer coefficient; an increase in surface heat transfer coefficient was noted when both volume fraction of nanofluids and Reynolds number were increased for all the cases. The improvement of heat transfer was about 36.6% for pure water at the expansion ratio of 2 compared to heat transfer obtained in a straight pipe. Augmentation of heat transfer could be achieved by using nanofluid at expansion ratio 2 where the total improvements were about 45.2% (TiO_2), 47.3%(CuO), and 49%(Al_2O_3). Also the increment in the pressure drop was about 42% for pure water at expansion ratio 2 compared with straight pipe whereas by using nanofluid they were 62.6% (TiO_2), 65.4% (CuO) and 57.6% (Al_2O_3). Good agreements were observed between numerical and experimental results all the way.

1. Introduction

Heat transfer and fluid flow through the annular concentric pipe are commonly used in power plants, chemical plants, nuclear reactors, evaporators, condensers, heat exchangers etc. Therefore, there are many experimental and numerical studies adopted analysis of temperature distributions, pressure drop, and velocity profile in annular passages. For high performance of cooling system the researcher studied effect of reconfiguration of geometry on efficiency of heat transfer devices such as addition of ribs or swirl generators in channel, expansion or contraction in passage, forward and backward-facing step passages etc. The separation of fluid flow in annular channel occurred due to the change in pressure gradient that caused by increase or decrease of cross sectional area of the annular channel. Thus the sudden expansion with one side or both sides of the annular pipes are representing some of the applications where the separation flow is seen. The separation region of the flow is accompanied by eddy that affects the heat transfer performance, as observed in several experimental and numerical studies by researchers [1–11]. Many methods are applied to improve the situation, among them, use of efficient materials, adjusting process parameters, modifications of design etc. are notable. Now researchers are more involved in exploration of better heat exchanging liquid where nanofluids are getting importance as heat exchanging liquid against conventional liquid. The numerical study of laminar nanofluid flow in sudden expansion is very limited and appears in the publications of Santosh Christopher et al., [12] where they performed numerical study on laminar Al_2O_3, Ag, Cu, SiO_2, and CuO nanofluid flow in sudden expansion. They used same method [13] for analysis of sudden expansion flow and backward facing flow with Reynolds number range from 30 to 150 and nanoparticles volume fractions of suspensions 0.1, 0.2, 0.5. They observed the decrease in reattachment length about1.3% as compared with others [14].

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* Corresponding author.
E-mail address: htokan_2004@yahoo.com (H. Togun).

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Nomenclature

Dh	Hydraulic diameter (m)
h	Heat transfer coefficient (W/m^2 K)
I	Heater current (AMP)
K	Thermal conductivity (W/m K)
L	Length of the test section (mm)
Qc	Convection heat transfer (W)
Qt	Total heat supplied (W)
Re	Reynolds number $\left(Re = \frac{UD_h}{v}\right)$
$(r_o)_{pipe}$	Outer radius of the outer pipe (m)
$(r_o)_{fiber}$	Outer radius of the insulation (m)
Tsx	Local surface temperature (K)
Tb	Bulk temperature (K)
V	Voltage (volt)

Abu-Nada, [14] can be considering as a pioneer in numerical study of heat transfer to nanofluid over backward facing step where Cu, Ag, Al_2O_3,CuO, and TiO_2 with volume frictions between 0.05 and 0.2 and range of Reynolds number from 200 to 600 were considered. The increase in Nusselt number at the top and at the bottom of the backward facing step was observed. Also the investigations found high thermal conductivity of nanoparticles as outside of the recirculation zones. Later, Kherbeet et al., [15] presented a numerical investigation of heat transfer and laminar nanofluid flow over a micro-scale backward-facing step. An increasing Reynolds number and volume fraction seemed to lead an increasing Nusselt number; the highest Nusselt number value was obtained with SiO_2 in comparison with other types.

Additional investigations concerning nanofluid flow over a backward-facing step for the laminar range [16–23]. Kherbeet et al. [24] conducted experimental study of laminar nanofluid flow over the microscale backward-facing step (MBFS) and forward-facing step (MFFS). The results showed that the highest Nusselt number noted with use MFFS in compared to the MBFS, which is approximately twice that of MBFS.

Also the influences of magnetic field on nanofluid and nano boundary-layer flows over stretching surfaces are solved analytically by applying a newly developed method [25–27].

Sano Masatoshi et al. [28] presented experimental results of the turbulent channel flow over a backward-facing step by using suction through a slit at the bottom corner of the step and the direction of the suction was perpendicular and horizontal to the main flow. They measured local heat transfer coefficient and wall static pressure behind the backward-facing step and the results indicated, the enhancement of the heat transfer coefficient in the recirculating region by suction and reduction of the pressure drop. They also observed the improvement of the heat transfer coefficient with the increase in turbulent energy.

Duangthongsuk & Wongwises [29] had conducted the experimental studies on performance of heat transfer and pressure drop of TiO_2 nanofluid flow in horizontal double pipe under turbulent flow. Their results showed that the heat transfer coefficient was about 26% at vol. con. 1% while less than 14% at vol. con. 2%. due to their opinion that at increase of volume fraction of nanoparticle will leads combined tighter and then created bigger size which caused decrease the performance of heat transfer. While Farajollahi et al. [30] conducted experimental study on heat transfer to turbulent ɣ-Al_2O_3/water and TiO_2/water flow through the shell and heat exchangers. They studied the effect of volume concentration, Peclet number and particle type on heat transfer, where the performance of heat transfer for two nanofluids shows that at a certain Peclet number the heat transfer characteristics of TiO_2/water nanofluid at its optimum nanoparticle concentration were higher in comparison to that of ɣ-Al_2O_3/water nanofluid.

From the literature survey, the study of turbulent nanofluid flow in annular pipe with sudden expansion has not been investigated as yet experimentally and numerically. Therefore in the present paper flow and heat transfer of Al_2O_3, CuO and TiO_2 water based nanofluids in an annular pipe with sudden expansion under turbulent flow regime were investigated.

2. Experimental step up

2.1. Design and construction

Schematic diagram of the experimental set up is shown in Fig. 1 while the photograph of the set-up is presented in Fig. 2. The facility mainly includes a jacketed liquid tank which has the capacity of 150 L, stirrer motor (Branco Model BA 6324) with speed controller to make a homogenously dispersed solution, the chiller (Model-NWS-2AC) which is connected with the tank for adjusting the temperature of the liquid, a bypass pipe having diameter of 3 cm and the length of piping 100 cm is connected to the top part of the tank, stainless steel centrifugal liquid pump (Three Phase, 3000 RPM, 415V 3HP TO 20 HP, LIQUID Temperature 15C to +90 C) which delivers the liquid to the test section, invertor to regulate the motor speed and run the centrifugal liquid pump and maintain different flow rates as used in this experiment, magnetic flow meter (Burkert S030) with digital display (Burkert types 8202-8222) mounted at the entrance pipe to measure the fully developed liquid velocity at 15D from the inlet region, entrance pipe section has length of 150 cm and has variable inner diameter ($d = 10, 8, 6, 5$ cm) to create the sudden expansion in the passage which is connected to the test pipe by Teflon flange to avoid the conduction losses, the test section has inner diameter 10 cm and length of 100 cm and the solid inner pipe has outer diameter of 25 mm and length of 270 cm which extend along the passage from the entrance section up to the end of the test section mounted at the center of the passage to develop the annular passage, a bend pipe of inner diameter 10 cm and length 30 cm is connected to the test section to channelize the discharge to the storage tank. Two thermocouples of PT100Tc located at the inlet and outlet of the passage to measure the inlet and outlet temperatures. 32 Groves on straight line are made on the surface of the test section for 32 thermowalls to hold 32 thermocouples type K on the surface of the test pipe to measure the surface temperature. Two thermocouples have been installed at the inlet and outlet of the test section to measure the inlet and outlet temperatures of the nanofluids. Flexible ceramic pad heater has been used to heat the pipe and obtain uniform heat flux. A differential pressure transmitter Model (Model EJA110E-DMS4J-912DB/D3) has been used to measure the pressure drop of the flowing fluid. Two signal tubes from the inlet and the outlet of the test section were connected to the pressure transducer which provides digital display and transmits signal to the data logger (Mounting Bracket: 304 SST2-INCH PIPE). To transfer and save the experimental data, all the thermocouples and other devices connected to the data logger (YOKOGAWA, MODEL MW100-E-1Q) and then continuous monitoring and recording of the data are conducted by a personal computer. The specifications and the accuracy of the measuring equipment used in the present experimental setup are presented in Table 1:

2.2. Nanofluid preparation and its properties

In the present work, a two-step method is used to produce Al_2O_3—water nanofluids with volume fractions from 0.5% to 2%.