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Heat transfer augmentation for annular flow due to rotation of inner finned pipe

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ABSTRACT

The present study aims to discuss the thermal characteristics for the flow through the annulus with inner finned pipe under stationary and rotating conditions. The experiments are carried out using one unfinned pipe and six finned pipes at rotating speeds of 0, 200, 250, 300, 350 and 400 rpm. The finned pipes have straight fins of different heights ranging from 10 to 30 mm for 2 and 4 fins. The axial Reynolds number ranged from 3×10^4 to 9×10^4, while the Taylor number ranged from 3×10^6 to 11×10^6.

The results showed an increase of the heat transfer coefficient over six times for the height of 30 mm and rotational speeds of 400 rpm at Re = 6×10^4, compared to the plain stationary pipe case. The rotational speed revealed no effect on the efficiency and effectiveness of the fin. Correlation for Nusselt number and the overall efficiency were obtained.

1. Introduction

A concentric cylindrical annulus heat exchanger at which either outer or inner cylinder is stationary or rotating is widely used in various mechanical systems such as annular heat exchangers, gas turbines, jet engines, chemical industry, petroleum processing, gas-cooled nuclear reactors, mechanical mixers, chemical mixers and drilling in the petroleum industry. Therefore, the forced convection heat transfer through the annulus is interesting for many industrial process developers. So many theoretical and experimental investigations initiated from both hydrodynamic and thermal point of views were conducted. Many active, passive and compound heat transfer enhancement techniques for the annular flow are discussed by Léal et al. [1]. Passive techniques need no direct contribution of external power [2], while active techniques require external power input such as surface and fluid vibrators, mechanical aids, electrostatics suppliers and jet impingements [3].

Most passive techniques affect the fluid bulk motion causing swirls and disturbances in the actual boundary layer. This operation enhances the heat transfer coefficient as it contributes to increase both the effective surface area and resident time of the flow. This method includes the use of fins with different geometries [4–7], surface finishing [8], and fluid additives that give a reasonable change to the physical properties of working fluid such as nanofluids [9,10].

The instantaneous use of more than one technique in the annular channel enhanced the heat transfer to higher than was found by use of either technique individually. Various composite techniques used to enhance heat transfer in annular channel could be found in literature [4,11–16]. Many studies have been performed for heat transfer enhancement on the annular space between two pipes.

Omkar et al. [15] evaluated the heat transfer characteristics data for the helical fins installed on the rotating inner pipe of double pipe heat exchangers. The laminar flow results showed that the Nusselt number is found to increase up to 64% at 100 rpm compared to the stationary inner pipe with helical fins. A-Ziyan et al. [5] evaluated the turbulent flow results [$Re = 8 \times 10^4$–1.8×10^5]; he reported that the Nusselt number enhanced by a factor of 7.5 at 400 rpm and the ratio of heat transfer to pumping power increased by a factor of 7.6, compared to the plain stationary pipe case at $Re = 1.5 \times 10^5$. Zhang et al. [7] investigated experimentally the delta-wing type of vortex generator on the heat transfer characteristics of the helical fins. Heat transfer characteristics were enhanced by 87–115% more than found in the heat exchanger with a smooth inner pipe.

Fénot et al. [17] utilized a slotted rotating inner cylinder to enhance the convective heat transfer in the entrance section of an annular channel. Experiments were conducted for the Taylor number from 0.1×10^5 to 0.4×10^7 to reproduce the conditions for an air gap of an open 4-pole synchronous motor and different correlations were presented. Ranjith et al. [18] carried out an experiment to measure the heat transfer coefficients and pressure drop for the twisted tape insert in a double pipe heat exchanger. The experimental results revealed that

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Nomenclature

A	Area, m^2
b	Annular gab width, m
C_p	Specific heat capacity, kJ/kgK
d	Outer diameter of the inner rotating pipe, m
D	Inner diameter of the outer pipe, m
D_h	Hydraulic diameter = (D - d), m
h	Convection heat transfer coefficient, w/m^2 K
H	Fin height, m
k	Thermal conductivity of air, W/mK
l_c	Fin characteristic length, m
L	Effective length of test section, m
$\dot{m}$	Mass flow rate, kg/s
n	Number of fins,
N	Rotational speed of inner pipe, rpm
Q	Rate of heat transfer, W
t	Fin thickness, m
T	Temperature, °C
V	Velocity, m/s

Greek letter

β	Surface area ratio = A_f/A_t,
ε_o	Overall effectiveness,
η	Efficiency
ν	Kinematic viscosity of air, m^2 /s
ρ	Density, kg/m^3
ω	Angular velocity of rotating inner pipe, rad/s

Subscript

a	Air
c	Cold
cm	Average bulk
f	Fin
in	Inlet
o	Overall
out	Outlet
s	Surface
t	Total

Dimensionless groups

Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
Ta	Taylor number

both the heat transfer coefficient and the pressure drop in the pipe with twisted tape were higher than those in the plain pipe.

El-Maghlany et al. [19] studied the fluid flow and heat transfer characteristics of a double-pipe heat exchanger with a rotating inner pipe. The experiments covered a range for rotational speed from 0 to 1000 rpm. The effectiveness and *NTU* number were obtained for parallel flow and counter flow arrangements. They found that rotation speed increases *NTU* and effectiveness values.

The foregoing literature reviews showed there have been no studies focused on the heat transfer performance of an annular space of rotating inner pipe with straight fins. The performance of the rotating fins has little interest for the researchers. The objective of this work is to assess the effects of using a compound heat transfer enhancement technique for the flow through the annulus by using the straight fins fixed on a rotated inner pipe. Both the efficiency and the effectiveness of the rotated fins are to be investigated.

2. Testing system and data reduction

2.1. Description of experimental setup

Fig. 1 shows the schematic diagram of the experimental apparatus designed for measuring the thermal and hydrodynamic characteristics for the flow through the annular space whereas the schematic diagram of the inner finned pipe is displayed in Fig. 2. The apparatus is a double pipe, counter flow, heat exchanger with rotating inner finned pipe; it is equipped with different operating configurations in order to alter different parameters such as rotating speed for the inner pipe, axial flow speed, number of fins, and fins height.

The system has two air paths, namely hot path (inside pipe) and cold path (annular passage), as shown in Fig. 1. The annular passage is 1600 mm in length, 150 mm outer diameter and 50 mm inner diameter. The outer pipe is made from polyvinyl chloride whereas the inner (rotating) pipe is made from brass. The outer pipe is covered with glass

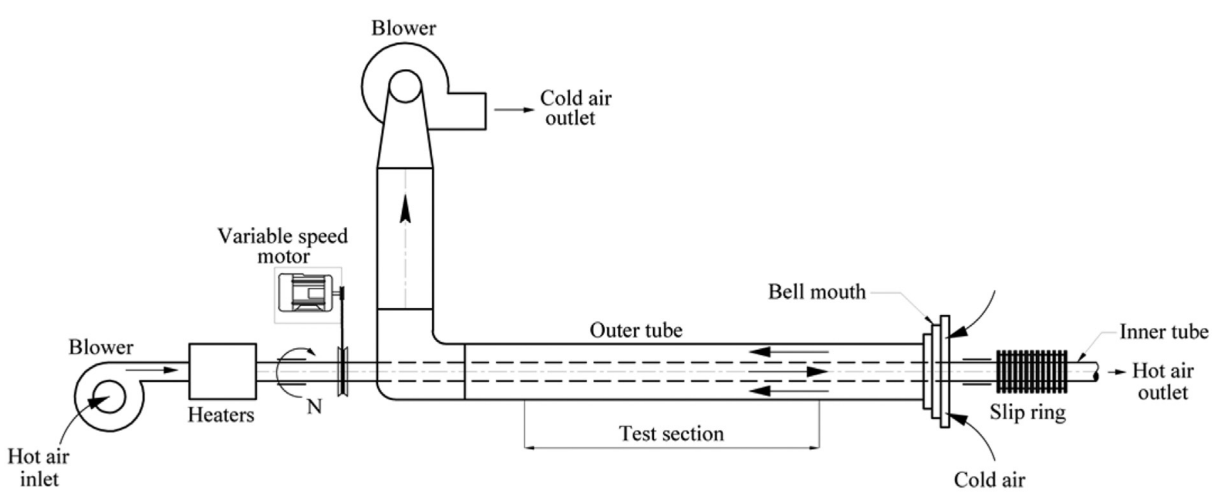

Fig. 1. Schematics of the experimental apparatus.