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The optimization of radial rotating convective pipes

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A R T I C L E I N F O

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A B S T R A C T

This paper presents the optimization of geometrical parameters of the heat exchanger with radial rotating pipes minimizing entropy generated and maximizing effectiveness. Three radial rotating models with different geometrical profiles and common model for all three models is complex rotating model is used in this investigation. Complex rotating model is the general model from which the change in geometric parameters such special cases can get each of the three tested models. Mathematical model generated total entropy and effectiveness of all three models, as well as the complex model is established. Complex model is subjected to optimization of geometrical parameters of rotating pipes generated by minimizing entropy and maximizing effectiveness. Finally, there was obtained the optimal geometric shape of the heat exchanger with radial rotating pipes.

1. Introduction

This work has been analyzed optimization of complex radial rotating convective pipes based on minimum generation entropy and maximum effectiveness. The complex radial rotating pipe consists of several sections various geometrical profiles and constant circular cross-section. Through the complex rotating pipes flowing hotter fluid (a primary fluid, i.e. water), and outside of the complex rotating pipes is ambient air (secondary fluid), thereby creating the exchange of heat between these two fluids. By establishing a rotation of complex pipe secondary fluid flows around its outside surface. Total length of complex pipe is made up of multiple sections of different shape and position in relation to the common axis of rotation. For each section of the pipe is characteristic appropriate entropy and effectiveness, whose values depend on the geometric profile of this section and its position in relation to the axis of rotation. In this heat exchanger affects the hydraulic and thermal irreversibility on the primary fluid and secondary fluid. Therefore, the total entropy generated radially rotating pipe consists of the total entropy of hotter and colder fluid, taking into account all the hydraulic and thermal irreversibility of both fluids. In this paper other than a mathematical model of the generated entropy and effectiveness of complex radial rotary pipes, have been made experimental investigations and indirect determination of entropy generated and effectiveness. The experiments were implemented on three extra radially rotating models, as well as the optimized complex model. In this paper other than a mathematical model of the generated entropy and effectiveness of complex radial rotating pipes, were carried out experimental research or determine the entropy generated and effectiveness. The experiments were implemented on three additional radial rotating models and the optimized complex radial rotating model. As regards the radial rotation of pipe, the relation between the generated entropy and effectiveness, there are many studies and analyzes, below some of them. Huajun Chen and Ben Zhao Zhang [1] have studied the fluid flow and mixed convection heat transfer in rotating curved pipe. Yasuo Mori and Wataru Nakayama [2] have analyzed forced convective heat transfer in straight pipe rotating around a parallel axis. Velocity of secondary fluid over each section radially rotating pipe the function of the number of rotations pipe and pipe sections in position relation to the axis rotation of the pipe. Velocity of secondary fluid around each section pipe directly influence the intensity of the hydraulic losses and heat transfer from the observed section pipe to the environment. In this way, hydraulic and thermal effects of each section of the rotating pipe causing the appearance hydraulic and thermal irreversibility on the side of secondary fluid. At the same time, within the radial rotating pipe flow and the primary fluid passes through all sections of the rotating pipe. A primary pressure drop of fluid within the rotating pipe in the function of water velocity, the local hydraulic resistance of pipe induced by

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Nomenclature

n	number of revolutions, 1/min
T	temperature, K
t	temperature, °C
p	pressure, Pa
$\dot{m}$	mass flow, kg/s
c	specific heat, J/kg K
A	heat exchange area, m^2
$\dot{S}_{gen}$	entropy generation rate, W/K
ΔT	gradient of temperature, K
F_D	drag force, N
C_D	drag coefficient
P_r	Prandtl number
d	inner pipe diameter, m
Re	Reynolds number
L	length of pipe, m
l	elementary length of pipe, m
R_{sf}	gas constant of secondary fluid, J/kg K
c_{sf}	specific heat of secondary fluid, J/kg K
$\dot{V}$	volume flow, m^3/s
w	velocity, m/s
k	overall heat transfer coefficient, W/m K

Greek symbols

ω	angle speed, 1/s
ρ	density, kg/m^3
α	convective heat transfer coefficient, W/m^2 K
ν	kinematical viscosity, m^2/s
β	angle, rad
ϕ	angle, rad
λ	thermal conductivity, W/m K
Γ	dimensionless function
Π	matrix
ε	effectiveness

Subscripts

pf	primary fluid
sf	secondary fluid
ΔT	thermal effect
Δp	hydraulic effect
avr	average value
$in-out$	inlet–outlet of pipe
w	wall
$AB,BC,CD\ldots$	pipe section
min	minimum
max	maximum
gen	generation

friction of the pipe wall and a common effect caused by the influence of the Coriolis force, centrifugal force and buoyancy force on the primary fluid. Yasuo Mori and Wataru Nakayama [3] gave a general overview of secondary flows and enhanced heat transfer in rotating pipes and ducts. Since these forces depend on the position of pipe sections to the axis of rotation and speed it follows that the primary fluid pressure drop is different for different sections of pipe. Also, changing the heat flux between the primary fluid and the inner wall of the pipe in the functions of that velocity and temperature of the primary fluid, and the common effects of centrifugal and Coriolis forces and buoyancy force forces of the primary fluid. Therefore, hydraulic and thermal effects on the primary fluid within each section pipe causing hydraulic and thermal irreversibility between the primary fluid – inner pipe wall. Adrian Bejan [4] have studied and found many exact solutions for the entropy generation of fully developed internal flow in ducts and around the ducts. M Basha, M Al-Qahtani and B S Yilbas [5] studied entropy generation in rotating rectangular channel on three–dimensional turbulent flow. According to the above, the total generated entropy of any part of the pipe consists of entropy generated by the primary and secondary fluid, induced by the hydraulic and thermal irreversibility. Finally, the total entropy generated radial rotating pipe becomes a function of geometric parameters of pipes, pipe position and shape of individual section pipe and pipe rotation velocity rate. Al-Qahtani et al. [6] studied numerical two-pass rotating normal and inclined channels. Alic F [7] studied total entropy generated radial rotating pipe in the function of pipe rotation velocity rate around the common axis of rotation. Because the rotating pipe consists of several sections of various lengths and positions, to the total generated entropy radial rotating pipe is the sum of all partial entropy generated of primary and the secondary fluid from each section pipe. Alic F [8] analyzed the thermal-hydraulic effects of pitched and flat impeller blades in a mixing vessel for different numbers of revolutions and various power levels of heaters in the blades. Alic F [9] studied the dimensionless analysis of generating irreversibility of vessels is done simultaneously mixing and heating fluid. In the first case the impeller within the mixing vessel is the heating body, and in the second case of heating bodies fixed ring and the impeller inside the vessel provides only mixing fluid. Shah and Skiepko [10] showed that heat exchanger effectiveness can be at maximum, having an intermediate value or minimum at the maximum irreversibility operating point. Bejan [11] introduced the concept of irreversibility due to fluid flow friction and temperature difference in heat transfer process based on the second law of the thermodynamics. Z.Y.Guo et al. [12] have analyzed relationships between the heat exchanger effectiveness and thermal resistance which do not depend on its flow arrangement. Cheng et al. [13] analyzed the entropy generation of the heat exchanger networks with two streams and heat exchangers and found that entropy generation does not decrease monotonically with heat transfer and effectiveness increased. Cheng et al. [14] studied relationships for the heat transfer performance of two-stream heat exchanges and two-stream heat exchanger networks with the entropy generation and entrance dissipation. Based on minimum entropy generation, Nag et al. [15], Sekulic et al. [16], Sara et al. [17] and Ko [18] investigated and analyzed the influences of thermal, geometrical and flow boundary conditions on entropy generation and optimized them in order to find the most efficient heat transfer performance. In the interest of equal treatment of the generated entropy and effectiveness in this paper presented two-criteria optimization of radial rotating convective pipes. In this regard was introduced dimensionless function which is minimized and the final result obtained optimal geometric parameters radial rotating convective pipes. The essence of this two-criteria optimization is getting a minimum of a dimensionless function that represents the best combination of minimum value generated entropy and maximum effectiveness.

In the context of the above, the two-criteria optimization can represent improvement optimization of heat exchangers with equal treatment of entropy and effectiveness, which at one-criteria optimization is not the case.