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Heat transfer and exergy loss in conical spring turbulators

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ABSTRACT

It would be misleading to consider only the construction costs of heat exchangers in their design because high service costs during their service life may also greatly increase total costs. Therefore energy saving aspects are very important in the design, construction and operation of the heat exchangers. For this reason, various active or passive methods have been sought to save energy by increasing the heat transfer coefficients in the cold and warm fluid sides in the heat exchangers. Conical spring turbulators (CST) are devised in this study. Performances of heat transfer and pressure drop in a pipe with the CST are experimentally examined for the CSTs' angle (θ) of 30°, 45° and 60° in Reynolds number (Re) range of 10,000–34,000. Heat transfer, pressure loss and exergy analysis were made for the conditions with and without turbulators and compared to each other. Some empirical correlations expressing the results were also derived and discussed.

1. Introduction

Techniques for increasing the efficiency of heat exchangers can be classified as active or passive methods. In the active methods, heat transfer can be improved by giving extra energy to the fluid or the equipment. In the passive methods, however, the improvement can be acquired without giving additional energy. Some examples of active methods include: the use of mechanical auxiliary elements, rotating the surface, mixing fluids with mechanical accessories and constituting electrostatic areas in the flow area. Passive methods comprise covering or changing the heat transfer surface and forming some projecting parts of the rough surfaces. In order to increase the heat transfer rates, various surface area extensions are used in almost all heat exchangers. Because of the difficulties in manufacturing finned surfaces, constant director fins and increasing heat exchanger dimensions and the difficulties in their maintenance, today, more consideration is given to attachable turbulators to use in heat transfer enhancement. Improvements in heat exchanger performance can be realized by decreasing the temperature difference between the cold and hot fluids in any given operating conditions. Increasing the heat transfer coefficient is one of the preferable ways for decreasing the temperature difference. On the other hand, heat transfer coefficients can be increased with one or several of the active or passive methods. The applications of swirling flow, or its effects, to the fluid for increasing heat transfer can be divided into two groups. One is the so-called non-decaying swirling flow type in which turbulators located through or in certain distances in the flow area continuously generates swirling flow.

In the second type, which is called decaying flow, the swirling effect to the fluid is only given in the inlet flow area, and then, the fluid flows freely in the following area. Giving the swirl effect continuously will naturally result in an increase in heat transfer as well as an increase in pressure loss. In the case of continuous turbulators, the heat transfer and pressure losses should be carefully analyzed and optimized for the energy economy aspects because they bring additional pumping power and construction costs, all increasing the total cost of a heat exchanger.

Accordingly, detailed investigation of the effect of twisted tape and wire coil turbulators on heat transfer augmentation has received considerable attention [1–3]. This passive heat transfer enhancement strategy has been used for various types of industrial applications such as shell-and-tube type heat exchangers, electronic cooling devices, thermal regenerators, internal cooling systems of gas turbine blades, and labyrinth seals for turbomachines. Periodically positioned baffles in baffled channels and periodic turns in serpentine channels periodically interrupt hydrodynamic and thermal boundary layers [4]. The effect of conical-ring turbulators on the turbulent heat transfer, pressure drop and flow-induced vibrations is experimentally investigated. Their experiments are analyzed and presented in terms of the thermal performances of the heat-transfer promoters with respect to their heat-transfer enhancement efficiencies for a constant pumping power [5,6]. An experimental study on the heat transfer and friction loss characteristics of a surface with cylindrical fins in a rectangular cross-section channel with large diameter fins and

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Nomenclature

A	heat transfer area of heat exchanger (m^2)
C	heat capacity rate ($=C_{min}/C_{max}$) (dimensionless)
C_{max}	maximum capacity (W/K)
C_{min}	minimum capacity (W/K)
C_p	specific heat at constant pressure (J/kg K)
d	diameter of inner pipe (m)
D	diameter of outer pipe (m)
D_H	hydraulic diameter for pressure drop ($=4A\text{co}/P_w$) (m)
e	dimensionless exergy loss
Ex	exergy rate (W)
f	friction coefficient(dimensionless)
g	acceleration of gravity (m/s^2)
H	average heat transfer coefficient (W/m^2 K)
h	specific enthalpy (J/kg)
k	thermal conductivity of fluid (W/m K)
L_{total}	total length of four turbulators a line (m)
L_{tur}	length of turbulator (m)
NTU	number of heat transfer unit (dimensionless)
Nu	average Nusselt number (=Hd/k)(dimensionless)
Pr	Prandtl number ($=\mu C_p/k = \alpha/\upsilon$) (dimensionless)
P_w	the total wetted perimeter of the annulus for pressure drop (m)
Q	heat transfer rate (W)
Re	Reynolds number (dimensionless)
s	specific entropy (J/kg K)
T	temperature (K)
ΔT_c	logarithmic mean temperature difference between constant temperature of inner pipe wall and air temperature (K)
U	overall heat transfer coefficient (W/m^2 K)
z	potential difference (m)
θ	angle of turbulators (°)
ε	effectiveness (dimensionless)
$\dot{m}$	mass flow rate (kg/s)
υ	kinematic viscosity of fluid (m^2/s)
α	thermal diffusivity of fluid (m^2/s)
μ	dynamic viscosity of fluid (Pa s)
η	second law efficiency of heat exchanger (dimensionless)

Subscripts

c	cold fluid
CH	chemical
e	environmental condition
h	hot fluid
i	inlet condition or inner
KN	kinetic
loss	loss
max	maximum
min	minimum
o	outlet condition or outer
p	pipe
PH	physical
PT	potential
w	wall

different channel geometries is carried out by Bilen et al. [7]. Also, the pipe flow with various grooves (circular, trapezoidal and rectangular) at constant wall heat flux condition, and hollow rectangular fins surface is studied experimentally [8,9]. Co-axis free rotating propeller type turbulators are devised by Kurtbaş et al. [10,11]. The effect of the turbulators on heat transfer and exergy loss is investigated experimentally. Cakmak and Yildiz [12] performed a similar study and investigated the influence of the injectors with swirling flow generating on the heat transfer in the concentric heat exchanger. Many numerical studies on swirl generators and fin- and tube heat exchangers are also performed and discussed [13–17].

Manufacturers of flue and smoke tube hot water boilers have employed several types of turbulators in flue and smoke tube boilers. Iron sheet flexed in a spring shape, which is known as the simplest turbulator, has been recently used for replacing finned surfaces. The turbulators located in the flue and smoke tubes improve boiler efficiency, but since they also cause considerable pressure losses, a decrease in chimney draught may occur, and therefore, the system may sometimes need a fan.

The goal of present work is to investigate the use of conical spring turbulators with different angle ($\theta = 30°$, 45°, 60°) ratios from both the heat transfer and friction coefficient points of view. Turbulators were placed in three different arrangements (converging conical ring (CR), diverging conical ring (DR), converging–diverging conical ring (CDR)).Thus the present also investigate the effect of conical spring turbulators arrangement (CR,DR and CDR arrays) on performance of heat transfer. In addition heat transfer, pressure loss and exergy analysis were made for the conditions with and without turbulators and compared to each other.

In this study the effects of disordering the flow area of air by placing conical type turbulators of different dimensions on the improvements in heat transfer with a passive method in a classical coaxial double pipe heat exchanger were studied. Four turbulators were placed in the inner pipe at 50 mm equal distances. So, each turbulator is supposed to disrupt the hydrodynamic boundary layer continuously, and therefore, a non-decaying swirl flow is generated inside the tube.

2. Experimental setup

The experimental set up is given Fig. 1. The system is a classical type double pipe heat exchanger. The outer surface of inner tube was maintained at a constant temperature by continuous contact with saturated water vapor introduced and filled into the annular space between the inner and outer tube and discharged by a channel, like a teapot. Experiments were performed under constant wall temperature boundary condition.

A constant temperature bath (annular space) was constructed in 770 mm length and 100 mm inner diameter. Inner pipe was constructed in 770 mm length and 60 mm inner diameter, by 1 mm thickness copper. Constant wall temperature was accomplished by sending saturated steam at atmospheric pressure to the test section, where this saturated steam was condensed on the surface of inner pipe. By this method, 100 ± 1 °C constant wall temperature boundary condition was sustained. This boundary condition was continuously checked by measuring surface temperature at 10 different locations on the test pipe (inner pipe). These temperature measurements were performed by using copper-constant thermocouples attached to pipes with 70 mm intervals. These thermocouples were placed in holes drilled from the rear face of the inner pipe (thin-wall approach). All thermocouples were made from 0.127 mm diameter Teflon-coated copper and constantan wire that had been specifically calibrated for the present experiments. In addition, the equipment used in experiments includes a radial fan, a manometer for pressure difference measurements between