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Effectiveness-NTU analyses in a double tube heat exchanger equipped with wavy strip considering various angles

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ABSTRACT

In the present study, effectiveness-NTU analyses in a double tube heat exchanger equipped with wavy strip considering various angles were experimentally studied. Moreover, variation of the effectiveness with hot water Reynolds numbers for different cold water flow rates were presented. These turbulators with different angles of 45°, 60°, 90°, 120° and 150° were made of galvanized plates with thickness of 1 mm and were installed in the inner tube of heat exchanger. The experiments were carried out at Reynolds numbers of 3000–13,500 at turbulent flow regime. Throughout the experiments, hot and cold water flowed through the inner pipe and the space between the pipes (annulus), respectively. It was tried to keep the inlet hot and cold water temperatures at constant values. Effectiveness-NTU analyses were made for the conditions with and without wavy strips including their different angles and compared to each other. Results showed the considerable effect of turbulators on effectiveness (ε) and number of heat transfer units (NTU) of double tube heat exchanger. In addition, some empirical correlations expressing the results were also developed based on curve fitting.

1. Introduction

A lot of studies have been done on the heat transfer enhancement and friction factor of heat exchangers in recent years. In addition, examining the effectiveness and NTU of heat exchangers has been an interesting topic for researchers [1–3]. Generally, methods to increase the heat transfer and effectiveness of heat exchangers are classified into three groups of active, passive and compound methods. In active methods such as using sound waves or magnetic fields [4], external power source is used to improve the heat transfer. To increase the heat transfer rate in passive approaches, external energy is no longer required. Some of the examples of passive methods include using different kind of turbulators. Compound methods are combinations of two or more of the active and passive methods such as simultaneous using of magnetic fields and Nanofluids [4]. All the mentioned methods can be used in different sectors of industries, for example cooling systems, power plants, food and dairy processes, nuclear and chemical reactors. Ibrahim [5] through some experiments studied the convective heat transfer characteristics in a flat tube with helical screw element with various twist ratios and spacer length inserts. Consequently reliable correlations for both friction factor and Nusslet number with *Re*, spacer length and twist ratio were provided. Their results demonstrated that Nusslet number increases with the increase of *Re* but it changes dramatically with spacer length and twist ratio. Sheikholeslami et al. [6] studied the effect of using typical and perforated discontinuous helical turbulators on heat transfer and friction factor of water to air heat exchanger. Experiments were carried out for various open area ratios and pitch ratios. Results show that Nusselt number reduces with the increase in open area ratio and pitch ratio while it augments with the increase in Reynolds number. Friction factor is a decreasing function of Reynolds number, open area ratio and pitch ratio. Raineri and Pagliarini [7] through some experiments studied the convective heat transfer and thermal performance behaviors in corrugated tubes at different pitch ratios. Obtained results indicated that The Nusselt number is practically independent of the corrugation shape. Fahed et al. [8] studied the effects of changes in twisted tape ratio on heat transfer coefficients of double tube heat exchangers. According to their results the heat transfer increases with the increase of the twist ratio. Naphon and Suchana [9] presented an experimental investigation of heat transfer and pressure drop in a concentric double tube heat exchanger equipped with twisted wires brush. Three different twisted wire brush densities (number of the

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Nomenclature

A	surface area of test tube, m^2
$C_{p,w}$	specific heat at constant pressure, $\frac{J}{kg\ K}$
C_{min}	minimum heat capacity, W/K
C_{max}	maximum heat capacity, W/K
C_r	heat capacity ratio (dimensionless)
NTU	number of heat transfer units (dimensionless)
U	overall heat transfer coefficient, $\frac{W}{m^2\ K}$
ΔT_{LMTD}	logarithmic mean temperature difference
Nu	Nusselt number
RMSD	root mean square deviation
D	smooth tube diameter, m
D_H	mean diameter, m
l	length of one wave, m
$\dot{m}$	mass flow rate, $\frac{kg}{s}$
q	heat transfer rate, W
Re	Reynolds number
T	water temperature, K
$\overline{U}$	mean velocity in tube, $\frac{m}{s}$
θ	wavy strip angle, °
$Y_{exp,i}$	experimental value
$Y_{pre,i}$	predicted value
W	total uncertainty in the measurement
X	independent variable
N	number of observations
RMSE	root mean square error analysis

Greek symbols

ε	effectiveness (dimensionless)
ρ	density, $\frac{kg}{m^3}$
μ	dynamic viscosity, $\frac{N\ s}{m^2}$
ΔT	temperature difference

Subscripts

ave	average
c	cold
h	hot
i	inner
o	outer
in	inlet
out	outlet
0	smooth
w	water
LMTD	logarithmic mean temperature difference

twisted wires per centimeter) were tested during their experiments. The heat transfer rate from the plain tube with 300 twisted wires brush inserts is higher than those of the plain tube with 200 and 100 twisted wire brush inserts. Durmus [10] investigated the effect of cut out conical turbulators on heat transfer, pressure drop and dimensionless exergy loss for the conditions with and without turbulators and compared the results to each other. In their experiments the outer surface of the inner pipe of the heat exchanger was heated with saturated water vapor, so outer surface temperature was kept constant. Continuously disrupting the hydrodynamic boundary layer is the purpose of using this kind of turbulators. Akpinar [11] studied the exergy loss in a double tube heat exchanger with helical spring inserts. Also NTU and effectiveness of heat exchanger with this kind of turbulators were studied. In their study the increase in friction factor was about 2.74 times compared to the smooth tube. The highest enhancement was seen to occur in counter flow mode of the exchanger with the helical wire having the pitch of 9 mm and the helical number of 137. The heat transfer rates in this heat exchanger increased up to 2.64 times with the help of this kind of turbulators. In further attempts, effectiveness of heat exchangers with swirl generator was studied by Akpinar and Bicer [12] which led to some significant results. All of the recent experimental studies show the significant effect of passive methods on heat transfer and effectiveness of heat exchangers.

By considering what was discussed so far, it can be concluded that lots of investigations have been done to study the effect of various geometrical configurations of turbulators on the heat transfer and friction factor of heat exchangers. However, to the author's best knowledge, this is the first attempt to investigate the effect of changing wavy strip angles on NTU and effectiveness of double tube heat exchanger. Further to this, the paper focuses on the experimental study on the ε-NTU analysis of the double tube heat exchanger with wavy strip considering various angles. In addition, the effect of cold water flow rate on the NTU and effectiveness of double tube heat exchanger were clarified in this study. The empirical correlations of ε and NTU are achieved based on the curve fitting.

2. Experiments

2.1. Experimental set-up and procedure

A schematic diagram of the experimental apparatus used in this investigation is shown in Fig. 1. The system includes two centrifugal pumps, two flowmeters, hot and cold water tanks, thermocouples and a data logger. The inner tube of heat exchanger was made of copper with inner and outer diameters of di = 26 mm and do = 29 mm, respectively, while for the outer tube, galvanized pipe with inner diameter of Di = 59 mm was employed. For the sake of minimizing the heat losses to surroundings a great insulation was done for the test section. Glass wool and foam are the insulation kind in this experimental set-up. Hot water was passed through the inner pipe, while cold water acting as a cooling medium was flowing through the space between the pipes. The inlet hot water temperature was adjusted in a way to reach the desired temperature (54 °C) by using two 2 kW heaters and subsequently hot water flowed into the inner tube of the heat exchanger using a 100 W centrifugal pump. Cold water flowed in the annulus by using another identical pump. Hot and cold water temperatures at inlet and outlet of the heat exchanger were measured by the k-type thermocouples. It was tried to keep the cold and hot water inlet temperatures at constant values. In order to compare the data at different Reynolds numbers, hot water flow rate was increased at specific steps of 1 l/min. Hot and cold water flow rates were controlled and measured by valves and rotameters, with range of 2–11 l/min, placed after the pumps. All measuring devices were calibrated before the tests. Moreover, all data were recorded at steady state by data acquisition system.

2.2. Wavy strips geometry

The geometrical configuration of the wavy strip inserts are shown in Fig. 2. The wavy strips were made of galvanized sheet with thickness of 1 mm. they were prepared at five different angles (θ) of 45°, 60°, 90°, 120° and 150° and were installed in the inner tube of heat exchanger.