International Journal of Thermal Sciences 122 (2017) 39–52

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Experimental investigation on the thermal performance of a double pipe heat exchanger with segmental perforated baffles

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A R T I C L E I N F O

Article history:
Received 12 July 2017
Received in revised form
9 August 2017
Accepted 11 August 2017

Keywords:
Perforated baffles
Heat exchanger
Passive technique
Heat transfer enhancement
Thermal performance
Friction
Experimental

A B S T R A C T

This work experimentally investigates the characteristics of convective heat transfer and pressure drop of water flow in the annulus-side of horizontal double pipe heat exchangers. Twelve heat exchangers of counter-flow configurations are constructed with/without Single Segmental Perforated Baffles (SSPBs), which are fabricated with different holes spacing, void, cut, pitch ratios and inclination angle. The experiments are performed for annulus-side Reynolds number from 1380 to 5700, and for Prandtl number from 5.82 to 7.86. The results revealed that increasing SSPBs holes spacing and void ratios and inclination angle and decreasing SSPBs cut and pitch ratios increase the annulus average Nusselt number ($\overline{Nu}_{an}$) as well as friction factor (f_{an}). The thermal performance index (*TPI*) is calculated to compare the thermal performance of perforated baffled double pipe heat exchangers with un-baffled one. It is observed that increasing SSPBs holes spacing ratio and inclination angle, and decreasing SSPBs void ratio, cut ratio and pitch ratio enhances the thermal performance index. Finally, correlations for $\overline{Nu}_{an}$ in addition to f_{an} for concentric tube heat exchangers with SSPBs as a function of the investigated parameters are obtained.

1. Introduction

Numerous applications involve heat transfer processes, whereas conversion, utilization, and recovery of the energy in every industrial, commercial, and domestic application involve a heat transfer process. In most of these applications, heat is transferred through heat exchangers as in the chemical, electrical, power, petroleum, air-conditioning, refrigeration, cryogenic, heat recovery, and manufacturing industries. Therefore, enhancing the thermal performance of heat exchange affects directly on energy, material and cost savings. Consequently, improving the heat exchange above that in the usual or standard practice can significantly improve the thermal efficiency in such applications as well as the economics of their design and operation [1].

Double pipe heat exchangers are the simplest devices in which heat is transported from the hot fluid to the cold fluid through a separating cylindrical wall. They are primarily adapted to high temperature and high-pressure applications due to their small diameters. They are cheap, but the amount of space they occupy is relatively high compared to the other types [2].

To achieve the desired heat transfer rate in the given design and size of the heat exchanger at an economic pumping power, numerous techniques have been proposed. These enhancement techniques can be categorized as active and passive techniques. Furthermore, any two or more of these techniques (passive and/or active) may be employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by only one technique itself. This simultaneous utilization is termed compound enhancement [3–6].

From the use and design point of view, active heat transfer enhancement techniques are more complex, as they require some external power to facilitate the desired flow modification and the associated improvement in the heat transfer rate. Thermal performance augmentation by this method can be attained by using mechanical aids, surface vibration, fluid vibration, electrostatic fields, injection, suction and jet impingement. While passive heat transfer enhancement techniques generally depend on the surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They provide higher heat transfer coefficients by disturbing or altering the existing flow behaviour except for extended surfaces. Passive techniques hold the advantage over the active techniques, as they do not need any direct input of external power. Heat transfer augmentation by this technique

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http://dx.doi.org/10.1016/j.ijthermalsci.2017.08.008
1290-0729/

can be achieved by using treated surfaces, rough surfaces, extended surfaces, displaced enhancement devices, swirl flow devices, surface tension devices, coiled tubes and use of additives [3–6].

Baffles are one of the passive enhancement techniques, which are utilized to improve the thermal performance of heat exchangers that are widely used in various industries: chemical, biological, petrochemical, biomedical and others. The wide using of the baffles in heat exchangers is because they direct the shell-side fluid to move back and forth across the internal tube to increase the turbulence level and provide good mixing of the fluid layers. In addition, they eliminate dead spots and increase heat transfer rate. Furthermore, in shell and tube heat exchangers, they minimize tube-to-tube temperature differences, which reduces the thermal stresses. Additionally, they support the internal tubes during operation, which prevents bending and vibration. Due to the extensive use of the baffles, knowledge about the heat transfer and shell-side fluid flow characteristics are very important.

Ko and Anand [7] studied experimentally the heat transfer rate in heated rectangular channel subjected to constant heat flux with wall mounted perforated baffles in staggered arrangement. Compared to no baffles, the results showed a heat transfer enhancement of 300%, while this augmentation per unit increase in pumping power was less than one for the range of parameters studied in that work. Yang and Hwang [8] numerically presented predictions on the heat transfer and turbulent fluid flow characteristics in a rectangular channel with solid and perforated baffles mounted in a staggered way. The simulations indicated that the flow patterns around the porous- and solid-type baffles are completely different due to different transport phenomena and it significantly influences the local heat transfer coefficient distributions. Compared with the solid baffle, the perforated baffled channel has a lower friction factor due to less channel blockage. Dutta and Hossain [9] experimentally studied the local heat transfer and friction loss characteristics in a rectangular channel with inclined solid and perforated baffles. A combination of two baffles of same dimensions was used. The results demonstrated that the local Nusselt number and friction factor are strongly depended on the position, orientation, and geometry of the second baffle plate. Karwa et al. [10] studied the heat transfer and friction in rectangular ducts with solid and perforated baffles (with void ratio from 18.4% to 46.8%) attached to one of the broad walls. The baffled wall of the duct was subjected to constant heat flux while the remaining three walls were insulated. The results revealed that the baffles with the highest open area ratio give the best performance compared with the smooth duct at equal pumping power.

Balikowski and Mollendorf [11] experimentally and theoretically examined the thermal performance of a double pipe heat exchanger with employing two types of phase change materials in the annular region and water circulated in the internal pipe. The study was performed for smooth and spined finned annuli. The results revealed that the presence of spined fins in the phase change material accelerated charging and discharging. Targui and Kahalerras [12] carried out a numerical study of flow and heat transfer characteristics in a double pipe heat exchanger in which porous structures inserted into the annulus in two configurations: on the inner cylinder, and on both the cylinders in a staggered fashion. It was found that the highest heat transfer rates are obtained when the porous structures are attached in the last configuration. Nasiri et al. [13] presented an experimental study on the heat transfer performance of Al_2O_3/water and TiO_2/water nanofluids through an isothermal annular channel. The results illustrated that for specific Peclet number, Nusselt number of nanofluids is higher than that of the base fluid. Also, there was no significant difference in the enhancement for both nanofluids, which increased with the increase of nanoparticle concentration. Ary et al. [14] experimentally and numerically studied the influence of a number of tilted (5°) perforated baffles on the turbulent flow structures and heat transfer in the rectangular channel with different types of baffles. The results illustrated that the flow patterns around the holes are completely different with different numbers of holes and it meaningfully affects the local heat transfer, and two baffles provide greater heat transfer performances than a single baffle.

Targui and Kahalerras [15] numerically investigated the effect of the simultaneous use of perforated baffles and pulsating flow on a concentric tube heat exchanger performance. The effects of the amplitude and frequency of pulsation in addition to the baffles permeability on the flow pattern and the heat exchanger efficiency were analyzed. The results demonstrated that the addition of an oscillating component to the mean flow affects the flow pattern, and enhances the heat transfer in comparison to the steady non-pulsating flow. The highest heat exchanger performance was obtained when only the flow of the hot fluid is pulsating. Chamoli and Thakur [16] mathematically studied the performance of solar air heaters with V-down perforated baffles as roughness on the airflow side of the absorber plate. They indicated that the thermal and effective efficiencies differ only slightly at lower flow rates. In another work, Chamoli and Thakur [17] numerically investigated the effect of transverse perforated baffles attached to the heated wall of a rectangular duct on heat transfer and friction factor. They observed that installing perforated baffles enhances the heat transfer, while friction loss increases over a smooth surface. Sheikholeslami et al. [18,19] conducted experimental studies on friction loss and heat transfer enhancement in an air to water double pipe heat exchanger. Typical circular-ring and perforated circular-ring turbulators were studied. In their investigation, air flowed in the annular pipe. Experimental analysis was carried out for open area ratio; 0, 0.0208–0.0833, Reynolds number; 6000–12000 and pitch ratio; 1.83–5.83. The results showed that installing perforated circular-rings decreased the heat transfer enhancement compared with the circular rings because of reduction of intersection angle between the velocity and the temperature field. In addition, the thermal performance increased with the increase in number of rings but it decreased with increase of Reynolds number and pitch ratio. Sahel et al. [20] numerically examined the performance of SSPB (having a row of four holes placed at three different positions) aiming to enhance the heat transfer phenomenon in a rectangular channel. They observed that there was an enhancement in the heat transfer rate from 2% to 65% compared with the simple baffle. Kumar and Kim [21] numerically presented heat transfer and fluid flow characteristics in a solar air heater channel with multi V-type perforated baffles. The baffle height ratio, pitch ratio, baffle-hole position ratio, inclination angle, and baffle void ratio were 0.6, 8.0, 0.42, 60°, and 12%, respectively. Multi V-type perforated baffles were shown to have better thermal performance as compared to other baffle shapes in a rectangular passage.

El-Maghlany et al. [22] experimentally tested the effect of a compound heat transfer enhancement technique on the thermal performance of a horizontal double tube heat exchanger. Cu/water nanofluid (volume fractions of 0–3%) was employed in the annulus-side, while the inner tube was rotated with speed from 0 to 500 rpm. The results demonstrated a significant augmentation in the heat transfer rate and heat exchanger effectiveness and number of transfer units. Moreover, the use of the nanofluid has a little penalty in pressure drop in compared with the inner tube rotation. Sheikholeslami and Ganji [23] presented an experimental and numerical investigation on convective heat transfer and friction loss in a double pipe heat exchanger employed with perforated turbulators in annulus region. Effect of turbulators pitch ratio, open area ratio and Reynolds number (6000–12000) were considered.