The Double-Tube Heat Exchanger Performance

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The double-tube heat exchanger is one of the most common designs of heat exchangers used in commercial and industrial applications. It is the simplest and one in which hot and cold fluids move in same or opposite directions. Various methods are presented to improve a double-tube heat exchanger.

nanofluids nanoparticles double-pipe heat exchanger pressure drop

1. Introduction

The double-tube heat exchanger is one of the most common designs of heat exchangers used in commercial and industrial applications. It is the simplest and one in which hot and cold fluids move in same or opposite directions [1]. A great advantage of the double-tube heat exchanger is the ability to process products with particles without any blockage risk.

The chemical, food, oil, and gas industries use double-pipe heat exchangers to perform tasks such as pasteurization, sterilization, reheating, preheating, digester heating, and effluent heating processes [2], for example, heating and/or cooling in sanitary and pharmaceutical applications. Moreover, the double-tube heat exchanger has been widely used in different renewable energy systems, such as solar energy, waste heat recovery, geothermal, combustion, latent heat energy storage, and air conditioning, due to its simple construction, easy cleaning, and low cost [3].

The heat transfer improvement in exchangers is usually accompanied by a pressure drop increase and, as a consequence, it requires higher pumping power. Therefore, any gains from improved heat transfer should be balanced against the associated pressure drop cost [4][5]. In this way, the main reasons for research work on heat exchangers are (i) to enhance their heat transfer rate, consequently reducing the heat exchanger's overall size, saving initial cost and space, and (ii) to minimize or avoid a large pressure drop, allowing pumping power to be reduced and saving operating costs. Therefore, knowledge about the pressure drop and convective heat transfer characteristics in heat exchangers is essential for adopting this technology into marketable products. Therefore, several techniques are scrutinized in order to enhance heat pipe performance, such as new structure configurations, designs, and technologies or their modification, the integration of heat pipes with other systems such as solar concentrators, improving the working fluid type, or employing heat storage systems [6].

In the recent decade, many scientists have worked to improve performance in heat exchangers using nanofluids as heat transfer fluids. Kavitha et al. experimentally used the CuO-water nanofluid as a heat transfer fluid to enhance a double-pipe heat exchanger [7]. Jassim et al. experimentally assessed TiO_2 and Al_2O_3 nanofluids on heat exchanger performance by considering nanofluids replacing conventional fluid, resulting in performance improvements from 13% to 23% with a concentration of 3% [8]. Ding et al. carried out a numerical simulation of TiO_2-water nanofluids in a double-pipe heat exchanger considering various flow rates and TiO_2 mass fractions. The results demonstrated that the heat transfer capacities of all mass fractions of TiO_2-water nanofluids were higher than those of deionized water, but they also increased the flow resistance in a corrugated pipe [9]. Akbar et al. achieved excellent results employing a hybrid nanofluid (Al_2O_3+TiO_2-water) to improve the heat transfer and pressure drop through horizontal tubes with diameter sizes of 30 to 45 nm. The results proved that the thermophysical properties of the hybrid nanofluid were enhanced from 7 to 13% compared to water, increasing the Nusselt number by approximately 30%, with a slight (5%) increase in pressure drop along a horizontal heated tube and a heat transfer highly appropriate for practical and industrial applications [10]. Jassim et al. experimentally assessed Al_2O_3 and Cu nanofluids on performance and heat leak in a double-pipe heat exchanger, showing that the Nusselt number was enhanced at all volume concentrations of Cu and Al_2O_3 nanofluids when compared to the base fluid (water). The Nusselt number was directly proportional to the Reynolds number for all cases. The use of nanoparticles in the base fluid causes an increment in exchanger effectiveness [11]. Mansoury et al. experimentally studied the heat transfer and flow characteristics of an Al_2O_3-water nanofluid in various heat exchangers on counter flow with a 20 nm nanoparticle size and turbulent flow. The double-pipe heat exchanger presented a 60% enhancement in the heat transfer coefficient, while the plate heat exchanger reflected an 11% increment in the heat transfer coefficient. However, the smallest percentage of pressure drop of 27% was reported in the plate heat exchanger, compared to the double-pipe heat exchanger at 85% [12].

Likewise, several studies confirmed simultaneous improvements in heat exchangers and solar collectors using a nanofluid as one of their heat transfer fluids. Vincely et al. performed an experimental investigation of solar flat plate collector performance using a graphene oxide–water nanofluid under forced circulation connected to a concentric-tube heat exchanger. It was observed that the collector efficiency was enhanced with increasing concentrations and flow rates. The heat transfer coefficient increments for the nanofluid in a laminar flow with concentrations of 0.005, 0.01, and 0.02 were 8.03%, 10.93%, and 11.50%, respectively [13]. Similarly, Henein et al. utilized a MgO/MWCNT-water hybrid nanofluid as a working fluid to enhance the thermal performance of a heat-pipe evacuated-tube solar collector with a 0.02% concentration at various volume flow rates ranging from 1 to 3 L/min. The results showed an enhancement in the energy and exergy efficiencies with an increase in the weight ratios of the MWCNT nanoparticles and the volume flow rate. The energy and exergy efficiency enhancements for the collector were 55.83% and 77.14%, respectively, for the MgO/MWCNT (50:50) hybrid nanofluid [14].

2. Heat Exchanger Performance

Different methodologies were investigated to improve heat exchanger performance. Examples of active and passive methods are summarized in **Table 1**. For active methods, external forces are required for heat transfer performance in double-tube heat exchangers. Generally, the main external forces used were mechanical forces, ultrasound, and magnetic fields [3]. As can be seen in **Table 1**, high-power and sophisticated devices were applied to improve the heat transfer rate by active methods. Contrastingly, passive methods did not require a powerful force. In that case, simple techniques were used to improve the heat transfer coefficient. Helical wires and porous media were two techniques considered with a greater percentage of pressure drop. However, this pressure drop could be compensated with a percentage of heat transfer improvement. Passive techniques were better when compared to active techniques because of their simplicity, low cost, and certain level of enhancement with a tolerable pressure drop [15]. The use of nanoparticles has been one of the most promising ways among the passive methods to improve heat exchanger performance.

Table 1. Examples of methods used to improve the double-pipe heat exchanger.

Methods	Improvement Approach	Observations (by Percentage, %)	Ref.
Active	Using air bubble injection	The percentage improvement of the overall heat transfer coefficient can be from 10.30% to 149.50%.	[16]
	Using surface vibrations	Heat transfer coefficient enhancement of 9%	[17]
	Using magnetic field	Heat transfer enhancement up to 320% and a slight increase in pressure drop	[18]
	Using ultrasonic vibration	Heat transfer is enhanced by about 60%.	[19]
Passive	Porous media	Enhanced heat transfer of 44% with larger pressure drops	[20]
	Using fins	Heat transfer rate enhancement of around 90–98%. Pressure drops for finned tube also increased.	[21]
	Helical wires	Augments Nusselt number by up to 2.64 fold. Increases friction factor by about 2.74 fold.	[22]
	Twisted tape	Significant (15%) enhancement in heat transfer rate. Friction factor increased by 10%.	[23]
	Metal foam	Nusselt number enhanced by 57.21%.	[24]
	Nanofluids (MgO-ethylene glycol)	Heat transfer coefficient enhancement of 27% for wt.% = 0.3 and 35% pressure drop at wt.% = 0.3.	[25]

Double-pipe heat exchanger performance consists of increasing the heat transfer rate and avoiding or minimizing a large pressure drop. Commonly, a fluid with a high viscosity value is the most appropriate for the side with the larger passage area (annular) since it implies a lower pressure drop [4]. In **Figure 1**, a diagram of a double-pipe heat exchanger is presented. When hot and cold fluids move in same or opposite directions in a double-pipe construction, this corresponds to the simplest heat exchanger model. One of the fluids passes through the smallest tube, while the other passes through the annular space between two tubes. Two types of flow arrangement are possible, one is employing both fluids in parallel flow, where cold and hot fluids enter at the same edges and move in the same direction (**Figure 1**a). In the other arrangement (**Figure 1**b), fluids enter at opposite inlets in counterflow, running in opposite directions [4][5].

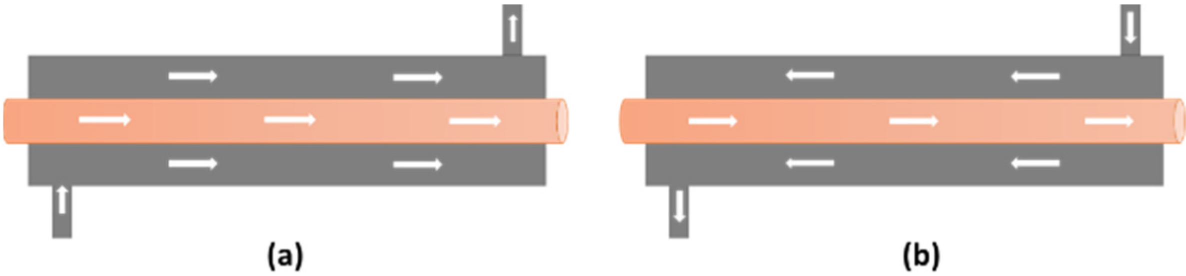

Figure 1. Double-pipe heat exchangers using (**a**) parallel flow and (**b**) counter flow [3].

The main factors that influence heat exchanger performance are the design, fluid properties, and flow types (**Figure 2**). A lower pressure drop helps avoid the requirement for a huge pump without affecting the initial cost. It also reduces electrical consumption, which affects operating costs. Low speeds are helpful to avoid erosion, tube vibrations, and noise as well as pressure drop [4].

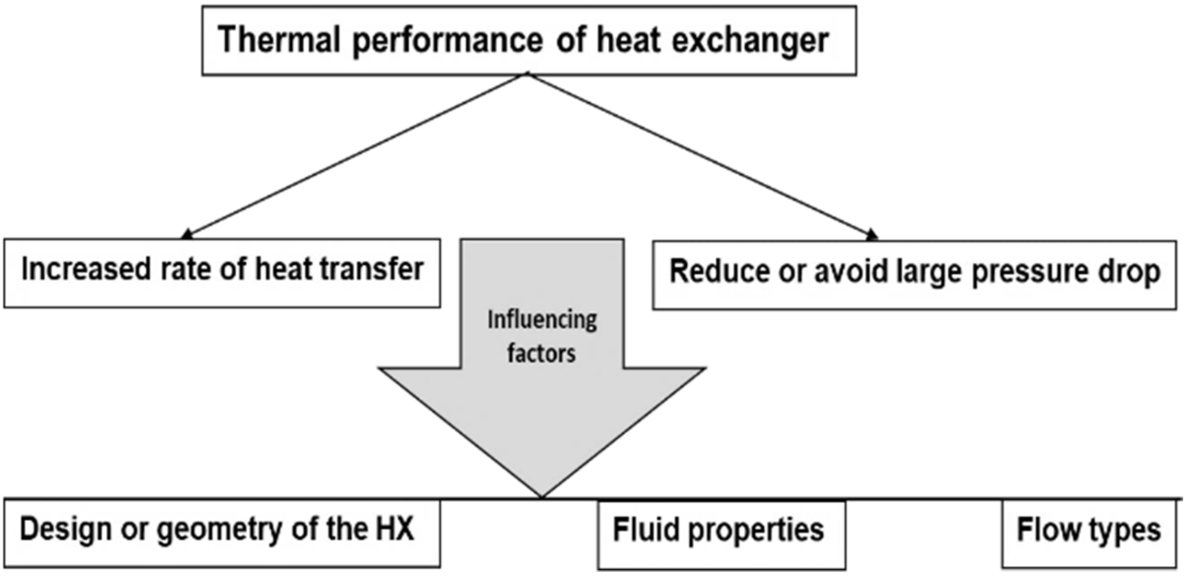

Figure 2. Scheme showing factors influencing heat exchanger performance.

A novel method that has been promoted recently is the use of nanofluids. Different nanofluids have been investigated to improve double-tube heat exchanger performance [26]. The heat transfer coefficient and the pressure drop are characterized by relative variations in nanofluid thermophysical properties that include the density, specific heat, viscosity, expansion coefficient, and thermal conductivity in addition to the flow regime [27]. According to Gupta et al., nanofluid thermophysical properties depend on the base fluid and on the influence of certain factors specific to nanoparticles, such as the concentration, size, and geometry (shape) [28].

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