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A review on heat transfer in heat exchanger

P.Jayapradha[1*], Arun Prakash J[2]

[1]*Assistant Professor, Department of Mechanical Engineering, Karpagam Academy of Higher Education, Coimbatore*

[2]*Assistant Professor, Department of Aeronautical Engineering,Hindusthan Institute of Technology, Coimbatore*

Abstract

In today's society, conserving energy is of paramount importance, and a heat exchanger is a great tool for doing just that. When it comes to processes like distillation, dissolution, crystallisation, fermentation, etc., a heat exchanger is obviously the most crucial part of the apparatus. Therefore, it is crucial in these process sectors to choose the right heat exchanger. Due to its small size and effective heat transmission, spiral heat exchangers have earned a stellar reputation. Since the fluids are moving in opposite directions, the heat exchanger may bring the temperatures of the two media it's working with quite near together. Spiral heat exchangers may be useful for a wide variety of fluids, including those that include particles or fibres, slurries, mixes with inert gases, waste water, cooling and heat recovery fluids, vapour/liquid condenser fluids, and vacuum condenser fluids with inert gases.

Keywords: Heat Exchanger, Heat Recovery, Sondenser fluids.

Introduction

An apparatus designed specifically to facilitate the transmission of heat from one medium to another is called a heat exchanger. A full wall separates the two mediums so that they can't interact with one another. Chemical and petrochemical factories, refineries, and wastewater treatment facilities all employ them. A wall dividing the routes of the hot and cold fluids is the simplest kind of heat exchanger. Many variables, including fluid flow, heat transfer area, thermal conductivity of the dividing wall, and so on, affect the total quantity of heat transmitted. Heat exchangers may be broken down into three broad

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categories based on the way in which heat is transferred. In a heat exchanger with a co-current or parallel flow, the fluids move in the same direction. In a heat exchanger with a counter-current or counter-flow, the two fluids move in the opposite direction. In a heat exchanger with a cross current, also called a cross flow, the two fluids move in directions that are nearly perpendicular to one another.

Heat exchangers may be broken down into three distinct groups based on the way in which heat is transferred. Similar to a parallel-flow heat exchanger, both fluids enter the device from the same end and travel in parallel to the other end. "Counter-flow" systems refer to heat exchangers that receive fluids from opposite directions. Due to the larger average temperature differential over any given unit of length, more heat may be transmitted from the heat (transfer) medium in the counter current setup. Consider the opposite current exchange. The fluids in a cross flow heat exchanger move at an inclination of about 90 degrees to one another as they pass through the exchanger.

Basic Types of Heat Exchangers

Multiple heat exchanger models have been proposed throughout the years, with modifications to the Conventional designs made to increase the heat transfer area, the heat transfer coefficient, and the viability of the designs from a financial standpoint. Traditional examples include the following:

1. Shell and Tube Heat Exchanger: The structure consists of a shell with a number of tubes within, all of which are sandwiched between two tube sheets. Used mostly for chilling hydraulic fluids, reboiler water, etc.
2. Plate Heat Exchanger: This is constructed from a series of interlocking square plates and supporting frames. The fluids may flow in four separate but interconnected channels via perforations in the four corners. It has extensive use in the petrochemical, medicinal, and culinary sectors.
3. Double Pipe Heat Exchanger: This model consists of only two pipes that are arranged in a circle, and as such, it is rather simple. The inner pipe carries one fluid, while the outer pipe carries another via an annulus between the two. It can replace plate heat exchangers, but it's usually not a better solution because of the extra space it requires. In order to determine which Heat Exchanger model is appropriate, you must know the fluid type, operational temperature range, available floor space, and desired flow rate. Whenever possible, designers of heat exchangers strive to maximise the area of heat transfer and the heat transfer coefficients across the operating temperature range. Heat transmission areas may be increased with the use of fins or corrugated plates. Baffles are installed to generate turbulence and raise the heat transfer coefficient. All of these considerations go into making the perfect Heat Exchanger for any given task. The upkeep of a spiral heat exchanger is simple. In order to get access to the inside of the heat exchanger, one need just open the side frame and move the hinges to reveal the inside of the closed spirals. The heat exchanger's transmission region on one side is easily accessible upon opening the side frame, allowing for cleaning without coming into touch with the opposite side. Hinge mechanisms built into the side frame prevent the need for any kind of lifting hardware. A space-saving option is the spiral heat exchanger. When compared to

more conventional heat exchanger options, this design takes very little room to be installed. This saves important manufacturing space and expenses(Tapre & Kaware, 2015).

Heat Transfer Characteristics in Coiled Tubes

For improved heat and mass transmission in a variety of industrial applications, including combustion systems, heat exchangers, solar collectors and distillation operations, helical coiled tubes provide a simple and efficient solution.

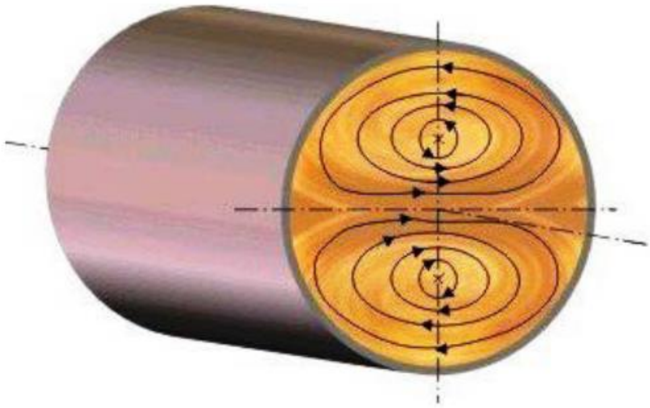

Figure 1. Secondary flow in a coiled tube.

Figure 1 shows how the atypical axial velocity distribution and secondary flow determine the heat transfer properties of coiled tubes. The fluid trajectory takes the shape of a double coil as secondary flow forms in the form of a pair of symmetrical vortices in the cross-section along the tube axis. So, the Equation (1) gives us the average heat transfer coefficient for laminar flow in coiled tubes.

$$\overline{Nu} = 0.06 Re^{0.7} Pr^{0.43} \left(\frac{Pr_f}{Pr_w} \right)^{0.25} \left(d/D_{coil} \right)^{0.18}$$

where the fluid's Prandtl number is Prf and the water's Prandtl number is Prw; The Reynolds number, Re, is measured in relation to the diameters of the tube (d) and the coil (Dcoil). Nu is the convective heat transfer coefficient, L is the typical dimension (such as the diameter for pipes) and is the thermal conductivity of the fluid; the Nusselt number is a dimensionless quantity characterising convective heat transmission. The rate of convective heat transfer, measured in terms of the Nusselt number, to the heat transfer achieved via pure conduction in a given volume of space. Using Pc as an example, the required parameters of shell and tube HCHE are shown in Figure 2.

For turbulent flow in coiled tubes, the heat transfer coefficient has an asymmetrical distribution over the tube's perimeter. Heat transfer from the inner to the outer generatrix may be responsible for the observed non-uniformity due to inhomogeneity in flow velocity and temperature distributions. It has been shown that decreasing the ratio of the coil diameter to the tube diameter (Dcoil/d) improves heat transport and results in a higher mean Nusselt number for coiled tubes compared to straight tubes. Compact heat exchangers often made use of coiled tubes due to their superior heat transfer coefficient and residence time distributions. Higher heat and mass transfer coefficients, narrow residence time distributions, and a compact construction all contribute to the use of flow and helix coils in heat exchangers and reactors.(Inyang & Uwa, 2022).

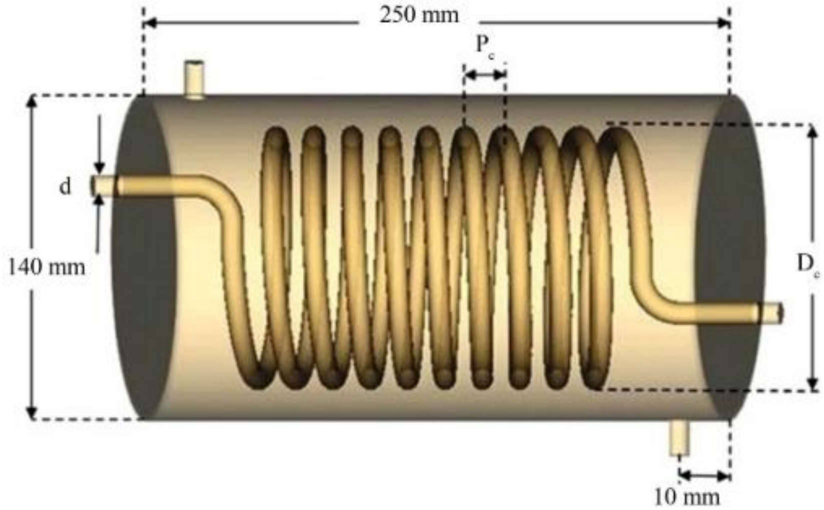

Figure 2. Shell and tube helical coil heat exchanger.

Thermal Conductivity Enhancement in Nanofluids

Nanofluids have much better thermal conductivity than conventional suspensions. Nanofluids, as compared to micrometer-sized suspensions, often provide many times greater thermal conductivity improvement than the base fluid. Too far, water, ethylene glycol, transformer oil and toluene have all served as base fluids. Ceramic nanoparticles, pure metallic nanoparticles, and carbon nanotubes are the three main categories of nanoparticles in use (CNTs). Various nanofluids may be created by combining different types of particles with various fluids. In this investigation, however, they will be primarily categorised according to particle type.

The ANL crew started their nanofluids research with ceramic varieties. In the first significant study of its kind, researchers measured the conductivity of solutions containing nanoparticles of Al_2O_3 and CuO in water and ethylene glycol. The standard transient hot-wire (THW) technique was used to determine the conductivity. Conclusions both Al_2O_3 and CuO nanofluids showed significant increases in thermal conductivity. Only 1-5% volume fractions were utilised. In cases where ethylene glycol served as the basis fluid, the improvement was greater. At 4% CuO by volume, performance was improved by 20%. When water was used as the base fluid, the improvement was less pronounced but still sizable, coming in at 12% at 3.5% CuO and 10% at 4% Al_2O_3. In comparison to Maxwell's model for suspensions, which was refined in 1962 to account for the impact of particle form, these results were very promising. These models estimate the effective thermal conductivity as a point-source-derived weighted average of the conductivities of the solid and liquid phases. This is how the original Maxwell model went down in history.(Das et al., 2006):

$$\frac{k_{eff}}{k_f} = 1 + \frac{3(k_p/k_f - 1)\,\phi}{(k_p/k_f + 2) - (k_p/k_f - 1)\phi}$$

whereas the Hamilton-Crosser model reads as

$$\frac{k_{eff}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)\phi(k_f - k_p)}{k_p + (n-1)k_f + \phi(k_f - k_p)}$$

The Rationale Behind Nanofluids

The thermal conductivity of all liquid coolants utilised today as heat transfer fluids is quite poor, as shown by a study of thermal properties (with the exception of liquid metal, which cannot be used at most of the pertinent useful temperature ranges). Water, like engine coolants, lubricants, and organic coolants, is around three orders of magnitude poorer at transmitting heat than copper. It goes without saying that the thermal conductivity of the fluid will be a limiting factor in any attempts to boost heat transmission by inducing turbulence, increasing surface area, etc. Efforts to improve the thermal conduction behaviour of cooling fluids are therefore warranted. More than a century ago, the idea of using a suspension of solids came to mind. Maxwell was an early innovator in this field by providing a theoretical foundation for determining the effective thermal conductivity of suspension. Many more theoretical and experimental experiments, including those by Hamilton-Crosser and Wasp, followed his pioneering work. When it comes to estimating slurries' thermal conductivity, these models perform well. All of these previous research efforts, however, focused only on the suspension of micro- to macro-sized particles, despite the following significant drawbacks.

Literature Review

(Tabatabaeikia et al., 2014) Using various inserts and altering the heat exchanger tubes are two of the most efficient techniques to increase the heat transfer rate of heat exchangers. Heat exchanger tubes may use a variety of inserts, including ribs, fins, baffles, and winglets. This study provides a review of the earliest research on optimising thermal system performance using inserts of various types. For whatever reason, the louvred strip insert worked better when the flow was going in the other direction.

(Meena et al., 2022) In addition to its many uses in industrial refrigeration, boiling is a significant heat transfer (HT) augmentation mode. When compared to alternative convection or conduction mechanisms of HT augmentation, boiling offers the ability to reduce energy losses from HT devices. The goal of this review study was to examine the work done over the last several decades to improve boiling heat transfer. In order to provide future researchers with some guidance, we set out to learn how nucleation sites affect HT enhancement on flat and curved surfaces.

(Kamble et al., 2014) Improving heat transmission is a crucial topic that has attracted a lot of study. Utilizing basic equations, applying standard correlations, or iteratively designing from experimental data are all viable options for this kind of study. This is compounded by the fact that modelling even a single stable phenomenon now requires knowledge of dynamics, system performance, optimization and control. To get around this problem, researchers have begun using artificial neural networks (ANNs) trained on experimental data to conduct heat transfer studies.

(Pardakhe et al., 2019) An example of a popular use of a heat exchanger is in the radiator of an internal combustion engine, where hot air is circulated over coils to simultaneously warm the incoming air and cool the engine coolant. One other kind of passive heat exchanger, the heat sink transfers thermal energy from a mechanical or electronic device to a fluid medium, often air or even a liquid coolant. According to their flow configuration, heat exchangers may be broken down into three broad categories. Both fluids enter the heat exchanger from the same end and flow in parallel all the way to the other side, as in a parallel-flow heat exchanger.

(Kumar, 2017) More studies are being conducted on the nanofluid forced convection heat transfer. Experimental research on the heat transfer and pressure decrease of nanofluids by forced convection is reviewed. Researchers have shown that using nanofluids in a helical coiled tube causes a little increase in pressure decrease. To improve heat transmission at low particle concentration, nanofluids must be used. More research under laminar and turbulent flow regions has shown a significant variation in Nusselt number.

(Kelvin et al., 2019) Nanofluid heat transfer is poorly understood, there is a dearth of experimental data, and there is no established framework for correlating the two. The task at hand will centre on elucidating the underlying mechanisms at play, identifying the barriers to widespread adoption of unconventional heat exchangers, and outlining the many ways in which nanotechnology might be used to boost efficiency. The research looks at heat exchanger tests conducted over the last decade, the information gap, and potential future uses of nanotechnology to enhance heat transmission. Recent energy conversion systems have made use of several nanotechnologies, all of which are summarised below.

(Zhang et al., 2019) Since its initial commercial use in the 1920s, plate heat exchangers have found widespread use in a broad variety of industrial settings. Improving the system's economics by reducing the capital investment required is only possible by increasing the thermal-hydraulic performance of plate heat exchangers. Plate heat exchangers may be made more efficient by geometric optimization or by using heat transfer improvement methods. With an emphasis on passive surface approaches and the use of nanofluids, this study presents a complete assessment of prior research on the impact of chevron corrugation geometrical factors on the performance of plate heat exchangers.

(Das et al., 2006) As these technologies and associated equipment continue to miniaturise, speed up their operations, and store more data, thermal management issues have become more pressing. The field of optical devices is another significant area that has struggled with heat control. The use of lasers, high-powered x-rays, and optical fibres is crucial to many modern technologies, including those used for computers, scientific measurement, medicine, material processing, material synthesis and communication. There has to be new innovations in cooling technologies for these devices because of their growing power and shrinking size.

(Inyang & Uwa, 2022) When two or more fluids, solid surfaces, solid particulates, or fluids are in thermal contact, heat may be transferred between them. The author has provided a short discussion of helical coils in heat exchangers of many configurations, including a comparison between HCHEs and straight-tube heat exchangers, as well as a discussion of the elements impacting the performance and efficacy of helical coil heat exchangers, including the curvature ratio. The author demonstrated that the HCHE outperformed straight tubes and conventional heat exchangers in terms of heat transfer efficiency and performance because secondary flow developed inside the helical tube, and that the heat transfer coefficient increased with an increase in the HCHE's curvature ratio at a given flow rate.

Conclusion

Several research have looked at passive methods for improving heat transfer rates on structured surfaces. Numerous studies have been conducted on both continuous and discrete nucleation sites, but more research is required to fully comprehend the interplay between these two types of sites. Research on boiling over a cylinder is limited since most structured surfaces are flat rather than cylindrical. More research on bubble formation, growth, and departure is required for cylinders with radii lower than the radius of departure, as well as for cylinders of very large sizes.

Spiral plate heat exchangers have been the subject of extensive study by a wide range of researchers, all of whom have come to the same conclusion. Maximum pressure drop and therefore minimum size were the outcomes of Nez's study. Based on their findings, Kondhalkar and Kapatkat concluded that as the Reynolds number rises, so does the heat transfer coefficient. Increasing the Reynolds number was shown to virtually linearly increase the heat transfer rate. Research into the impacts of feed flow rate and coil diameter found that raising the former led to a higher pressure drop while lowering the latter had the opposite effect. For a Newtonian fluid in a steady condition, a relationship between the pressure drop and the feed flow rate into Archimedean spiral tubes was derived.

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