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A Review of Baffles and Heat Exchanger Performance Enhancement

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Abstract: *In order to transfer heat between two fluids of different temperatures in various industries such as power generation, chemical processing, and home heating and cooling systems, Heat exchangers are widely utilised. This review paper provides an overview of heat exchangers, their classifications, as well as the various methods utilised for enhancement of heat transfer in heat exchangers, such as fins, dimples, and nanofluids. The paper also focuses on double-pipe heat exchangers, their advantages, applications, and construction design. Furthermore, the use of baffles in heat exchangers to improve fluid flow and turbulence is discussed.*

Keywords: *Double-Pipe Heat Exchanger, Heat transfer enhancement, Baffles, flow arrangements,*

I. INTRODUCTION

A device that prohibits the mixing of two fluids by transferring heat between them while maintaining their individual temperatures is known as heat exchanger. In heat exchangers, external heat and work normally do not interact. Heat exchangers restrict mixing of the two fluids, in contrast to mixing chambers. Heat transfer typically takes place in a heat exchanger through conduction along the wall separating the two fluids and convection within each fluid. In the actual world, heat exchangers are frequently used for a variety of tasks, such as power production, industrial chemical processing, and home heating and cooling systems. It is convenient to analyse with an overall heat transfer coefficient when studying a heat exchanger that takes all of these influences into account for heat transfer [1].

The process of boosting the efficiency of the heat transfer system in order to drop the coefficient of heat transfer is referred to as a heat transfer enhancement technique. Applications for heat exchangers in the automotive, industrial, and refrigeration industries, as well as in thermal power plants, have commonly utilised technology in order to enhance the heat transmission. In order to keep transportation vehicles from overheating, liquid coolants are frequently employed. A variety of techniques have been used to increase the heat transfer coefficient over the past 20 years. Fins, dimples, additives, and other embellishments can be used to improve heat transmission.[2]

A. Classification of heat exchangers

a) Flow arrangement (cross flow/counter flow as well as parallel flow)
b) Heat transfer mechanism (single phase as well as two phases)
c) Construction type (plate, tube along with extended surfaces)
d) Transfer process (direct or indirect contact)
e) Recuperators or Regenerators

The most sophisticated sort of heat exchanger that poses the maximum number of quantities and has somewhat alleviated some issues is a double-pipe heat exchanger. Examples of passive techniques that could be used to increase the capacity of a double-pipe heat exchanger include fins, helical coils, along withturbulators. Using a magnetic field and changing the flow conditions are two examples of active approaches. Compound methods can also be used in order to improve heat transfer. Furthermore nanofluids are essential to increasing the system's effectiveness. Moreover, studies on nanofluids are a crucial component of the system for improving heat transfer, and concerns must be expressed about the safest usage and dumping of nanoparticles[3].Suction-line heat exchangers (SLHX), also referred to as liquid-suction heat exchangers, are commonly used in vapor compression refrigeration systems to boost system efficiency. The specific cooling capacity and occasionally the required work of the compressor are elevated by utilising vapour in the suction line that is colder in temperature as compared to the liquid refrigerant leaving the condenser. The efficiency of the compressor in relation to the temperature of the refrigerant at its suction determines the specific work of the compressor. Systems for absorption cooling and heat pumps use a liquid solution of refrigerant as well as absorbent to function under steady state flow conditions. An absorption cooling system, similar to a vapour compression system, comprises of a condenser that removes heat, an evaporator which provides cooling, along with an expansion valve that maintains the pressure differential. The mechanical compressor is also replaced with a solution circuit while transmitting refrigerant vapor from low pressure to high pressure. The gaseous refrigerant must still be compressed in the absorption cycle because it gets separated from the absorbent mixture utilising low-grade thermal energy and a liquid pump which pressurizes an incompressible liquid solution.[4]

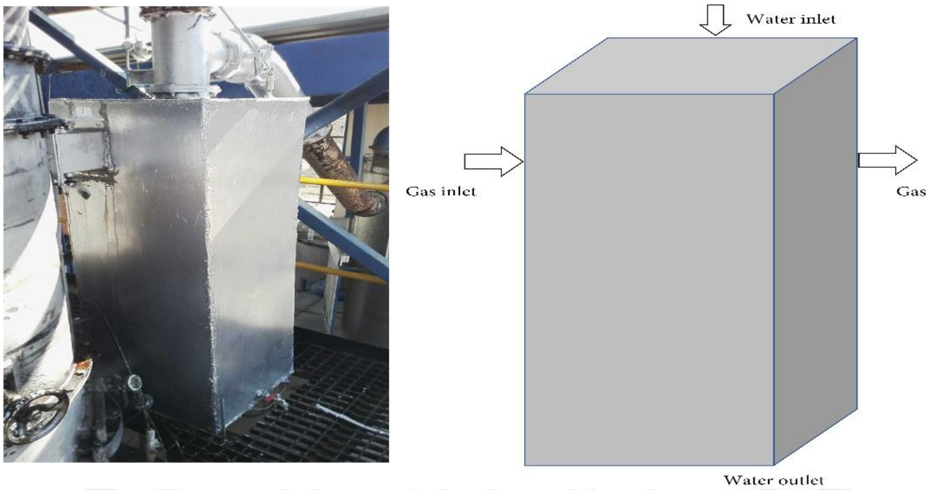

Figure 1 Heat exchanger's Pictorial and schematic view [5].

II. DOUBLE PIPE HEAT EXCHANGER

A double pipe heat exchanger is primarily utilised for the sensible heating and cooling of process fluid (up to 50m2) when there is a requirement for small heat transfer regions. The fittings are constructed to transmit the flow from one section to the next in a double pipe heat exchanger, while one pipe is fitted inside of another pipe (with a bigger diameter) concentrically. In addition, where one or both fluids are under high pressure, this geometry performs effectively.A double pipe heat exchanger might get configured in a number of series and parallel layouts to satisfy the pressure drop and mean temperature difference parameters.Axially finned inner tubes can be employed when the annulus's heat transfer coefficient is insufficient. The main drawbacks of double pipe heat exchangers are their size along with high cost per unit of transfer surface inner tube (that can be single or multi-tube). Double pipe heat exchangers are frequently built in the form of hairpins or with a modular design. [6]

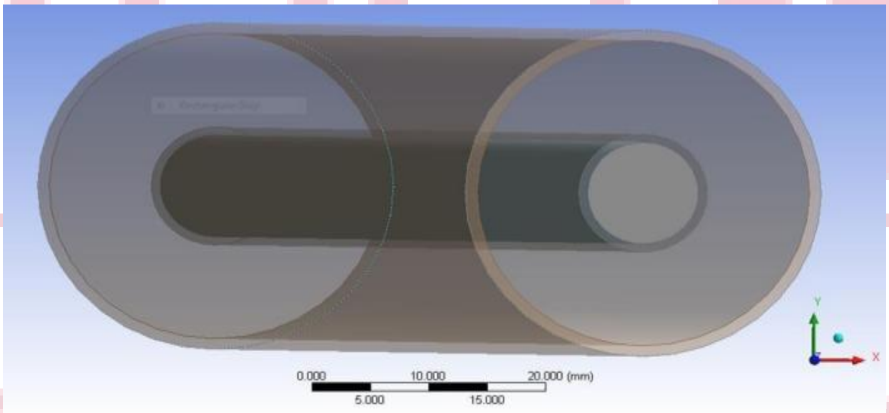

Figure 2 The diagram of Double-Pipe Heat Exchanger [6]

A. *Double pipe heat exchanger applications*

- Digester
- Effluent cooling
- Heat Recovery
- Pasteurization.
- Pre-heating

B. *Benefits of Double pipe heat exchanger*

- It is quite simple to build and operate. By using a component of the hairpin type, it can manage different thermal expansions.
- Modular design enables the installation of sections at a later time or the rearranging of the sections for new services.
- Utilization of stock components which might be put together into standard parts will save the time of delivery.
- Cleaning inspection as well as tube element replacement facilitated by easy construction.
- A low efficiency of heat transfer is the result of the utilisation of longitudinal finned tubes.
- Easy to clean, proper maintenance, as well as repairmen.

III. LITERATURE REVIEW

Shaojie Zhang et al. (2019) [7] explored the parameters of heat transfer along with the fabrication factor of heat exchanger tubes using self-rotating twisted tapes (SRTTs).According to the experimental findings, the twist ratios were found to have less of an impact on the first stages of the rotating behaviour, and under the same operating conditions, the SRTTs with lower twist ratios rotated more swiftly. SRTTs, as opposed to STTs, may improve heat exchanger thermal performance in rotating scenarios. Lower twist ratios were shown to increase the Nusselt number, pressure drop, and thermal performance factor. In turbulent flows ($12000<Re<45000$), SRTTs and stationary twisted tapes (STTs) were experimentally compared, and the impact of SRTTs with various twist ratios ($Y = 2.2$, 3, 4, and 6) on the thermal properties were examined. Finally, within a 10% error of the experimental data, several relationships between the Frication factor and Nusselt number were found.

According to the definition given by **Mustafa M. Gabiret al. (2021) [8]**, a heat exchanger is a thermal device that transfers heat to a fluid with a lower temperature from one with higher temperature. The goal of the study was to review articles that cover the main double pipe heat exchanger types and variables that affect pressure drop and heat transfer rates. There is a rising need of improving heat exchanger efficiency, development of a range of studies for speeding up heat transfer, and scale down the cost and size of industrial equipment. Devices called double pipe heat exchangers are utilised in varied sectors of the economy. Several double pipe heat exchanger models were suggested by researchers. Double pipe heat exchangers have been utilized in numerous industrial processes, sustainable energy applications, refrigeration devices, cooling technology, and other fields. Double pipe heat exchangers can be classified as parallel, counter flow, or cross flow. Moreover, research has been done to enhance the efficacy of double pipe heat exchangers through the addition of turbulators, inserts, rips at both ends, modifying the geometry of channel, injecting fluids in several ways, etc. Their efforts to achieve the necessary effectiveness decision parameter were depicted in a variety of research investigations on double pipe heat exchangers.

Chao Luo et al. (2021) [9]suggested the double pipe heat exchanger utilisation that comprises of two co-twisting oval pipes with various twist pitches. The findings demonstrate that as the twist pitch ratio increases, heat transmission first rises and subsequently falls Numerical analysis is used to analyse the impacts of the twist pitch ratio of the outer pipes to inner pipes, which ranges between 1.0 and 2.0, on the properties of fluid flow and heat transfer in the laminar regime. The greatest differences in friction factor as well as Nusselt number among several twist pitch ratios are, respectively, 71.4% and 19.0. The increase in heat transfer is proportionally greater than the equivalent rise in flow resistance. Even though the friction factor only rising by 43.7% compared to a simple straight annular pipe, the Nusselt number expands by 97.0%.The heat transmission enhancement is at its greatest when the twist pitch ratio elevates to 1.5. Additionally, it is suggested that fitted relationships for the friction factor, the Nusselt number, as well as thermal performance factor be developed with variances under 12%.

In their work, the impacts of $Al2O3$ nanofluid on the Nusselt number were examined at various volume concentrations between 0.05% and 0.4%, as well as the nanofluid's mass flow rates inside the tube and the water flow through the annulus.The study by **Hozaifa A. Mohamed et al. (2023) [10]** intends to increase the convective heat transfer coefficient inside the tube of the double pipe under turbulent flow circumstance through the combination of water and nanopariticles of aluminum oxide ($Al2O3$). Empirical correlations are presented, concealing the process' impacting variables and illuminating the Nusslet number and friction factor of $Al2O3$ nanofluid flow via the tube of double pipe heat exchangers. The convective heat transfer coefficients peaked at $Al2O3$ nanoparticle volume concentrations of 0.1% and then began to decline as the volume concentrations increased from 0.1% to 0.4%. . The level of fiction increases as nanoparticle volume concentrations do. The Nusselt number increases as the Reynolds numbers of the flows via the annulus and later the inside of the tube do.

For the purpose of building heating, ventilation, and air conditioning (HVAC) systems, it is needed to develop creative engineering solutions, according to **Saud Ghani et al. (2018) [11]**, due to the rising demand for energy in domestic applications. Domestic buildings are the most energy-intensive sector, hence reducing air conditioning energy use is currently receiving greater attention. It was demonstrated that the compressor work decreased while the COP increased by boosting the evaporator's DIW flowrate. Using double-pipe evaporator as well as condenser units with the greatest DIW flowrates alleviated compressor work by around 53% and enhanced system COP by a similar amount when compared to a conventional rated air conditioner.

According to **EbrahimTavousi et al. (2023) [12]**, it is crucial to develop effective heat exchangers that are less sophisticated, cheaper to build, capable of transferring more heat, and have a low pressure drop because of the rising need for energy. Due to their versatility and ease of use, double tube heat exchangers have drawn researchers' interest throughout history. In double tube heat exchangers, a variety of techniques, such as the addition of turbulators, enlarged surfaces (fins), modifications to the tube's geometry, nanofluids, and combinations of these techniques, can help speed up heat transfer.It had been discovered that the most effective combination for accelerating heat transfer rate is nanofluids technology and turbulator inserts. Additionally, based on standard deviation, this approach has the highest potential for enhancing heat transfer. Yet, due to high friction factor, expanded surface (fin) is the least effective technique. This review study offers new perspectives and information gaps that could be investigated further.

According to the analysis of **Marwa A.M. Ali et. al. 2018 [13]**, double pipe heat exchangers transport heat at a lower rate than other types of heat exchangers. The article spins the inner pipe of the heat exchanger while also altering the eccentricity of the pipe to increase the rate of heat transfer for that specific type of heat exchanger. To determine how rotation and eccentricity affect the rate of heat transfer, a three-dimensional, steady-state, incompressible CFD model was built.The double pipe heat exchanger employed in this study has an outer pipe with a diameter of 150 mm and an inner pipe with a diameter of 50 mm. It has a 2000 mm length. The inner pipe is anticipated to rotate between 0.0 and 40 mm from the center of the outer pipe at a variable speed of 0, 100, 200, 300, 400, and 500 rpm. The numerical simulation's validation and verification are presented. The outcomes showed that the inner pipe rotating at 500 rpm along with the change up to 40 mm substantially increased the rate of heat transfer by 223%.Penalties were accepted, but when the inner pipe's rotational speed was raised to 500 rpm with a 40 mm eccentricity, the pressure penalty through the heat exchanger elevated by 53%.

According to **Louis, S.P et. al. (2022) [14]**,due to the fact thatnanofluids have better thermal and rheological properties than conventional fluids, they can be used as one of the two fluids required to enhance heat exchanger performance. This review examines the connection between nanoparticles and the properties of nanofluids by evaluating factors such particle concentration, shape as well as shape. The flow rate and the rmophysical properties of nanofluids have a direct influence on the pressure drop as well as heat transfer coefficient. When compared to the base fluid, metallic oxide nanoparticles (such MgO, TiO2, and ZnO) substantially enhance this property by up to 30%. High thermal conductivity nanoparticles increase the heat transfer coefficient. Another issue to take into account is the shape and size of the nanoparticles. For example, by lowering the size of the Al2O3 nanoparticles from 90 to 10 nm, it was possible to increase thermal conductivity from 6.41% to 9.73%. This had an impact on the density and viscosity of the nanofluid. It was discovered that the pressure drop is impacted by nanofluid viscosity, while nanofluidthermal conductivity is the major factor directly influencing the heat transfer coefficient.

According to **Ebieto, C. E.,et. al. (2020) [15]**, Laboratory practises are essential to a thorough engineering education. One of the types of laboratory tools that all engineering students must use during their undergraduate studies is the heat exchanger. According to author, a laboratory-type double pipe heat exchanger with parallel and counter flow configurations is designed and built in detail. Galvanized steel was used in the heat exchanger's construction for both the shell and the tube. To evaluate the efficacy of the heat exchangers, experiments were created and executed. For the two designs, measurements and comparisons were made of the heat exchangers' logarithm mean temperature difference (LMTD), efficacy, overall heat transfer coefficient along with heat transfer rate. The LMTD becomes essentially constant as flow rate rises in both parallel and counter-flow systems, albeit with a larger value in the former. The heat exchanger with the counter-flow design functions more effectively due to its higher heat transfer rate, efficiency, and total heat transfer coefficient. It is essential because this development has enabled mechanical engineering students to work with a double pipe heat exchanger in a lab environment.

IV. AUGMENTATION TECHNIQUES OF HEAT TRANSFER

Techniques for enhancing heat transfer are often segregated into the following three groups [16]:
a) Active Techniques: Active techniques for improving heat transmission entail some external power input. Examples include mechanical assistance, fluid vibrations, surface vibrations, and jet impingement.
b) Passive Techniques: Passive techniques don't need any direct external power input. They often modify the geometry or surface of the flow channel by adding inserts or other devices. For instance, coiled tubes, extended surfaces, swirl flow devices, and rough surfaces.
c) Compound Techniques: Combining active and passive strategies can result in an increase in heat transfer that is higher than what would be obtained by using any one of those techniques alone. Compound enhancement refers to this simultaneous utilization.

A. Baffles In Heat Exchanger

Baffles are structural elements that are frequently employed in heat exchangers to improve fluid flow and raise turbulence inside the exchanger, which improves heat transmission. They are typically positioned perpendicular to the flow direction of the fluid and serve to improve flow distribution, lessen pressure drop, and shield the exchanger tubes from vibration-related damage. Baffles can increase heat transfer efficiency by drastically increasing the heat exchanger's heat transfer rate. Still, the positioning and arrangement of baffles must be thoughtfully planned out to prevent producing an excessive pressure drop or flow maldistribution, which can decrease the effectiveness of heat transfer.[17]

Heat exchange systems use a range of baffle types, like segmental baffles, disc as well as donut baffles, and helical baffles. The application-specific requirements and the required flow patterns determine the type of baffle to use[18,19]

- Segmental baffles: At regular points throughout the heat exchanger's length, these flat plates are installed perpendicular to the tube axis. These are the simplest and most prevalent kinds of baffles, & their primary purpose is to make the fluid flow more turbulent. For low-pressure situations where the heat transfer coefficient needed to be enhanced, segmental baffles are appropriate.

- Disc and donut baffles: These circular baffles are usually utilsed in shell-and-tube heat exchangers. Disc baffles are flat disks, whereasDonut baffles were hollow cylinders containing a huge center hole. Both kinds of baffles can promote heat transmission and improve fluid distribution when positioned perpendicular to the tube axis. Applications requiring high pressure and high temperature can use disc and donut baffles.
- Helical baffles: Such spiral-shaped baffles are positioned within the heat exchanger's outer shell. A whirling flow pattern produced by helical baffles encourages mixing and improves heat transfer. In high-viscosity fluids, high-pressure usages, and circumstances in which fouling is an issue, they are frequently used.
- Wire mesh baffles: These are introduced into the heat exchanger to increase turbulence and encourage improved fluid distribution. They are formed of wire mesh. Because they are simple to take care of and clean, wire mesh baffles are frequently employed in areas where fouling is a problem.

Because fluid flow in a heat exchanger might be laminar or turbulent depending on the flow rate, viscosity, and exchanger design, baffles are necessary in heat exchangers. Laminar flow is distinguished from turbulent flow by the uniform and smooth motion of the fluid particles, whereas turbulent flow is distinguished by the erratic and chaotic motion. By rupturing the laminar boundary layer and causing mixing and eddies in the fluid, baffles are employed to encourage turbulent flow.[20]In a heat exchanger, baffles perform a number of tasks, including as enhancing heat transfer efficiency, enhancing fluid distribution, lowering pressure drop, and minimizing vibration-related tube damage. Because it increases the convective heat transfer coefficient, turbulent flow is preferable in heat exchangers since it improves the efficiency of heat transfer.Baffles make guarantee that there are no dead zones or hot patches produced in the exchanger by distributing the flow in a more uniform manner.[21] By segmenting the flow into smaller pieces, baffles also lessen pressure drop by lowering the fluid's velocity and minimizing the pressure drop.

V. CONCLUSION

In various industries, heat exchangers are essential for transferring heat between two fluids of different temperatures without causing them to mix. Heat transfer performance and efficiency have grown as a result of developments in heat transfer improvement technology. Due to their straightforward construction, simplicity in cleaning and maintenance, and modular design, double-pipe heat exchangers are frequently utilized. The use of baffles has improved fluid flow and turbulence in heat exchangers, resulting in better heat transfer performance. Heat exchangers continue to play a vital role in industries, and further research on new heat transfer enhancement techniques and nanofluids is needed to improve their efficiency and effectiveness.

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