

A Review of Heat Exchanger Technologies from Fundamentals to Advanced Designs

¹Arvind Gwatiya, ²Rahul Rajput, ³Arunesh Kumar Mishra

¹Assistant Professor, ²Assistant Professor, ³Assistant Professor

¹Department of Mechanical Engineering, RKDF University, Bhopal (M.P)

²Department of Mechanical Engineering, RKDF University, Bhopal (M.P)

³Department of Mechanical Engineering, RKDF University, Bhopal (M.P)

Email Id: ¹arvindmpu@gmail.com, ²rahulrajput063@gmail.com, ³arunesh.pankaj@gmail.com

* Corresponding Author: Arvind Gwatiya

Abstract: Heat exchangers play a critical role in numerous industrial and engineering applications by enabling efficient thermal energy transfer between fluids. This review explores the fundamental principles, classifications, and operational challenges associated with heat exchangers. The three main types direct contact, indirect contact, and regenerative are discussed in terms of their mechanisms and applications. Special attention is given to the design and function of the triple tube heat exchanger (TTHE), a modification of the double tube model that offers enhanced performance through a three-concentric-tube configuration. Despite their generally robust and long-lasting construction, heat exchangers face performance issues when operating under non-ideal conditions such as partial loads or dynamic process changes. Effective design strategies, including appropriate safety margins and consideration of process variability, are essential to ensure reliable and adaptable performance. This review underscores the importance of selecting the appropriate heat exchanger type and design to meet specific thermal management needs across diverse industries.

Keywords: Heat Exchangers, Thermal Energy Transfer, Direct Contact Heat Exchange, Indirect Contact Heat Exchanger, Triple Tube Heat Exchanger, Fluid Dynamics.

I. INTRODUCTION

A device which cheaply as well as efficiently transmits heat from a hot fluid to a cool fluid, is known as heat exchanger. The operational lifespan of heat exchangers is typically designed to last for many years, frequently reaching decades. The components may change throughout this service life, and occasionally the process requirements may change as well. Even though heat exchangers are typically built without moving parts, ASHRAE 2022 covered a number of real-world problems and difficulties. In conclusion, potential issues may occur when heat exchangers are operated at partial loads, when mechanical vibrations were not sufficiently considered during the initial design, or when design parameters are based on inaccurate data. If modern design principles are followed, heat exchangers operate efficiently when used in the circumstances for which they were initially intended. However, if their reuse is required for various applications or a change in the process conditions such as variations in mass flow, pressure, or temperature, this may necessitate remodeling and potentially a new design approach. According to the presenter's insights, it's advisable that the design margin should not exceed 20%. Because of this, the efficient operation of the process and the integrated heat exchanger depends on the design of heat exchangers that consider all relevant requirements and contributing factors. But it might be necessary to redesign the integrated heat exchangers if the process's requirements change or if any of its parts are modified [1]. It can be difficult to design heat exchangers for dynamic, non-steady-state operations. Nevertheless, there are specialized firms with the knowledge to design heat exchangers, even for challenging and unusual applications.

The heat-exchange (or heat-utilizing) apparatus is one of the most prevalent and significant components of electrical, utility, and technological installations. Any type of energy conversion or energy transfer from one device to other results in a portion of the energy changing from one form to another and becoming heat. Heat transport is therefore crucial in practically all devices and machinery [2]. Technology, energy, oil refining, manufacturing, transportation, air conditioning, cryogenic, and recovery systems all depend on heat exchangers [3].

The two most popular types of heat exchangers are plate heat exchangers and shell-and-tube heat exchangers. In a shell-and-tube heat exchanger, numerous tubes are arranged inside a cylindrical shell and run parallel to the axis of the shell [4]. To improve heat transfer over the tubes and reroute fluid flow, several vertical plates known as baffles are typically inserted into the shell. On the other hand, plate heat exchangers are made up of a number of thin plates that are stacked one on top of the other inside of a frame [5].

II. KINDS OF HEAT EXCHANGERS

a) Direct Contact Type Heat Exchanger

- b) Indirect-Contact Heat Exchangers
- c) Regeneration Type Heat Exchanger

a) Direct-contact heat exchanger

Two immiscible fluids of various temperatures come into contact and transferring heat is known as direct transmission. Due to its low temperature driving force, simpler design, as well as higher heat transfer efficiency, heat transfer technologies offer more advantages over the traditional direct-contact heat exchanger. To use gas-liquid phase change heat exchangers in the working fluid, direct-contact heat exchangers (DCHEs) are used. In the absence of a partition, DCHEs take advantage of heat transfer between two different types of fluid. The desalination of seawater, heat recovery, conversion of ocean thermal energy, thermal energy storage systems, etc. are all applications for direct contact heat exchangers. DCHEs have also been used to help with solar energy harvesting and to clarify the processes by which ice originates, develops, and separates from droplets to form ice slurry [6].

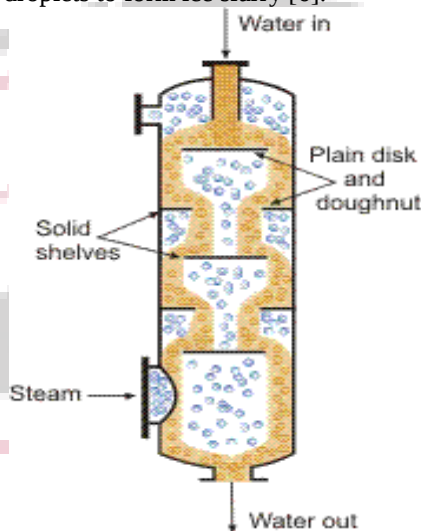


Figure 1: Heat Exchanger with Direct Contact Design (Source: Jacobs, H. R. (2011). *Direct contact heat exchangers*. In *Thermopedia*. Begel House Inc.)

b) Indirect-Contact Heat Exchangers

The fluid streams are kept apart, and heat is continually transmitted via an impervious dividing wall or briefly into and outside of a wall. Hence, in the ideal scenario, there would be no direct contact between fluids which interact thermally. These heat exchangers, also referred to as surface heat exchangers, can be further classified into fluidized-bed, storage-type, as well as direct-transfer types [6]

c) Regeneration Type Heat Exchanger

The terms "regenerative heat exchange" and "regeneration" refer to an approach or device that uses internal heat exchange between two working materials operating at various temperatures for precooling and preheating one another. In order to distinguish between them, we divided the regeneration techniques utilized in several cooling systems into three groups, as shown in fig.2 The first category of "recuperators" refers to cooling systems that are run in steady state. The second "regenerators" have been used in cyclically operated systems with gaseous working fluid, on the other hand, the third "cyclic heat recovery" is for cooling systems operated cyclically with solid-state functioning materials [7].

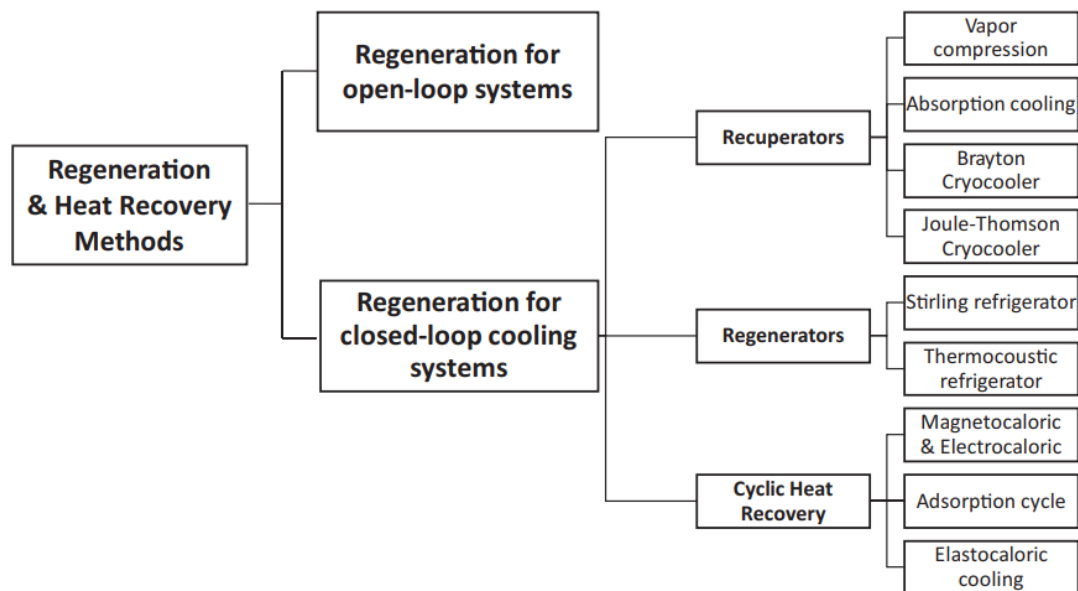


Figure. 2 A list of various cooling techniques and how they regenerate [7]

III. THE TRIPLE TUBE HEAT EXCHANGER (TTHE)

Heat exchangers are components that are designed for enabling the heat transmission from a fluid maintained at a higher temperature to a fluid maintained at a relatively lower temperature than the first one. The two ways in which this heat transfer between two fluids might happen are: Direct contact between the fluids or preventing them from mixing and also allowing heat to flow through. Since the fluid in the first case is directly made incident on another fluid, like a cooling tower, only convection is possible. The latter is far more sophisticated and prevents fluids from mixing since a barrier is placed between them. This barrier needs to be a good heat conductor. The process of heat transmission is as follows: Convection is the process through which a hot, moving fluid transfers energy to a stationary barrier. Conduction: It takes place inside the barrier and moves heat from one side to the other. Convection: It takes place at the opposite end of the barrier when heat must be transmitted from one fluid to another fluid that is kept at a fluctuating temperature. A triple tube heat exchanger (TTHE), which composed of three concentric tubes, is a modified version of a double tube heat exchanger (DTHE). The inner tube, inner annulus, along with an outer annulus make up its three components. While the heated (or cooled) service fluid circulates both inside and outside the inner tube, the fluid that needs to be heated (or cooled), such as the product used in food preparation, flows into the inner annulus [8].

IV. CONCLUSION

Heat exchangers are indispensable components in a wide range of industrial systems, facilitating the efficient transfer of thermal energy between fluids. This review has highlighted the various types of heat exchangers direct contact, indirect contact, and regenerative each with distinct working principles and applications. The design and operation of these systems must account for factors such as thermal load, fluid properties, and operational conditions to ensure optimal performance and longevity. Particular emphasis was placed on the triple tube heat exchanger (TTHE), which offers improved heat transfer efficiency due to its three-layer configuration. As process requirements evolve, it becomes increasingly important to adapt or redesign heat exchanger systems to maintain efficiency and reliability. Ultimately, the successful implementation of heat exchangers depends on thorough design, careful material selection, and an understanding of the operational environment, all of which are critical for meeting the thermal management demands of modern industry.

REFERENCES

- [1] Hohm, M. (2023), *ACHEMA 2022 – Heat Exchanger*. *Chemie Ingenieur Technik*, 95: 858-862. <https://doi.org/10.1002/cite.202200182s>.
- [2] Gugulothu, R., Somanchi, N. S., Reddy, K. V. K., & Akkiraju, K. (2017). A Review on Enhancement of Heat Transfer in Heat Exchanger with Different Inserts. *Materials Today: Proceedings*, 4(2), 1045–1050. doi:10.1016/j.matpr.2017.01.118
- [3] Edreis and A Petrov 2020, Types of heat exchangers in industry, their advantages and disadvantages, and the study of their parameters, *IOP Conf. Ser.: Mater. Sci. Eng.* 963 012027

- [4] Tkachuk, V., Navas, H., Petrov, A., & Protopopov, A. (2019, August). Hydrodynamic modelling of the impact of viscosity on the characteristics of a centrifugal pump. In IOP Conference Series: Materials Science and Engineering (Vol. 589, No. 1, p. 012007). IOP Publishing.
- [5] Kakaç, S., Liu, H., & Pramuanjaroenkij, A. (2020). Heat exchangers: selection, rating, and thermal design. CRC press
- [6] Wang, H., Xiao, Q., & Xu, J. (2017). Direct-Contact Heat Exchanger. InTech. doi: 10.5772/66630
- [7]] Suxin Qian, Jianlin Yu, Gang Yan, A review of regenerative heat exchange methods for various cooling technologies, Renewable and Sustainable Energy Reviews, Volume 69, 2017, Pages 535-550, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2016.11.180>.
- [8] Gomaa A, Mohamed M and Elsaid A M 2016 Experimental and Numerical investigation of a triple concentric-tube heat exchanger Appl. Therm. Eng. 99 1303

