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Reveiw Article

APPLICATION OF HEAT EXCHANGERS IN BIOPROCESS INDUSTRY: A REVIEW

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ABSTRACT

This article elucidates the application of different types of heat exchangers in the bioprocess industry. The use of heat exchangers in the bioprocess industry is inevitable. It is required in the process of heating or cooling of fluid foods; and the evaporation, freezing or crystallization of liquids for the manufacture of sorbet, ice creams and juices. Heat exchangers find application not only in the food and dairy industry but also in pharmaceutical industry, alcohol production and biochemical processing. The application of heat exchangers in bioprocess industry varies over a wide range, from the thermal treatment of fluid foods to the concentration of juices to the cooling of stirred yoghurt or freezing of liquids. It is also being applied in cryogenic processes, sterilization techniques and production of ethanol.

Keywords: Heat Exchangers, Types of heat exchangers, Bioprocess Industries, Applications.

INTRODUCTION

A Heat exchanger is an efficient device constructed for the efficacious heat transfer between two fluids of different temperatures. The media maybe separated through a solid wall, to prevent mixing, or they may be in direct contact [1]. Heat exchangers are extensively used in food processing industry, dairy industry, biochemical processing, pharmaceuticals, chemical plants and petroleum plants to name a few. The use of heat exchangers in bioprocess industry is ubiquitous; from high temperature pasteurization to low temperature freezing.

Types of heat exchangers

- Shell and tube heat exchanger – It is a type of heat exchanger which consists of a series of tubes containing the fluid that must be either heated or cooled with the second fluid being circulated over the tubes that need to be heated or cooled. Shell and tube heat exchangers are typically used for high pressure applications (with pressure greater than 30 bar and temperature greater than 260 °Celsius) owing to its robustness [02]. Figure I illustrates a typical shell and tube heat exchanger.

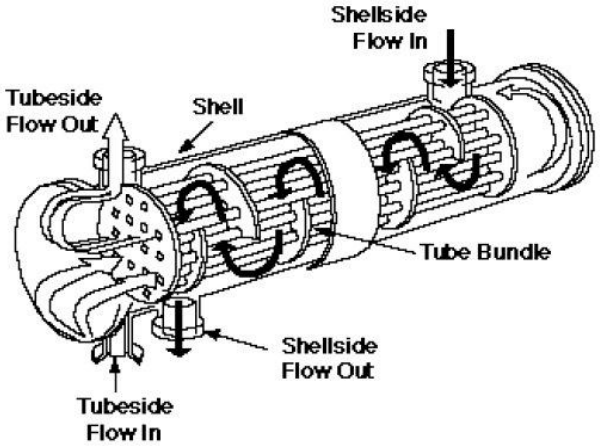

Fig. 1: It shows a typical shell and tube heat exchanger

- Plate heat exchanger- Another type of heat exchanger commonly used in a wide range of chemical process and other industrial applications with a particular attention from the food industry due to various reasons such as a compact design, a very large surface area over a small volume which can be modified as per requirement by increasing or decreasing the number of plates and advances in material technology [03]. It consists of several thin plates slightly separated from each other with provision of a passage for fluid flow for heat transfer. Figure II represents the set-up of a plate heat exchanger.

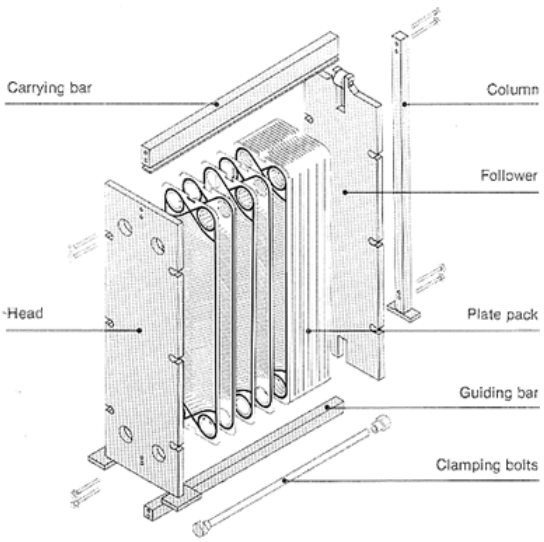

Fig. 2: It shows a Set-up of a plate heat exchanger

- Plate and shell heat exchanger- It is a type of heat exchanger which combines plate heat exchanger with shell and tube heat exchanger technologies. This offers a number of advantages such as high heat transfer, high operating temperature, compact size and low fouling to name a few.
- Plate fin heat exchanger- It is a type of compact heat exchanger extensively used because of its high degree of compactness which helps in saving materials [04]. It is usually made of aluminum alloys for greater heat transfer efficiency. It consists of fins of various configurations sandwiched between the two plates. Till now mostly genetic algorithm has been applied for optimization of these heat exchangers to reduce cost [05-10].
- Waste heat recovery units- Another type of heat exchanger that recovers heat from a hot gas stream, of a gas turbine or waste gas from an oil refinery, while transferring it to a working medium, typically water or oil.
- Dynamic scraped surface heat exchanger- This type of heat exchanger is mainly used for processes such as sterilization, freezing, gelatinization and cooling of high viscosity products such as ice creams, chocolate, yoghurt, jams and the likewise [11]. Continuous scraping of the surface with the help of steel blades

avoids fouling, provides a longer running time and sustainable heat transfer rate during the process.

- Phase change heat exchangers- It usually consists of an evaporator or a condenser, to either heat a liquid to evaporate it or cool a vapor and condense it to a liquid, respectively.
- Double pipe heat exchangers- It is one of the simplest heat exchangers with a concentric tube like construction with one fluid flowing inside the pipe and another fluid flowing outside the first pipe enclosed within a second pipe circumventing it. The flow of a fluid in a double pipe heat exchanger can either be co-current or concurrent. Porous materials are now being used to increase the heat transfer [12].

Figure III and IVdemonstrate a double pipe heat exchanger in parallel and counter flow respectively.

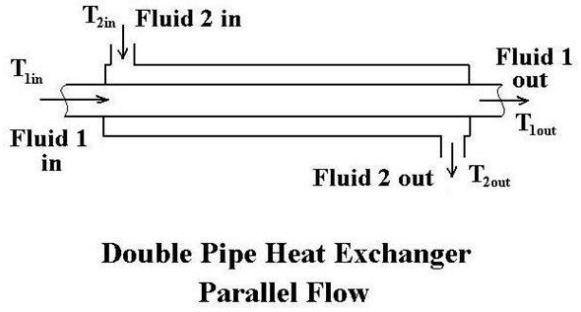

Fig. 3: It shows a Double Pipe Heat Exchanger in Parallel Flow

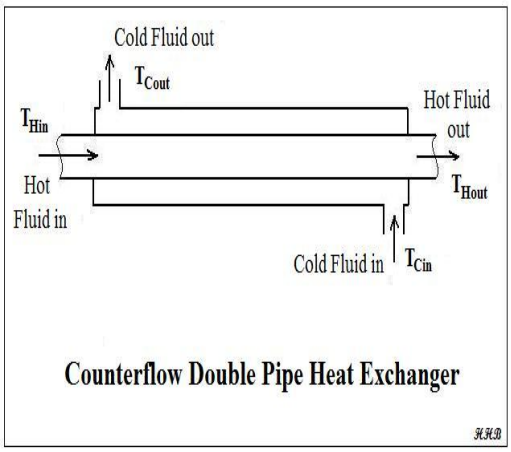

Fig. 4: It shows a Double Pipe Heat exchanger in Counter Flow

Depending on the nature of heat exchange, heat exchangers can be further divided into Direct Contact Heat exchangers, such as a cooling filter, and Indirect Contact Heat Exchangers. Furthermore, heat exchangers can also be characterized based on the flow paths (Co-current, counter current, cross flow), material of construction (metallic, non-metallic and graphite) and the number of pass (single pass and multi-pass heat exchanger).

Principle

The basic principle of heat exchanger is the transfer of heat between two fluids. Two fluids are brought in close contact with each other but are prevented from mixing by a physical barrier. The temperature of the two fluids will soon come to an equilibrium temperature. The energy from each fluid is exchanged and no extra heat is added or removed [13]. Since the heat in the process is not constant and the heat amount of the fluids is also not constant thus the Heat exchanger must be designed in a way that it is suited for all the cases of heat exchange and the performance is best suited for all conditions. Also the design should be such that the heat exchange is at a particular rate required by the process. Heat exchangers are originally designed to be over sized so that in cases of fouling, the surface of heat exchanger is still large enough to carry out operations. Once cleaned the heat exchanger would be again over sized.

For the use of any heat exchanger the proper study of various technical and economical parameters is required such as life of heat exchanger, cost per unit area , Overall Heat Transfer Coefficient , Low heating value of fuel, Effectiveness, Efficiency , Heat Capacities, Annual variation of temperatures of fluid under observation. [14][15]

Various types of heat exchanger follow this general principle. Whether it isa Double Pipe heat exchanger or Shell and Tube or Plate Heat exchanger or others of various kinds the underlying principle is same although specifics differ greatly.

Some factors that influence the heat exchanger performance are:

- width of the material of the tubes
- Temperature variation between two fluids
- Thermal Conductivity of the material of fabrication
- Physical features of the exchanger and Surface Area of the tubes
- Type of flow i.e. Counter current or co current or mixed flow
- Properties of the liquid i.e. viscosity, Heat capacity etc.

Plate Heat exchangers widely used in industries provide a large surface area for the heat exchange and thus is used in various food industries like Juice, Pulp, and Hazel nut paste as discussed below. More over Scraped Surface Heat exchangers have also been developed for the purpose of reduced fouling effect and increased effectiveness[16]. For any Bioprocess employing the use of Heat exchanger requires proper understanding of the exchanger, its working, principle, efficiency and other parameters.

Applications

Heat Exchanger in Food Industry

Heat exchangers can be used in food Industry as a process of cooling down various products in the industry. Large number of products like hazelnut paste and other types of food pastes are required to be cooled down or heated up in order to be processed further [17]. For this process Heat exchanger can be used.

The type of Heat Exchanger used is a Scraped Surface Heat Exchanger or SSHE. SSHE is designed for processing various high viscosity materials and heat exchanging a variety of heat sensitive products like fruit pulps [17]. The continuous scraping action exerted on surface ensures uniform heating of the contents, prevents fouling. It is also heavily used for materials that solidify at the wall. A wide variety of SSHE have been developed for the same purpose. Dynamic Scraped Surface Heat Exchanger, Rotary Scraped Surface Heat Exchanger, Conventional Design Scraped Surface Heat Exchanger, Alternate Blades Scraped Surface Heat Exchanger are a few studied. It has been researched and concluded that ASSHE is highly effective in food paste heating and cooling and the amount of heat transfer can be manipulated by changing various parameters of the Heat Exchanger. Studies show that the A-SSHE gives heat transfer coefficient values almost twice that of an equivalent C-SSHE [18].

Heat exchanger in Ethanol Production

Ethanol produced from various sources is gaining popularity worldwide for being the next alternative fuel which will replace the conventional fossil fuels and help in saving the environment. In the process of ethanol production a network of heat exchangers is used instead of single or double heat exchangers. The use of heat exchanger networks fulfill the utilization of waste heat and enable considerable savings of energy in short payback period[19].

The entire method includes pinch analysis [20]. Pinch analysis is a methodology for minimizing energy consumption of chemical

processes by calculating thermodynamically possible energy targets and achieving them by optimizing heat recovery systems, methods of operation and process operating conditions. It is known as process integration.

Thus, Formulation of optimized heat exchanger networks can help in two functions; reduced cost and increased efficiency. Studies show that the use of Heat Network can increase the efficiency of the heat exchanger and almost 50% of the heat recovery[20]. Reduction in the utility equipment helps in reducing the cost of the process.

Heat exchanger in Cryogenic Process

Cryogenic process is an important part of bioprocess industries. Cryogenics is the production of very low temperatures below −150 °C, −238 °F or 123 K and cryogenics is applied in various industries. Liquefied gases, such as liquid nitrogen, liquid carbon dioxide and liquid helium, are used in many cryogenic applications. Liquid nitrogen is the most commonly used gas in the process. Frozen food industry uses cryogenics most vastly. Use of heat exchangers in the process of cryogenics is unavoidable. Such low temperatures are obtained only by the use of specially designed heat exchangers.

The major problem face by the use of heat exchanger in the process of cryogenics is the high costs involved, inadequate effectiveness and accuracy. Various challenges are the complex operating conditions and physical effects, like changes in fluid properties, flow misdistribution, axial conduction and heat leakage. [21]. Thus better systems of heat exchange need to be designed. The main points that are to be focused on in future research are the reduced pressure drops and existence of partial flow mixing. Figure V shows graphically the various factors affecting the efficiency of heat exchanger. The various types of heat exchangers that can be used in the process are Tubular Heat exchanger or Plate Heat exchanger. Further in each the heat exchanger can be classified as Concentric tube and Coil wounded tube heat exchanger and perforated plate and plate fin heat exchanger.

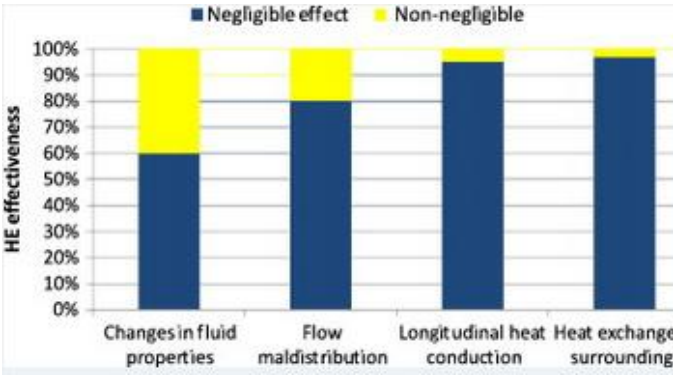

Fig. 5: It shows the factors affecting the efficiency of heat exchanger [21]

Also a custom Three-fluid Heat exchanger can be used for this process. A three-fluid heat exchanger provides a possibility of changed parameters. Thus it can be utilized for higher efficiency and no leakage of heat in the process [22].Figure VI demonstrates the Tubular arrangement of the three-fluid heat exchanger.

Heatexchanger in Sterilization

Packagedjuice manufacturers follow a procedure of Flash Pasteurization for the sterilization of juices when packaged. Hot juices at a temperature of 95°Celsius are heated using heat exchangers[23]. Then the pack is sealed and inverted and rapidly cooled using rotary or spin action. However once in container cooling is not as rapid as expected and also problem of handling the packs after filling is difficult.Many types of heat exchangers are used. The simplest design is a conducting coil submerged in boiling water with the flow of juice adjusted in such a way that pasteurization temperature is achieved.

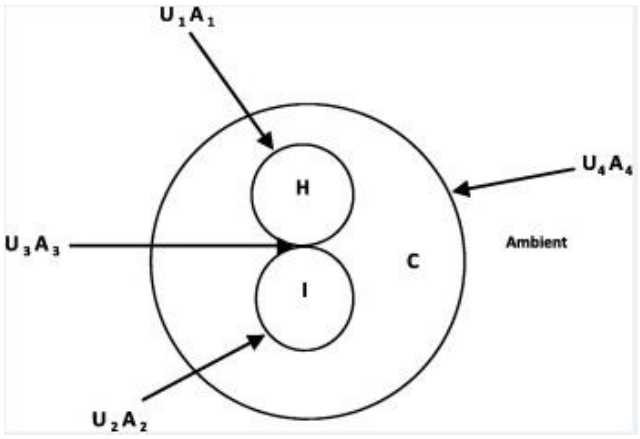

Fig. 6:It shows the Tubular arrangement of the three-fluid heat exchanger. [22]

Another additional advantage of using hot fills is the deaeration that takes place. A partial or complete vacuum maybe created in the process. This helps in sterilizing and further inert gases can be used in the packs. Sterilization is very critical especially when organisms like *Bysochalmous fulva* and *Talarmyces flavus* are present which require very high temperature to be killed. Temperature of almost 100°Celsius is required for 60 seconds for sterilizing the equipment. [23]

Scraped surface heat exchanger in manufacturing of sorbet

Heat exchangers also find application in the beverage industry where they play an important role in the cooling process. The scraped surface heat exchanger plays an integral part in the manufacturing of sorbet. Sorbet is a frozen dessert made from sweetened water flavored with fruits, typically fruit juice or puree, wine or liquor. It is served as a low-fat alternative to ice cream in most of the western countries and is cherished by the consumers for its texture and flavor. Such quality of texture requires the ice crystals to have a mean size of 10-20 micrometer [24]. Sufficient number of ice crystals having a size greater than 50 micrometer confers a coarsetexture to the final product [25]. Thus the freezing process in the scraped surface heat exchanger needs to be controlled meticulously to ensure uniformity in size of the ice crystals being formed.

The initial freezing process takes place in a scraped surface heat exchanger which consists of a cylindrical cup equipped with a vessel jacket, where the refrigerant fluid is circulated to allow the cooling of the product. The scraper, driven by a variable speed motor, consists of four stainless steel blades located in contact with the inner cooling surface. The freezing of the liquid entering the heat exchanger occurs in two stages. The first stage involves the introduction of crystal seeds to initiate crystal nucleation of the liquid, stabilized at a defined temperate below its freezing point [26]. In the second stage, a bath refrigerating fluid having a temperature of -20 °Celsius is used for further cooling, resulting in partial crystallization[26]. A mixture of ice and liquid, exits the heat exchanger at the end of the process, known as sorbet.

Plate heat exchangers in cooling of stirred yoghurt

Plate heat exchangers (PHEs) are being widely used nowadays in the food and dairy industry for myriad purposes from cooling to boiling to concentrating. A plate heat exchanger is a type of heat exchanger which uses metal plates to transfer heat between two fluids. It is therefore being used for performing tasks such as the high temperature short time pasteurization of milk, beer and juices [27]. In the production of stirred yoghurt, plate heat exchangers are used for the cooling of yoghurt to stop lactic acid fermentation upon reaching a desired acidity [28].

The factors attributing to the extensive use of PHEs in food and dairy industry, chemical industry, pharmaceutical industry and biochemical processing, to name a few is because of its easy dismantling, which allows proper cleaning and sterilization, less space requirement, low fouling tendency and high efficiency[29].

The industrial manufacture of yoghurt is a sequential process. It involves collection of raw material, pasteurization, homogenization, fermentation, set or stirred yoghurt, cooling, storage, packaging and distribution. The cooling process of stirred yoghurt, a non-Newtonian fluid, is carried out in a plate heat exchanger. This cooling process in the PHE is greatly dependent on geometrical properties of chevron plates, area enlargement factors and channel aspect ratio as well as the thermal behavior of yoghurt in the PHE [30].

Concentration of apple and pear juices in a multi-plate freeze concentrator

Freeze concentration provides an alternative to the conventional processes such as evaporation and other membrane technologies. It is an effective method of concentration which is based on the separation of soluble solids from a liquid phase by means of freezing the water content of the liquid. An advantage of this process is that it solves the problem of loss of volatile compounds as is seen in evaporation and the need for frequent replacement in membrane technology. It is therefore being used for the concentration of liquid foods such as fruit juices [31].

The method makes use of a freezer unit, freezing system, hydraulic system and an electric system [32]. Plate heat exchangers are used in the freezing and freezer unit for chilling the fluid to be concentrated resulting in the formation of ice. The circulating fluid is in direct contact with the cold surface of the plate exchanger made of stainless steel, through which a refrigerant fluid is flowing, which results in formation of an ice layer on the surface. An evaporator plate is used for defrosting instead of a mechanical method [32]. This results in the concentration of apple and pear juices through the freeze concentration method.

Heat treatment of fluid foods in a shell and tube heat exchanger

Pasteurization is a method of food preservation based on the principle of high temperature treatment. Fluid foods are subjected to a temperature of 62.8 °Celsius for 30 minutes or 71.7 °Celsius for 15 seconds according to the need. Heat exchangers are extensively used for this purpose of the thermal treatment of fluid foods such as whole milk, cloudy orange juice, and apple and apricot puree [33]. A shell and tube heat exchanger equipped with helically corrugated walls is ideally used. Such heat exchangers having helically corrugated walls are preferred over smooth walls because it enhances heat transfer through convection thus increasing efficiency [34].

CONCLUSION

Heat exchangers find a variety of applications in various bioprocess industries in Food industry: for production of juices, hazel nut pastes, yoghurts and other products, Ethanol production and Beverage Industry for production of wines, beer, ethanol, vinegar etc., Cryogenic Processes and Sterilization Techniques. Pharmaceutical Industries also employ heat exchangers to a large extent. The limitations in each industry are different and according to each modification are made in the design of the exchanger.

Process Requirements is important for choice of heat exchanger such as Pressure of fluids, Pressure drop across the exchanger, Heat transfer Rate and the type of fluids being processed. [33-35]

The Heat exchanger with High effectiveness is the best type of heat exchanger. The best type of heat exchanger can be obtained by the comparison of maximum heat gain. Cost effectiveness should be an important attribute.Reduced fouling, Increased surface area for heat exchange, Less heat leakage, Low heating value of fuel are other important factors. Hence for best results newer models of heat exchanger are important and thus further research is to be done so that better performance heat exchangers are produced. The use of non-conventional heat exchanger will be the key to better bioprocesses and better results.

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