Chapter 1

# Introductory Chapter: Advanced Features and Applications of Heat Exchangers–An Outline

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## 1. Introduction

This chapter aims to provide an outline of the various applications of heat exchangers, taking in particular attention related to advanced features as well as to briefly highlight the main aspects from each chapter contribution of this book.

The importance of the advances on the development of new generation heat exchangers and their innovative applications and the subsequent improvement in energy efficient processes relates directly with the energy issues that occupy the first place in the list of the most urgent to solve problems for mankind [1]. It is well accepted that any contribution to improve the way we deal with energy will help in solving our most dramatic problems like water, food, environment, poverty, violent conflicts, disease, education, and population.

Heat exchangers are present in every industrial processes from geothermal and fossil power generation to refrigeration and desalination, in general, as a fundamental part of energy transfer and saving systems. They are also present in our everyday life in all kind of vehicles (terrestrial, nautical and aeronautical), air conditioning, domestic heating and cooling, electronics cooling, and domestic appliances. Heat exchanger technology has been extensively explored and reported in the literature. Nevertheless, there is always the need of more work in this field for a comprehensive understanding of the advances related to edge applications that will contribute decisively to improve the sustainable uses of energy.

In the first of this two book series, "Heat Exchangers—Design, Experiment and Simulation", our attention is centered on the fundamental aspects related to the making of a heat exchanger and its more recent developments [2]. The present volume complements the study of heat exchangers, having under view the aspects related to the innovation in terms of construction and materials and also related to their applications from the most common to the more special cases.

## 2. Contributions highlight

Each chapter contribution of this book has been briefly highlighted in this section.

The authors Oh and co-workers demonstrated the two-phase flow pressure drop and heat transfer of a refrigerant during boiling in macro-scale and mini-scale channels type heat exchangers. The pressure drop and local heat transfer coefficients were obtained for varying heat and mass fluxes, vapor quality, and saturation temperatures in test sections of various tube diameters. The effects of all these variables on pressure drop and heat transfer coefficient were analyzed. The experimental results were compared against several existing pressure drop and heat transfer coefficient correlations. A new heat transfer coefficient correlation was also proposed that achieved a good agreement with the experimental data.

Having a decade long experience on compact heat exchangers, Erbay and others made a short review on history and basic features on the subject to introduce the offset strip fin geometry. Then, they analyzed the effect of the fin geometry on the performance of the offset strip fin based on experimental and numerical approaches. They demonstrated physical impact on the flow using different offset strip geometries. The thermo-hydraulic features of the flow in the offset strip fin were investigated by considering the Colburn j-factor and friction factors (f) in diverse flow regimes. Furthermore, other criteria derived from the mentioned dimensionless factors were also used as a measure of the performance of the structure.

The same research group leading by Erbay follows in the next contribution with the description of the basic physical features and the analysis of the thermal-hydraulic performance of the heat exchangers with louver fins. They referred the terminology, which is used widely in the field of this kind of compact heat exchanger. They used different flow visualization techniques to study how the flows are affected by the operating conditions of the heat exchanger and the geometric parameters of the louvered fin. A methodology was introduced to calculate the heat transfer coefficient and the friction factor. As in the previous chapter, Colburn j-factor and friction factor and also the Stanton number were defined as performance criteria and once more, the variations of these criteria with respect to Reynolds number and the geometric parameters of the louvered fin were analyzed in terms of the thermo-hydraulic features. The combinations of these dimensionless numbers were discussed in terms of overall performance criteria. Finally, the correlation of the louvered fin heat exchanger and the resulting data were summarized.

The present state of knowledge of free-convection condensation heat transfer on geometrically enhanced tubes was presented by Ali, covering the research on condensate flooding or retention and the experimental as well as theoretical works on geometrically enhanced tubes. Extensive experimental work performed on integral-fin tubes was addressed showing that geometry is not the only point of interest for enhancement of heat transfer. Also a reasonable amount of experimental work was reported on condensation heat transfer on enhanced pin-fin tubes. This showed the superior performance of such tubes over equivalent integral-fin tubes. The extent of condensate retention and formation of many sharp surfaces enhancing surface tension effects on pin-fin tubes was identified to be the important parameters contributing toward the heat transfer enhancement. A previous model by this author was referred and reported to reasonably predict heat transfer on the pin-fin tubes by taking into account the effect of both gravity and surface tension condensate drainage.

Author Ito described the heat transfer between supercritical fluid flows and solid walls and also between compressible flows and solid walls. It started with the explanation of the physical fundamentals of supercritical and compressible fluids. Then, heat transfer performance was obtained by using estimation methods based on the physical fundamentals and conventional experimental results as well as by known correlations. Finally, examples of practical heat exchangers using supercritical fluid flows and/or compressible flows were presented.

Heat exchangers are crucial in the aviation engineering and have a fundamental role especially into reducing the temperatures of the fuel increasing the efficiency of the aircraft engines. The contribution by Carozza explores methods for the design and the choice of heat exchangers to be used with such aeronautical applications and provides some practical case studies. Through this contribution, the author focused on the two main aspects of this class of flow systems, which are widely investigated: fluid flow and heat transfer performances as well as criteria for evaluating those performances. Besides this, several other important aspects related to the need to use a smart and light equipment inside a transport system were discussed. It was stressed that a particular attention should be paid to the selection of components, for example, in the engine zone, not only to reduce the weight but also to improve the whole heat transfer efficiency. Thus, engineers are focusing on new materials, for example, porous materials that have attracted a number of efforts to develop methods suitable to the design and use of such new technologies.

Steam generators used in nuclear power plants are a particular type of heat exchangers. In the steam generators, the heat produced in the reactor core is transferred to the secondary side, the steam supply system, generating the steam to propel the electrical turbine generators. Steam generators have to fulfill special nuclear regulatory requirements regarding their size, selection of materials, pressure loads, and impact on the nuclear power plant safety, among others. The primary side fluid is liquid water at the high pressure, and the fluid on the secondary side is saturated water-steam mixture at the pressure twice as low. A special attention must be given to preserving the boundary between the contaminated water in the primary reactor coolant system and the water-steam mixture in the secondary system. The authors Šadek and Grgić provided a brief overview of the steam generators used in nuclear power plants, its design, operation, and the mathematical correlations used to quantify heat transfer in these devices. Results of the steam generator transient behavior obtained by the simulation with a best-estimate computer code developed for safety analyses of nuclear power plants were also presented. In particular, two types of steam generators were analyzed: the inverted U-tube steam generator which is commonly found in the present-day pressurized water reactors and the helical-coil steam generator that is part of the new generation reactor designs.

In the last contribution, Teng and co-authors proposed a mitigation approach to deal with the major unresolved problems in heat exchanger operation, fouling and corrosion. Here, they consolidated basic background and concepts for the design and operation of heat exchangers to introduce closely related industrial practices for cleaning and green technology maintenance of heat exchangers. For an industry, the proper cleaning method and control play an important role to reduce the production costs. Production cost significantly increases due to chemical usage, maintenance work and downtime loss, and water wastage. Therefore, the authors underlined the importance of corrosion control, fouling cleaning, and enforcement of specific standards for cleaning procedures in the industries. They also proposed the application of a mitigation approach to deal with fouling and corrosion.

## 3. Other selective complementary sources

A very general review on advances in heat transfer enhancements was performed by Siddique et al. [3]. They addressed most usual heat transfer enhancers: fins and microfins, porous media, large particles suspensions, nanofluids, phase-change devices, flexible seals, flexible complex seals, vortex generators, protrusions, and ultra-high thermal conductivity composite materials. In addition, theoretical enhancement factors along with numerous heat transfer correlations were presented in this review for each heat transfer enhancer.

### 3.1. Materials

The conventional heat exchangers are manufactured in metal (such as stainless steel, copper and aluminum) and have disadvantages in terms of weight and cost. In addition, specially treated metal heat exchangers are needed if the working fluids are corrosive. Alternative materials have been used for heat exchangers that can overcome some of the disadvantages of the conventional ones like weight, cost, and chemical resistance, be more adequate for particular applications, and also have comparable heat exchange efficiency and be easily fabricated.

Due to their low cost, lightweight, and corrosive resistant features, *polymer* heat exchangers are receiving growing interest from researchers, engineers, and other industry related players. Thus, as a better alternative to metallic heat exchangers in a wide range of applications, these particular heat exchangers have extensively been investigated in recent years. This can be evidenced from a recent review paper by Chen et al. [4] who reported developments including theoretical modeling, experimental findings, heat transfer enhancement methods of polymer materials, and a wide range of applications of polymer heat exchangers. Another interesting review work by T'Joen et al. [5] discussed the use of polymer matrix composites in HVAC&R applications, showing how a careful material selection and modification of the design allows to fully exploit the material properties.

Lin et al. [6] proposed a new compact *graphite foam* heat exchanger for vehicle cooling application that allows to match the increasing cooling power and space limitation in vehicles. Their simulation results show that the wavy corrugated foam presents high thermal performance and low pressure drop. A comparative study between the wavy corrugated foam heat exchanger and a conventional aluminum louver fin heat exchanger was also carried out to evaluate the performance of graphite foam heat exchangers. Furthermore, several recommendations were made about the further development of the application of graphite foam heat exchangers in vehicles.

For heat exchanger applications needing extreme operation temperatures such as in the field of power generation or heat recovery, *ceramics* and ceramic matrix composites are suitable to design heat exchangers and particularly adequate to attain optimal overall efficiency, cost, and size of the system. The review by Sommers et al. [7] provides the current state-of-the-art of ceramic materials for use in a variety of heat transfer systems.

### 3.2. Nanofluids

Recent advances in nanotechnology have allowed the development of a new category of fluids termed "nanofluids" [8]. Among many other applications, nanofluids can be used as thermal fluids and are considered heat transfer enhancers. The review by Huminic and Huminic [9] summarized the important available publications on the enhancement of the convection heat transfer in heat exchangers using nanofluids. They also presented the theoretical and experimental results for the effective thermal conductivity, viscosity, and the Nusselt number reported in the literature. It also focused on the application of nanofluids in various types of heat exchangers: plate, shell and tube, compact, and double-pipe heat exchangers.

A special type of nanofluids is ionanofluids that can be defined as suspensions of nanomaterials in ionic liquids. Ionic liquids possess promising thermophysical properties and great potential for numerous applications, particularly as new heat transfer fluids. Since ionic liquids are the base fluids in ionanofluids, the above-mentioned heat transfer enhancement obtained with nanomaterials suspensions can be potentiated by the thermophysical properties of ionic liquids. Nieto de Castro et al. [10] presented some pioneering researches that indicate that ionanofluids show great promises to be used as innovative heat transfer fluids in heat exchangers and novel media for many green energy-based applications.

### 3.3. Special design

The efficient design of heat exchangers is more critical in some applications, requiring devices having superior performance and reliable mechanical characteristics at high pressure and high temperature and complying with geometric constraints. Therefore, design of heat exchangers is one of the aspects where continuous advances are registered.

The review by Li et al. [11] reported the performances of *compact* heat exchangers, including well-established devices, some relative newcomers to the market and also designs still being tested in the laboratory. The structures, heat transfer enhancement mechanisms, advantages, and limitations are summarized, and an example of an application as a solar receiver is given. It also referred available correlations for heat transfer and friction factor developed by various researchers.

*Microchannels* represent the next step in heat exchanger development due to their high heat transfer performance and reduced weight as well as their space, energy and materials savings potential. Khan and Fartaj [12] made a survey of the published literature on the status and potential of microchannels, identifying research needs. They also developed an experimental infrastructure to investigate the heat transfer and fluid flow for a variety of working fluids in different microchannel test specimens.

The study by Abu-Khader [13] presented the advances in *plate* heat exchangers both in theory and applications. The selected areas discussed in this review are the ones that attracted more attention recently, namely compactness and downsizing without the loss of performance, which is crucial for the industry; theoretical developments; reducing fouling and corrosion of plates in sever processes, with a direct impact on operational cost; and using nanofluids.

In the paper by Wang et al. [14], a general review was provided on developments and improvements of *shell-and-tube* heat exchangers with helical baffles of different improved designs. Extensive results from experiments and numerical simulations indicated that these heat exchangers have better flow and heat transfer performance than the conventional baffled heat exchangers, therefore allowing to save energy, reduce cost, and prolong service life and operation time in industrial applications.

The heat pipes are accepted as an excellent way of saving energy due to the high heat recovery effectiveness of these devices. A brief literature review was performed by Srimuang and Amatachaya [15] on the applications of *heat pipes* heat exchangers for waste heat recovery in both commercial and industrial applications. The authors also summarized the experimental studies on the conventional heat pipe, two-phase closed thermosiphon, and oscillating heat pipe heat exchangers.

### 3.4. Applications

There are review studies available on other types of heat exchangers used in particular cases of applications where innovative and state-of-the-art equipment must be developed and used, such as exemplified with the cases of geothermal processes with ground heat exchangers [16] and biotechnological industries [17].

## 4. Conclusions

This chapter briefly discusses the importance of heat exchangers and their advanced applications in terms of energy efficiency and process intensification, minimizing environmental and societal impacts. It highlights main research and findings from each contributed chapter of this book. It also provides key topics related to advanced features and applications of heat exchangers and corresponding reference sources. We believe that this book will be a useful reference source of information on advanced features and applications of heat exchangers.

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