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# Introductory Chapter: An Overview of Design, Experiment and Numerical Simulation of Heat Exchangers

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## 1. Introduction

This chapter aims to provide an overview of various aspects of heat exchangers as well as to briefly highlight research and findings from each contribution of this book.

Heat exchangers are devices that facilitate the exchange/transfer of heat between two media/ matters (fluids, solid surface/particulates and fluids) at different temperatures. Heat exchangers are commonly used in practice in a wide range of applications from heating and air-conditioning systems in a household to chemical processing and power production plants, bioprocess, and heavy industries. One of the well-known heat exchangers is car radiator in which heat is transferred from the hot water flowing through the radiator tubes to the air flowing through the closely spaced thin plates outside attached to the tubes.

Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. Different thermal applications demand different types of hardware and different configurations of heat transfer equipment, and thus, wide range of heat exchangers are manufactured and available in the market. Heat exchangers are classified based on various features such as transfer processes, fluids flows direction (i.e., parallel flow and counter flow), number of fluids (e.g., two, three fluids), surface compactness, heat transfer mechanisms, construction etc. In general, the classification of heat exchangers by transfer processes includes (i) indirect-contact and (ii) direct-contact exchangers [1, 2].

In indirect-contact heat exchangers, the two flowing fluids are separated by a wall and heat exchange between these two fluids occurs through this wall. As a separating wall hinders the heat flow, these heat exchangers are less effective than the direct-contact ones. However,

these heat exchangers are widely used because most of the practical cases fluids cannot be allowed to contact or mix. Common examples of indirect-contact exchangers are shell and tube, bayonet, concentric tube, plate, spiral plate, radiator, storage or regenerators, and compact exchangers. On the other hand, two fluids streams come into direct contact with each other and exchange heat before separating. The direct-contact heat exchangers include moving bed contactor, fluidized bed, moving belt conveyor, immiscible fluids, boiling and immiscible fluids, and cooling tower exchangers.

The analysis of heat exchangers is commonly performed through two well-known methods, which are log mean temperature difference (LMTD) and effectiveness-number of transfer units ($\varepsilon$-NTU) [3]. LMTD is easy to use in heat exchanger analysis when the inlet and the outlet temperatures of the hot and cold fluids are known or can be determined from the energy balance, and it is very suitable for determining the size of a heat exchanger to realize certain/required outlet temperature. On the other hand, NTU is directly a measure of the heat transfer surface area, and therefore, the smaller the NTU the smaller the heat exchanger. Heat transfer enhancement in heat exchangers is usually accompanied by increased pressure drop and thus by higher pumping power. Therefore, any gain from the enhancement in heat transfer should be weighed against the cost of the accompanying pressure drop.

## 2. Contributions highlight

This book covers every areas mentioned in its title. Except this overview, each chapter contribution has been briefly highlighted in this section.

Starting with the design of heat exchangers, author Ezgi discussed the basic design methods of two-fluid heat exchangers. The design techniques of two main types of heat exchangers namely recuperator and regenerators were analyzed and theoretical developments are presented in his study. The solutions to recuperator problems are discussed in terms of LMTD, $\varepsilon$-NTU, dimensionless mean temperature difference ($\Psi$-P), and (P1-P2) methods. It is reported that the rating or sizing problem of recuperator exchangers can be solved by any of these methods and will yield identical solution within the computation error. For example, if inlet temperatures, outlet temperature of one of the fluids, and fluids mass flow rates are known, LMTD method can suitably be employed to solve sizing problem. Otherwise, $\varepsilon$-NTU method needs to be used. As the P1-P2 method includes all major dimensionless heat exchanger parameters, the solution to the rating and sizing problems is noniterative and straightforward. On the other hand, regenerators are basically classified into rotary and fixed matrix models, and the thermal design of these models can be realized by two methods, which are effectiveness-modified number of transfer units ($\varepsilon$-NTU$_0$) and reduced length and reduced period ($\Lambda$-$\pi$) methods. Usually, $\Lambda$-$\pi$ method is used for fixed matrix regenerators.

Authors Silva Rosa and Moraes Junior focused on the heat transfer surfaces in agitated vessels and their study was based on the determination of the heat exchange area which is necessary to abide by the process conditions as mixing quality and efficiency of heat transfer. Based on the overall heat transfer coefficient obtained from Nusselt number, they determined the heat transfer area. The authors also summarized literature studies related to heat transfer

in agitated vessels. A numerical analysis was also made to project the heat transfer surface area in an agitated vessel using vertical tube baffles and a 45° pitched blade turbine. It was emphasized that the selection of a suitable type of heat transfer surface for the process to be projected in agitated vessels must be done through an analysis between the kind of impeller and its interaction with the adopted surface.

Topology optimization is a useful design tool for physical systems especially for structural ones, and its application in the field of thermal transport is slowly increasing. Topology optimization is as a physics-based and automated lay-out (best material) optimization method, which follows the governing equations taken into consideration under a user-defined set of conditions and limitations. Authors Christian and Lin re-introduced this topology optimization with special focus on the progress of heat exchanger design. In order to assess the current progress of topology optimization in the field of heat transfer and heat exchanger design, they provided a chronological review of available literature. Then, they have conceptually introduced different methods developed over the years in topology optimization. Heat exchanger designs arising from topology optimization have now been realized, and continuous efforts are still being made to further improve both methods and implementation. Topology optimization is expected to play a bigger role in the near future for heat exchanger design.

Isafiade and Bahadori reported a new simplified synthesis method for designing small-sized to medium-sized flexible heat exchanger networks using a mixed integer nonlinear programming multi-period synthesis approach. The methodology used involves a two-step approach where in the first step, a multi-period network is designed for a large number of critical operating periods using a finite set of operating points while considering the impact of potential fluctuations in periodic durations of each of the chosen critical points on the network. In the second step, the flexibility of the resulting multi-period network of the first step is tested using very large randomly generated set of finite potential operating points together with their periodic durations. The solutions obtained in their study using this new approach were compared favorably with those in the literature.

In a different study, author Naik highlighted issues related to the thermal design of gas turbine blades and examined several heat transfer technologies. Some of the basic heat transfer phenomenon associated with both the external hot gas side and the coolant's internal flows in turbine aerofoils has been discussed. By establishing the hot gas side external heat loads, which generally varies with different turbine design, it is possible to design efficient aerofoil internal cooling systems. Typical methods for validating the thermal designs of gas turbine aerofoils were also outlined.

As mentioned before, direct contact heat exchangers (DCHE) involve the exchange of heat between two immiscible fluids by bringing them into contact at different temperatures. Among some advantages of direct-contact heat exchangers over indirect contact ones include achievable very high heat transfer rates, relatively inexpensive exchanger construction and absence of the fouling problems due to not having any wall between the two fluids. The direct-contact heat exchangers have been comprehensively studied by Wang and co-workers. Based on algebraic topology, they have developed a new technique for quantifying the efficiency of multiphase mixing. A novel method relying on image analysis and statistics was

also developed to accurately estimate the mixing time in a DCHE. L2-star discrepancy (UC-LD)–based uniformity coefficient (UC) method presented for assessing the uniformity and mixing time of bubbles behind the viewing windows in a DCHE was found to be effective. Furthermore, they have shown some advantages including rotation invariance (reflection invariance), permutation invariance, and the ability to measure projection uniformity. Their experimental results revealed that UC-CD gives more sensitive performance than uniformity coefficient based on wrap-around discrepancy (UC-WD) and thus, the UC-CD method is more appropriate for industry. Nonetheless, authors believe that the complexity of the bubble swarm patterns can be reduced, their mechanisms can be clarified, and the heat transfer performance in a DCHE can be elucidated.

Author Jaremkiewicz described a method for measuring the transient temperature of the flowing fluid in heat exchangers based on time-temperature changes of the thermometer, which was considered as an inertial system of first and second order. To reduce the influence of random errors in the temperature measurement, the local polynomial approximation based on nine points was used. As a result, the first and second derivatives of a temperature that indicates how the temperature of the thermometer varies over time were determined very accurately. Then, the time constant was defined as a function of fluid velocity for sheathed thermocouples with different diameters. The applicability of their method was validated with real experimental data. They inferred that this method is mostly suitable for measuring the transient temperature of gases in the exchangers, and it can also be used for the online monitoring of fluid temperature change with time.

A detailed description and comprehensive review of the transient effectiveness methodology for heat exchanger analysis are reported by authors Tianyi and co-workers. Three important applications for transient effectiveness methodology are reported that include (i) characterization of heat exchanger dynamic behaviors, (ii) characterization of the transient response of closed coupled cooling/heating systems with multiple heat exchanger units, and (iii) development of compact transient heat exchanger models. For studying heat exchangers' transient characteristics, authors introduced novel transient effectiveness methodologies, which were found very useful for thermal dynamic characterization of heat exchangers as well as development of compact CFD transient models. The transient effectiveness curves capture the transient response and the impact of thermal capacitance of each heat exchanger unit. The two CFD compact modeling methodologies (i.e., a full transient effectiveness methodology and a partial transient effectiveness methodology) were also developed and validated in their study. These models were found to be accurate and fast and can be integrated into large-scale models as well.

Salcedo and co-authors carried out numerical simulations to study the unsteady laminar flow and mixed convection heat transfer characteristics around two identical isothermal semicylinders arranged in tandem and confined in a channel. Simulations were performed using the control-volume method on a nonuniform orthogonal Cartesian grid. The immersed-boundary method was employed to identify the semicylinders inside the channel. The variation of the mean and instantaneous nondimensional velocity, vorticity and temperature distributions with Richardson number were presented along with the nondimensional oscillation

frequencies (Strouhal number) and phase-space portraits of flow oscillation from each semicylinder. In addition, local and averaged Nusselt numbers (Nu) over the surface of the semicylinders were also obtained. Their results demonstrated how the buoyancy and wall confinement affect the wake structure, vortex dynamics, and heat transfer characteristics.

Authors Çetin and co-workers reported a study on computational modeling of vehicle radiators using porous medium approach in the last contribution. They believe that a successful implementation of such porous modeling can lead to a dramatic reduction in computational cost and time. The implementation of the computational methodology through a commercial software can also benefit from the powerful meshing, solving, and postprocessing capabilities. As demonstrated, a CFD analysis of a radiator by using porous medium approach gave reasonable and reliable results. Using CFD analysis, design cost may be decreased dramatically by easing the experimental testing process. They reported that the porous parameters of a given fin geometry can be obtained within a couple of hours which may enable the hydrodynamic and thermal optimization of a radiator. Although the proposed methodology was discussed in the context of a vehicle radiator, it can be implemented to any compact heat exchanger with repetitive fin structures, which is an important problem for many industrial applications. Authors suggested that more realistic computational models may be developed, and the coupling of the flow and temperature field with the structural analysis may lead to way more efficient and robust radiator designs.

## 3. Other complementary sources

Many areas and features of heat exchangers that are not covered or not detailed in the above-introduced contributions can be found in many other available reference sources. For example, among many books and sources, very popular and useful sources of knowledge on the design of heat exchangers and application of related theories and modeling of designs are the two popular and comprehensive books by Thulukkanam [4] and Shah and Sekulic [2]. The second edition of heat exchanger design handbook by Thulukkanam [4] also provides current advances in heat exchanger technology particularly design and modes of operation. The book by Rao and Savsani [5] describes research works that explore different advanced optimization techniques. It also includes algorithms and computer codes for various advanced optimization techniques that can be useful to the readers. In a study, Lee et al. [6] reported numerical methodologies of the fluids flow and heat transfer analysis in various types of heat exchangers. They also proposed an analysis method for the conjugate heat transfer between hot flow-separating plate and cold flow of a plate heat exchanger. More detail on recent development on the numerical simulations of the heat exchangers and advances in numerical heat transfer can also be found in a very recent book edited by Minkowycz and other co-editors [7].

Over the past few decades, a large number of research efforts have been devoted to enhance the heat transfer performance of heat exchangers by various methods, which have been discussed in a recent compressive review on double pipe heat exchangers by Omidi et al. [8]. Generally, the heat transfer enhancement methods are classified as active method, passive

method, and compound method. While active and compound methods are less popular and used, passive methods are widely employed to improve the heat transfer of heat exchangers. Among passive methods, extended surface (e.g., fins), twisted tape insert, and wired coils are commonly used particularly in double pipe heat exchangers [8]. The book edition on the heat transfer enhancement of heat exchangers by Kakac et al. [9] is a good source of knowledge and references.

For compact heat exchangers, the second edition of a popular book by Hesselgreaves et al. [10] is a complete reference, which compiles all aspects of theory, design rules, operational issues, and the most recent developments and technological advancements in these heat exchangers. A comprehensive review on performance of compact heat exchangers was also reported by Li et al. [11]. Among other books and works, the book published by Sundén and Faghri [12] is a good source for numerical simulations in compact heat exchangers.

In recent years, there are large numbers of research works reported on improving the design and performance of heat exchangers to meet the cooling demands of modern devices and industries. This book provides topic-wise detailed and state-of-the-art information on the development of design, experiments, and numerical simulations on heat exchangers. It is noted that various advanced features and applications of heat exchangers are provided in our other volume of this book [13].

## 4. Conclusions

This chapter briefly discusses various aspects of heat exchangers and highlights main research and findings from each contributed chapter of this book. It also provides key topics related to heat exchangers and corresponding reference sources. We believe that this book will be a useful source of information for researchers, postgraduate students as well as designers and engineers working in the fields of heat exchangers and related industries.

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