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Plate heat exchangers: Recent advances

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ABSTRACT

This study presents the advances in plate heat exchangers both in theory and application. It dresses the direction of various technical research and developments in the field of energy handling and conservation. The selected areas of heat transfer performance and pressure drop characteristics, general models and calculations change of phase; boiling and condensation, fouling and corrosion, and welded type plate heat exchangers and finally other related areas are highlighted.

Contents

1. Introduction

Plate heat exchanger (PHE) is now commonly used in a wide range of chemical process and other industrial applications with a particular attention from the food industry due to several reasons such as: suitability in hygienic applications, ease of cleaning and the thermal control required for sterilization and pasteurization. Also PHEs exhibit excellent heat transfer characteristics which allow more compact designs than achievable with conventional shell and tube heat exchangers, and have a very large surface area in a small volume and can modified for different requirements simply by increasing or decreasing the number of plates needed. With these advantages, along with advances in material technology in the form of new temperature- and pressure-resistant materials for gasket or graphite plates, it is now possible to use this class of heat exchangers appropriately for the power and chemical processes.

Even though plate heat exchangers are mostly used in liquid-liquid heat transfer duties which require uniform and rapid heating or cooling. But there is an increase trend to use PHEs in the evaporation and condensation duties for plant energy conversion.

On the other hand, the main disadvantage of PHE is the limit of its operational range where the maximum operating pressure is limited to 20.4 bar and the operating temperature to about 150 °C. These operational conditions can be extended to about 40.8 bar and

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800 °C in lamella type PHE which does not have the flexibility of the gasket plate unit.

Plate heat exchangers can be fabricated in gasketed, welded, or module welded design characterized by the model in which the flow channels for the two heat exchanging media are sealed. According to the type of heat exchanger the individual plates are sealed relative to each other by gaskets placed in circumferential grooves or by welding.

Plate heat exchangers are first fully described in [1], and there are several comprehensive compiled materials on various design aspects in the literature [2–7].

The main objective of this review is to highlight the recent advances which affects the performance of plate heat exchangers specially in the industrial section. As an industrial application, Karlsson [8] evaluated the performance of plate heat exchangers in residential water radiator heating systems receiving their heat from geothermal resources. Recent experimental and numerical work to analyze the flow in an oil/water plate heat exchanger for the automotive industry was conducted [9]. Also, the use of plate heat exchangers to improve energy efficiency in phosphoric acid production was illustrated [10]. Downsized exchanger without loss of thermal-hydraulic performance is crucial matter for the industry applications [11]. The improvement of compactness is a vital issue carried by more competitive surface shape under the carefully designed riblet angle [12]. The use of nanofluids as coolants in industrial heat exchangers seems inauspicious [13], and the only drawbacks so far are the high price and the possible instability of the nanoparticle suspensions [14].

2. Thermal & hydrodynamic characteristics

From the early literature on the effect of plate arrangements on flow distribution and pressure drop was presented by Bassiouny [15,16]. On the other hand, Thonon and Mercier [17,18] presented an overall design method used for sizing plate heat exchangers. The method is based on the temperature enthalpy diagram, and introduced a model taking into account flow maldistribution effects for single and two phase flows [19]. The effects of flow maldistribution was presented through a general thermal model in terms of Effectiveness-Ntu and LMTD relationships.

Rao et al. [20], showed in details the effect of flow maldistribution and presented a wide range of parametric study which brings out effects such as those of the heat-capacity rate ratio, flow configuration, number of channels and correlation of heat transfer. Also, the experiments showed the effect of pressure drop on flow maldistribution [21]. Noninvasive technique of Positron Emission Particle Tracking (PEPT) was used to investigate the flow pattern in a plate heat exchanger [22]. Recently, Tsai et al. [23] investigated hydrodynamic characteristics and distribution of flow in two cross-corrugated channels of plate heat exchangers. Effects of dissipation and temperature-dependent viscosity on the effectiveness calculation was addressed by Gherasim et al. [24].

Martin [25] developed the generalized Lévêque equation – a theoretical equation – to predict the plate heat exchanger thermal performance. Also, Dovic et al. [26] developed generalized correlations for predicting heat transfer and pressure drop which are used to predict the performance of chevron-type plate heat exchangers by obtaining the heat-transfer coefficients in fully developed laminar or turbulent channel flow. Dumas and Corradini [27] analyzed the influence of the thermal resistance of the fluid film, temperature distribution profiles and enthalpy efficiency in the range of temperatures normally used in civil applications. Ciofalo [28] Explored the effect of the longitudinal heat conduction along the dividing walls and showed that it may enhance the exchanger's performance.

2.1. Influence of plate types & configurations

Extensive experimental works were conducted on different chevron type plates to study the effects resulted from the variation of parameters such as: pitch, amplitude, and chevron angle. This is to understand their influence on heat transfer and flow patterns [29,30]. Heat transfer and isothermal pressure drop data for single-phase water flows in a single-pass U-type counter-flow PHE and in low Reynolds number flows are presented through the use of different chevron plate arrangements: two symmetric plate arrangements with beta = 30°/30° and 60°/60°, and one mixed-plate arrangement with beta = 30°/60°. Also, the effects of chevron angle beta in these three different plate arrangements were illustrated. The impact of corrugation aspect, ratio gamma, and flow conditions on Nusselt Number (Nu) and friction factor (f) characteristics were outlined [31–38].

The size (i.e., height and pitch) of the corrugation embossed on the plates, and the orientation of the corrugation with respect to the main flow direction on the heat transfer performance of the exchanger were investigated [39]. Charre et al. [40] presented a general heat transfer and pressure drop model which is based on the theory of porous media and included the influence of 11 geometric parameters of the plate. A new-type corrugation Plate was designed where t the flow resistance of the working fluid in this new corrugation PHE, compared with the traditional chevron-type one, was decreased by more than 50% [41]. The laminar flows of Newtonian and power-law fluids through cross-corrugated chevron-type plate heat exchangers (PHEs) were numerically studied in terms of the geometry of the channels [42].

The influence of grooves in the U-turn areas for the multi-channel-plate heat exchangers (MCPHEs) was investigated by Chang et al. [43] using of acrylic plates. Plates with dimples [44] were designed to enhance heat transfer and reduce fouling. Various shapes of rib-roughened surfaces, different rib spacing and rib arrangements were applied to the wider walls of the duct to enhance the heat transfer in a plate heat exchanger [45].

Pinto and Gut [46] and Gut [47,48] developed an optimization method for determining the best configuration(s) of gasketed plate heat exchangers, and their objective was to select the configuration(s) with the minimum heat transfer area that still satisfies constraints on the number of channels, the pressure drop of both fluids, the channel flow velocities and the exchanger thermal effectiveness. A general method for the optimal design with undulated surfaces was proposed by Kanaris et al. [49] and Arsenyeva et al. [50]. Recently, exergy analysis was included as an important variable in the design procedure [51,52].

2.2. General procedure calculations

General calculation procedure for plate heat exchangers and useful charts were developed [53], in terms of the number of transfer units (Ntu) and the heat capacity rate ratio (R), for 150 plate heat exchanger configurations. These exchangers were classified on the basis of number of channels, number of passes of each fluids and flow arrangement. Specific guidelines for selecting the appropriate plate heat exchanger configuration were proposed. Wright and Heggs [54,55] calculated the effectiveness of a single pass two stream plate heat exchanger (PHE) when one stream undergoes a phase change; specifically condensation, and presented analytical solution for the system under the assumption of constant overall heat transfer coefficient when run in either co-current or counter-current arrangements. Also the authors extended their analysis to systems in which the overall heat transfer correlation is dependent upon the quality of the phase change stream. Recently, Lin et al. [56] derived dimensionless correlations using the Buckingham Pi theorem to characterize the heat