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Two types of welded plate heat exchangers for efficient heat recovery in industry

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A B S T R A C T

The developments in design theory of welded Plate Heat Exchangers (PHEs), aiming to enhance the heat recovery and efficiency of energy usage, are presented. The thermal and hydraulic performance of the unit is estimated using two approaches: by proper selection of plate corrugation pattern and by adjusting the numbers of passes for heat exchanging streams. The optimisation problem targeting the minimal heat transfer area under the requirements of proper operating conditions is observed. The optimising variables include the number of plates with different corrugation geometries in one pass. To estimate the value of the objective function in a space of optimising variables the mathematical model of PHE is developed. The possibilities of their application as heat exchangers in preheat train of crude oil distillation unit of the oil refinery are analysed basing on obtained design parameters with the effect of flow movement arrangement in the unit and its influence on shear stress and fouling formation. The comparison of Plate-and-Shell and Compabloc types of welded PHE is discussed.

1. Introduction

The separation of the oil products into fractions such as LPG, naphtha, kerosene, diesel and atmospheric residue is carried out in the crude oil distillation unit due to the different boiling point temperatures. Oil refining is energy-intensive, requiring significant amounts of heat energy. From 7% to 15% of the crude oil input is used by the refinery processes, according to Szklo and Schaeffer [1]. The amount of energy consumed by the distillation unit comes up to 35–45% of the total energy consumption by the refinery [2]. Usually this process is performed by the crude oil heating by other products, available at the refinery, among which are light and heavy distillates, atmospheric residue and others. These hot products are pumped in the preheat trains prior to the distillation fire heater to increase the temperature of crude oil by heat recuperation. The bigger amount of recuperated heat can lead to considerable saving of energy required to be supplied in the fire heater and corresponding reduction of green house gases emission. But the increasing of heat recovery for the preheat train with traditional shell-and-tube heat exchangers (HE) requires additional heat transfer area in a number of locations. This has an adverse effect on economics considerations, as the installation of additional heat transfer area can be very expensive. One way to overcome this problem is to enhance the performance of heat exchangers with intensified heat transfer technique, as it is shown by Jiang et al. [3] on example of shell-and-tube HEs enhanced with tube inserts. Another important issue is to maintain the heat recovery on higher level over the period of plant operation before cleaning heat exchangers [4], that is also possible with fouling mitigation on intensified heat transfer surfaces.

The heat transfer intensification is an intrinsic feature of modern Plate Heat Exchangers (PHEs). The design and operation of PHEs are well described in the literature, e.g. [5]. PHE channels are formed by specially corrugated plates produced by stamping from thin metal sheets. It is observed that high heat transfer coefficients and low fouling tendencies are typical characteristics of PHE channels of complex geometry because of high levels of turbulence, effects that are similar in principle to those observed in enhanced tubes and tubes with inserts [6]. The advantages of PHEs in many applications were demonstrated by plate-and-frame type of PHEs, which were initially introduced in 1930th and gradually undergone significant improvements in their construction and design, especially in the last decades [7]. In many industrial applications plate-and-frame PHE has up to four times higher overall heat transfer coefficients than traditional shell-and-tube HEs at

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the same conditions, require much less material for heat transfer surface, much more compact and suitable for economically viable solutions [8]. It is confirmed by a number of researchers, as e.g. Hajabdollahi et al. [9] have found in their study case of water to water HE that the comparison of the optimum results for plate-and-frame PHE shown 13% improvement in the total cost compared with shell-and-tube heat exchanger at the same operating conditions. To similar conclusion came Perevertaylenko et al. [10] in their study of cost effective ways for amine absorption unit design in CO_2 post-combustion capture process. The use of PHEs in Heat Exchanger Network (HEN) of Absorption Desorption Unit allowed with the same or even 15% smaller purchased cost of heat exchangers to save up to 13% more energy as compare to optimised HEN with conventional shell-and-tube HEs.

Important feature of plate-and-frame PHE is its ability to be disassembled for mechanical cleaning of heat transfer surface, as the channels between plates are sealed by elastomeric gaskets. On the other hand, the presence of gaskets is limiting the range of plate-and-frame PHE application by temperatures lower than maximum 180 °C and pressures below 25 bar. In the construction of welded PHE the gaskets between plates are eliminated, that allows to widen significantly the range of its application on temperatures and pressures. Such PHEs can be used in preheat trains of crude oil distillation units with temperatures up to 350 °C [12]. Nowadays there are a number of different by construction principles types of welded PHEs produced by contemporary PHE manufacturers, as is discussed in a book by Klemes et al. [5]. In this paper are considered two recently most widely used types of welded PHEs: Plate-and-Block HE and Plate-and-Shell HE (PSHE).

The most known representative of Plate-and-Block type is Compabloc HE [11], which was originally developed and manufactured in 1980s. According to the data, published by Andersson et al. [12] for the moment of publication it was installed more than 750 Compabloc HEs in oil refineries around the world on different positions, among which 200 units were installed for operating in the crude oil preheat train. Comparing with the conventional shell-and-tube units, Compabloc is more compact and requires less space for installation. The value of surface area per unit volume for heat transfer core can reach up to 200 m^2/m^3 and more, while for shell-and-tube HEs this parameter is from 7 to 10 m^2/m^3. The complex channel geometry formed by the corrugated plates provides the different channel spacing, which varies from zero value in contact points to the double height of the corrugation in the largest gap.

The Compabloc heat exchanger is based on the square shaped plates welded in blocks arranged in different passes combination for hot and cold streams movement, see Fig. 1. At the presented picture each stream goes through four individual groups of plates with cross flow between two heat exchanging streams. The flows are directed into passes using the baffle plates extending across the whole cross-section of the heat exchanger collector. The hot stream enters the unit from the top, and cold from the bottom of the unit creating overall counter flow arrangement with cross flow in individual groups of plates. While cross flow is less effective for heat transfer, the conditions for streams distribution across individual channels are much better, than in conventional plate-and-frame PHE with pure counter flow. There are much smaller local hydraulic resistances in channels inlet and outlet zones, where the channel cross section area not changing so dramatically as in distribution zones of counter flow PHE. The stream is entering Compabloc PHE channel through the full its width, no additional change of cross section area. In plate-and-frame PHE and PSHE with parallel flow of streams (see Fig. 2) part of the channel width is blocked to arrange the outlet (or inlet) of opposed stream. It creates additional hydraulic resistance at channel inlet and exit.

The Plate-and-Shell type HE was first commercially produced by Vahterus Oy Company [13] in 1990s and now is manufactured by all major producers of PHEs. The PSHE consist of a number of welded together round plates, as shown in Fig. 2. The schematic drawing of heat transfer plate is presented in Fig. 3a. The plates with prolonged form are also manufactured by some producers. In this PHE the counter flow arrangement of streams can be organised and also multiple passes on both streams. The possible corrugations forms are presented in Fig. 3b. In Compablocks produced by AlfaLaval the triangular shape of corrugations is used (see Figs. 3b and 4).

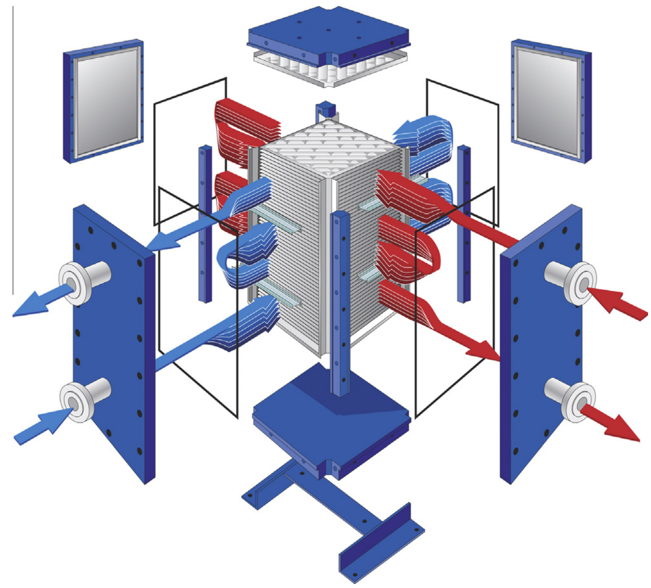

Fig. 1. The construction and operation principle of Compablock heat exchanger (courtesy of OAO AlfaLaval Potok).

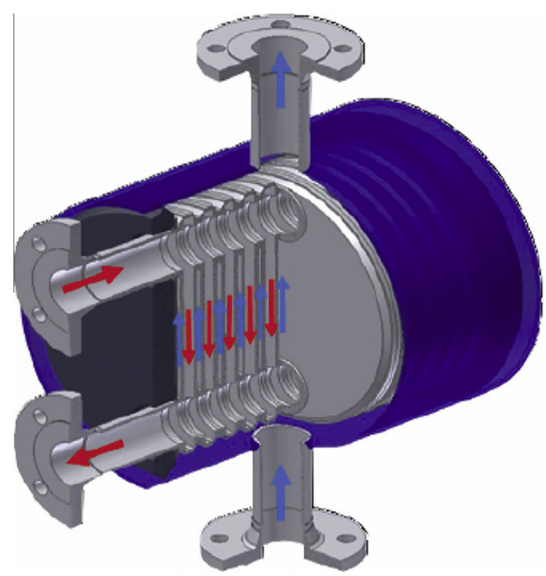

Fig. 2. The construction and operation principle of Plate-and-Shell PHE, after Freire and Andrade [14].

In some applications PSHE can be less costly than Compabloc HE and consume less material for production. Welded construction of plate pack prevents any intermixing between channels (Freire and Andrade [14]). PSHE allow using this type of heat exchangers for high temperature and pressure. They can be used for general cooling and heating duties, as condensers, evaporators, reboilers and steam heaters and operate under the temperature beyond