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Tube bundle replacement for segmental and helical shell and tube heat exchangers: Experimental test and economic analysis

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HIGHLIGHTS

- Helix bundle achieved two to three times of operation run times than segmental bundle.
- Inspections show little fouling on the helix bundle in comparison with segmental bundle.
- The total cost for helix bundle is less than segmental bundle.
- The effectiveness of helix bundle is obviously higher than that with segmental bundle.

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ABSTRACT

In this investigation, the second test analysis with more comprehensive evaluation with a focus on fouling mitigation, increased running-time and economic analysis are shown and then, the thermal design procedure for tube bundle replacement of critical heat exchanger of Butene-1 unit in Petrochemical Company as a case study are described. Finally, experimental data for the average heat transfer coefficient and pressure drop of shell-side in segmental and helix bundles are measured and calculated for the mass flow rate of 14.24 kg/s and then these data are compared with the data from code and EXPRESS. Moreover, additional comparison between code and EXPRESS results are provided to ensure the accuracy of calculation program in various mass flow rates. Based on the same shell in the case studies, the results showed that in addition to improved heat transfer performance of the helix bundle over segmental bundle, helix bundle achieved two to three times longer operational run times. From economic point of view, the results for replacement of segmental bundle with a helix bundle showed that initial and installation costs of helix bundle to segmental bundle could be increased, but maintenance and operating costs can be decreased in the helix bundle, 60% and 20%, respectively. Comparison between code and EXPRESS results with experimental data for the mass flow rate of 14.24 kg/s showed that the deviation in heat transfer coefficient and pressure drop are quite reliable for segmental and helix bundles.

1. Introduction

Shell and tube heat exchangers are regarded as the most prevalent equipments which contain a lot of percentage of heat transfer processes in various industries. Therefore, the increase efficiency of these equipments has always been aimed by designers as an important issue. In recent years, significant progress has been made in order to increase efficiency of these types of heat exchangers. One of these technologies which for the first time developed in the Czech Republic proposes helical baffles instead of segmental baffle in this type of heat exchanger. It worth mentioning that, a similar exchanger was also developed independently by a Norwegian group [1].

Helical heat exchanger, also known as a Helixchanger, minimizes the main shortcoming of the conventional segmental baffle design. ABB Lummus Company acquired Helixchanger technology from Vuchz, Czech Republic in 1994, which had already achieved excellent results in its own plants [2].

In a Helixchanger heat exchanger, the conventional segmental baffle plates are replaced by quadrant shaped baffles positioned at an angle to the tube axis creating a uniform velocity helical flow through the tube bundle. Four baffles make one set baffle and the fluid returns to its starting situation after crossing the set. Near plug flow conditions are achieved in a Helixchanger heat exchanger with little back-flow and eddies [3]. Exchanger run times are increased

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by two to three times than those achieved using the conventionally baffled shell and tube heat exchangers. Heat exchanger performance is maintained at a higher level for longer periods of time with consequent savings in total life cycle costs (TLCC) of owning. Feedbacks on operating units are presented to illustrate the improved performance and economics advantages achieved by employing the Helixchanger heat exchangers [4]. In Helixchanger, the shell-side flow configuration offers a very high conversion of pressure drop to heat transfer. Effective bundle penetration leaves no stagnant areas where fouling may accumulate. Quadrant shaped baffle plates in a Helixchanger can be spaced to reduce unsupported tube spans without affecting pressure drop or heat transfer characteristics. Tube bundles in a Helixchanger are safer against flow-induced vibrations [5].

Optimum design of a Helixchanger heat exchanger offers the following characteristics:

- Uniform flow velocities through the tube bundle offering uniform film and metal temperatures
- Elimination of backflow and eddies
- Shell-side flow approaches plug flow conditions improving the temperature driving force
- Improved shear stress at the heat transfer surface achieved by higher flow velocities with the same pressure drops.
- Reduced shell size achieved with the Helixchanger heat exchanger, offers higher tube-side velocities as a secondary benefit in reducing the tube-side fouling rates as well.

All of the above characteristics achieved in a Helixchanger heat exchanger contribute significantly in lowering the fouling tendency and maintaining higher performance over longer run cycles as compared to conventional heat exchangers [4].

This paper studies the performance of tube bundle replacement for segmental and helical baffles by experimental method. A heat exchanger with segmental bundle has been selected as a case study for replacement. Fig. 1 illustrates helical baffles arrangement with overlap in the case study of this work. The aim of the replacement was to reduce fouling and improve heat transfer of the critical heat exchanger and; as a result, reduce operation and maintenance costs. In addition to the issues outlined in the companion paper [6], in this paper the second test results with more comprehensive evaluation with a focus on fouling mitigation, increase running-time and economic analysis is presented. Initial and installation costs for tube bundle replacement and operating cost and maintenance cost for an annual working cycle of tube bundle were analysed. Also, a computational code developed by authors based on well-known Bell–Delaware method has been used as thermal design calculation of tube bundles. Finally, experimental data for the average heat transfer coefficient and pressure drop of shell-side in segmental bundle and helix bundle have been measured and calculated for the mass flow rate of 14.24 kg/s. The heat transfer and pressure drop measurements of the present work are compared with the data from code and EXPRESS [7]. Moreover, additional comparison between code and EXPRESS results has been provided to ensure the accuracy of calculation program in various mass flow rates.

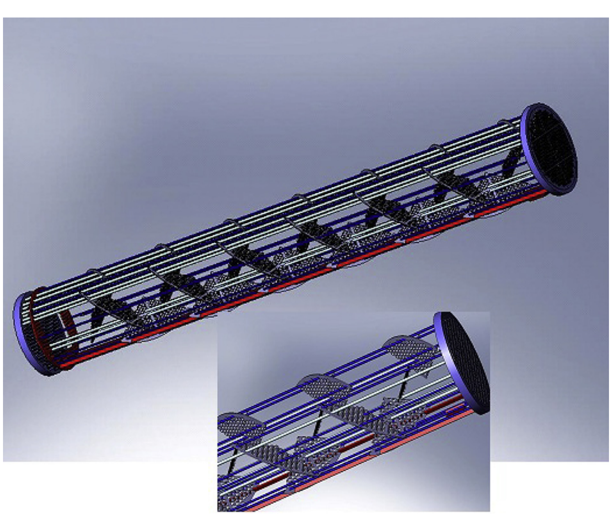

Fig. 1. Helical baffles configurations in the case study of this work.

2. Descriptions of a case study

Segmental shell and tube heat exchanger which named 12-E-301, 'AES' (TEMA type), from Butene-1 unit in Tabriz Petrochemical Company/Iran is the main subject of this study due to its critical position in the unit. This part of the process in the unit consists of two parallel heat exchangers. At any time, one of them works and the other one is in standby mode. Tube-side fluid, Butene-1, is cooled from 55 °C to 50 °C and then sent to Reactor R-300 for polyethylene reactions. This mass transfer in tube-side is highly susceptible to chocking. In the other side, cooling water is used as shell-side fluid for this application which to some extent is corrosive. Considering the reported high fouling tendency, high overhaul costs caused by short running-times, and unsatisfactory performance, a new design or a new heat exchanger needed to be replaced in order to reduce its maintenance and operation costs [6]. The process input and physical properties for 12-E-301 are listed in Table 1. In order to investigate the criticality reasons of selected heat exchanger, three major steps were conducted: cooling water analysis in shell-side inlet and outlet, shell-side fouling analysis, and shell-side flow characteristics study.

2.1. Cooling water analysis in shell-side inlet and outlet

For the sake of determining state of the system, chemical analysis of water was conducted in shell-side inlet and outlet of the heat exchanger. Analysing parameters were: pH, temperature, free chloride, alkaline, conductivity, TDS (Total Dissolved Solids), phosphate content, oxygen content, total Fe (Iron) content, and microbial contamination.

This research studied oxygen content, total Fe and phosphate contents values. During 12 days of experiment, water sampling was carried out at six different times. Fig. 2(a) shows deviation in oxygen content in shell-side inlet and outlet in this period. The rate of changes in oxygen content shows that an active corrosion exists in the system. A reduction in oxygen content in shell outlet indicates that oxygen is consumed in oxidation reaction and it represents the

Table 1
The process input and physical properties for 12-E-301.

	Tube side (Butene-1)	Shell side (cooling water)
Inlet temperature, T_i (°C)	55	27
Outlet temperature, T_o (°C)	50	37
Mass flow rate, m (kg/s)	40.66	14.24
Density, ρ (kg/m^3)	499	995.8
Constant pressure specific Heat, C_p (J/kg K)	2964	4179
Viscosity, μ (Pas)	0.00009	0.00086
Fouling resistance, R_f (m^2 K/W)	0.0034	0.00034
Thermal conductivity, k (W/mK)	0.09	0.614