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Thermal Performance Assessment of Heat Exchangers In An Industrial Ethylene Production Facility

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Abstract

This study provides a comprehensive performance assessment of three critical heat exchanger units (2-H-301, 3-H-601, and 3-H-501) within an industrial Ethylene production facility in Ras Lanuf plant. Steady-state monitoring and direct data acquisition from operational equipment were conducted with subsequent data analysis performed using energy balance equations to quantify key thermal performance parameters. These parameters included overall heat transfer coefficients, heat duties, hot and cold fluid temperature and pressure ranges, capacity ratios, and effectiveness of each exchanger. Results reveal that the 2-H-2301 unit exhibits an overall heat transfer coefficient over 50% below the design specification and a heat duty exceeding 80% of the intended design. In the 3-H-901 unit, both heat duty and overall heat transfer coefficient were observed to fall over 75% below design standards, likely due to fouling, which adversely impacted effectiveness, capacity ratio, and the temperature profile of hot and cold streams. Conversely, performance of the 3-E-401 exchanger was within acceptable limits, with the heat duty, hot-side temperature differential, and capacity ratio aligning closely with design expectations. These findings offer a rigorous qualitative performance evaluation of the heat exchangers, highlighting areas requiring operational optimization to maintain design efficiency within industrial polyethylene processes.

Keywords: heat-exchanger, heat, performance, energy

1. Introduction

Heat exchangers are critical components in industrial applications, designed to transfer thermal energy between two fluids separated by a solid barrier. These devices are essential for processes involving high temperature and pressure conditions or requiring the handling of large fluid volumes for heating or cooling purposes. Diverse types of heat exchangers have been engineered, tailored to specific applications through variations in flow configurations, construction, and operational principles. Widely utilized in industries such as space heating, air-conditioning, power generation, oil distillation, waste heat recovery, and chemical processing, heat exchangers play a crucial role in efficient energy management. In a polyethylene production plant, for example, heat exchangers facilitate the controlled transfer of thermal energy between process fluids, enabling temperature regulation, steam generation, and phase separation essential to the plant's operation.

Heat exchangers are generally categorized by flow arrangement—either counter-current or co-current (parallel flow)—and construction type, including tubular, plate, and shell-and-tube configurations. Recent advancements have focused on optimizing heat exchanger performance through various evaluation methods, with enhanced surfaces playing a prominent role. These surface enhancements are typically divided into passive and active methods. Passive methods, which improve efficiency without external energy input, include extended surfaces, inserts, twisted or finned tubes, surface treatments, and additives. Such innovations contribute significantly to the improved thermal performance and versatility of heat exchangers across diverse industrial applications.

Active enhancement techniques for heat exchangers include methods such as surface vibration, electrostatic fields, and suction, each aimed at boosting efficiency by influencing fluid dynamics within the system. Recent studies have employed the effectiveness-NTU (number of transfer units) approach to predict thermodynamic performance, particularly in Joule-Thomson refrigerators using nitrogen and argon gases. Findings indicate that while the effectiveness of heat exchangers decreases with increased mass flow rate, cooling capacity remains stable under high pressures. Design improvements in shell-and-tube heat exchangers have also been explored, informed by practical experience and numerical analysis. By examining various geometries through both theoretical and experimental methods, particularly within chemical processing applications, researchers identified that geometry near the outlet is critical to the performance, maintenance, and lifespan of vertical shell-and-tube evaporators. This work provides an experimentally validated modeling approach that assists in optimizing design decisions and understanding wear mechanisms essential for enhanced durability and efficiency.

Recent studies have explored performance enhancements in heat exchangers using the method of characteristics. In one study, airflow within the heat exchanger was modeled as one-dimensional and unsteady, enabling the simplification of governing equations into non-homogeneous first-order partial differential equations. This approach allowed for the assessment of fin improvement factors on mean air temperature, mean heat transfer rate, and air properties in the heat exchanger. Numerical results under specified operating conditions were validated against experimental data, using air and heat exchanger thermal conductivities of 0.0099 J/smK and 117.49 J/smK, respectively. Complementing these findings, computational fluid dynamics (CFD) simulations using Fluent software have been employed to predict heat transfer behavior in shell-and-tube heat exchangers, with simulation outcomes showing good alignment with experimental results. This integrated approach highlights the effectiveness of combining theoretical, numerical, and simulation techniques for comprehensive performance evaluation and optimization in heat exchanger design.

This study investigates the heat transfer and pressure drop characteristics in the shell side of helically baffled heat exchangers, combining experimental measurements with numerical simulations. Using commercial CFD software, flow fields and heat transfer performance were simulated in the shell side, and the numerical results for Nusselt numbers and pressure drops aligned closely with experimental data, underscoring the utility of CFD simulations in optimizing heat exchanger efficiency. Additionally, exergy analysis has emerged as a valuable performance evaluation tool. By comparing effectiveness (based on the first law of thermodynamics) with exergy (considering both the first and second laws and system irreversibility), researchers can gain a more comprehensive understanding of system efficiency through exergetic efficiency. Numerical analyses have also been extended to plate heat exchangers, particularly to assess performance in co-current flow configurations, providing insights into fluid flow and thermal performance.

This study presents a theoretical and numerical analysis of a co-current plate heat exchanger. Using known inlet temperatures for hot and cold fluid streams, their respective heat capacities (mCp), and the overall heat transfer coefficient, a one-dimensional mathematical model based on steady-state energy balance was developed for various device lengths. This model yielded a set of first-order differential equations with boundary conditions, where the number of equations corresponded to the number of channels. The shooting method was used to numerically solve the equations, enabling predictions of temperature distributions within the heat exchanger and an evaluation of its thermal performance. A parametric analysis further examined the effects of NTU and heat capacity rate ratios on exchanger performance. Simulation results were validated against theoretical predictions, showing excellent agreement and demonstrating the model's accuracy in performance evaluation.

This study explores the impact of surface coatings on the performance of compact plate heat exchangers, focusing on coating effectiveness and fouling behavior over time. In an experimental investigation, both coated and uncoated heat exchangers exposed to untreated lake water were analyzed over various time periods, with transient observations capturing changes in heat transfer surface appearance. Results showed that fouling rates were significantly lower in coated plates, which accumulated deposits up to 50% slower than uncoated plates, resulting in approximately 20% better performance retention. Over time, however, the thermal performance of all units declined, potentially leading to undersized exchangers. The study concludes that customized enhanced plates, produced by Ridgidized Metal Corporation, provide a promising solution for mitigating fouling and sustaining higher thermal efficiency in plate heat exchangers.

This study evaluates heat transfer enhancement techniques in tube-in-tube heat exchangers, particularly focusing on affordable augmentation methods for small manufacturers. Three simple yet effective techniques were explored to improve heat transfer within the annulus: (i) inserting a round tube inside a twisted square tube to increase rotational flow, achieving a 50% boost in heat transfer coefficient and a 9% rise in friction factor; (ii) incorporating a spiraling tube within the annulus to induce swirl flow and expand cross-sectional flow area, allowing fluid to move through both the annulus and spiraled tube; and (iii) utilizing angled spiraled tape to create swirl in the annulus. Results indicated a 206% increase in the Nusselt number for exchangers with smaller pitch angles and flow opposing tape curvature. Among the techniques examined, angled spiraling tape inserts proved the most effective for enhancing heat transfer performance, offering a promising solution for efficient and cost-effective heat exchanger design.

2. Materials and Methods

The research methodology involved the following:

1- Direct collection of data from the equipment in the plant and operation log books from Ethylene production facility in Ras Lanuf plant.
2- Field investigation and observation of the various heat exchanger units.

The parameters considered during the data collection were inlet and outlet temperature and pressure of the process fluid, cooling water and the flow rate. In the analysis and treatment

of the data, mean values of daily parameters were computed using statistical methods. This was followed by monthly average and the overall average for the period the research is carried out. From this, such parameters as temperature and pressure ranges, heat duty, capacity ratio, effectiveness and overall heat transfer coefficient were determined.

Analytical model: A typical shell and tube heat exchanger is shown in Fig. 1 below. The various equations used in the analysis are also presented.

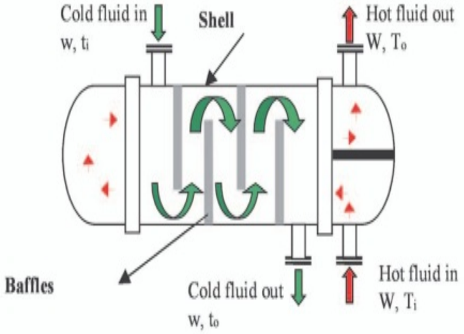

Fig.1 Diagram of shell and tube heat exchanger

Pump around cooler is a co-current heat exchanger which is mainly used in the dimerization process and used for the production of butene-1 by IFP (process licensor). The dimerization reaction is exothermic; thus, the heat of reaction is removed by the pump around cooler. The process passes the tube-side and cooling water the shell-side. The first stage condensers are vertical single-pass water cooled heat exchangers responsible for cooling cyclohexane solvent vapour flash separated from molten polymer which is the first stage low pressure separator. The solution pre-heater are responsible for solution heating. That is increasing the reactor outlet solution temperature to the solution absorbers in order to promote the adsorption of catalyst residues on an activated alumina bed in the solution absorbers. DTA (dowtherm synthetic organic heat transfer fluid) is used instead of steam as the heating medium.

Overall Heat Transfer Coefficient U: This is defined by the relation

$$U = \frac{Q_h}{ALMTD} \quad KW/m^2K$$

Where $Q_h = mC_{ph}(t_{hi} - t_{ho})\ KW$ $\qquad$ $Q_h = m\ C_{ph}\ (t_{hi} - t_{ho})$

$$A = Heat\ transfer\ Area \qquad LMTD = \frac{(t_{hi} - t_{ci}) - (t_{ho} - t_{co})}{\ln(\frac{(t_{hi} - t_{ci})}{(t_{ho} - t_{co})})}$$

where Q_h Heat duty of the hot fluid

m - mass flow rate

Cp_h - specific heat capacity of hot fluid

t_{hi} - inlet temperature of hot fluid

t_{ho} - outlet temperature of hot fluid

2.2. Capacity Ratio (R): This is the ratio of the temperature range of the hot fluid to that of the cold fluid.

$$R = \frac{t_{hi} - t_{ho}}{t_{co} - t_{ci}}$$

where: t_{ci} – inlet temperature of cold fluid

t_{co} - outlet temperature of cold fluid

3. Results and Discussions

Performance evaluation was based on steady state monitoring and direct collection of data from the various heat exchanger units in the plant. The data measured were inlet and outlet temperatures of hot and cold fluid and inlet and outlet pressures. The various monthly average calculated values of **Q,U**

Table 1 Calculated average values

S/NO	Q_h(W)	Δt_h	Δt_c	R	P	U (W/m^2.c^o)	LMTD
1.00	12604.88	13	10	1.3	0.59	34	4.13
2.00	16774.29	15	10	1.5	0.53	40.26	4.63
3.00	26917.45	19	10	1.9	0.43	48.32	6.19
4.00	36074.016	22	10	2.2	0.38	57.26	7.00
5.00	39448.00	23	10	2.3	0.37	61.82	7.09
6.00	46595.25	25	10	2.5	0.34	69.00	7.51
7.00	54365.904	27	10	2.7	0.32	73.67	8.20
8.00	62704.73	29	10	2.9	0.30	75.48	9.23
9.00	71638.27	31	10	3.1	0.29	86.81	9.17
10.00	86189.80	34	10	3.4	0.26	98.32	9.74
11.00	81201.58	33	10	3.3	0.27	93.69	9.63
12.00	86189.80	34	10	3.4	0.26	98.32	9.74
13.00	91326.69	35	10	3.5	0.26	101.47	10.00
14.00	102085.81	37	10	3.7	0.24	107.52	10.55
15.00	113402.48	39	10	3.9	0.23	122.21	10.31
16.00	125313.88	41	10	4.1	0.22	124.88	11.15
Average	65802.05	28.56	10	2.86	0.33	80.81	8.39

Table 2 Comparing average outputs with design numbers

PARAMETER	UNITS	TEST DATA	DESIGN DATA
HEAT DUTY(Q_h)	W	65802.05	75116.5
HEAT TRANSFER COEFFICIENT (U)	W/m^{2}C^o	80.81	166.96
TEMPERATURE RANGE HOT FLUID (ΔT)	(C ^{o})	28.56	31.95

TEMPERATURE RANGE COLD FLUID (Δt)	**(C^{o})**	10	8.83
LMTD	**(C^{o})**	8.39	10.79

4. Conclusions

Heat exchangers are vital part of the process plant in which they are installed in terms of heat transfer within the plant. As such, in order to maintain them at high efficient level. A periodic performance evaluation of the equipment is required.

This paper has considered the overall heat transfer coefficient, heat duty, capacity ratio, and effectiveness as relevant parameters for the evaluation of the heat exchanger performance using steady state monitoring and direct collection of data from the equipment in the plant. The results were compared with the equipment design data and this provided qualitative performance evaluation of the heat exchangers.

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