# EVALUATION STUDY ON PERFORMANCE OF HEAT EXCHANGER – 4000 IN CENTRAL PROCESSING AREA PT. PERTAMINA EP ASSET 4 SUKOWATI FIELD

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***Abstract***

*PT Pertamina EP Asset 4 is one of Pertamina's subsidiaries operating in the oil and gas industry. In its production process, PT Pertamina EP Asset 4 requires heat exchangers for various purposes. Impurities on the shell and tube walls is unavoidable, which, if left unchecked, will disrupt the efficiency of the heat exchanger. These impurities accumulate over time and hinder the heat exchanger's efficiency due to debris adhering to the shell and tube surfaces. Therefore, this calculation is aimed at determining the heat transfer efficiency during industrial processes. Heat efficiency, which describes the ratio of heat transferred from a high-temperature fluid (water) to a low-temperature fluid (oil) per unit of time, is a crucial metric for evaluating the effectiveness of the heat exchanger. The research findings show that the overall net coefficient ($U_c$) and overall design average coefficient ($U_d$) are recorded at 88.2422 Btu/ft$^2$.hr.°F and 51.7160 Btu/ft$^2$.hr.°F, respectively. Meanwhile, the fouling factor ($R_d$) is assessed at 0.0079 ft$^2$.hr°F/Btu. Based on the significant difference between Uc and Ud as well as the high Rd value, it can be concluded that the heat exchanger unit has experienced considerable fouling, necessitating a special mechanical cleaning to restore its performance.*

***Key words :*** *heat efficiency, heat exchanger, shell and tube.*

## INTRODUCTION

PT. Pertamina EP Asset 4 is a subsidiary of Pertamina specializing in the upstream sector of the oil and gas industry, encompassing exploration and exploitation activities. It was established on September 13, 2005. Subsequent to the establishment of PT. Pertamina EP, PT Pertamina (Persero) entered into a Cooperation Contract (KKS) with BPMIGAS (now SKKMIGAS) on September 17, 2005. This contract, which retroactively came into effect on September 17, 2003, grants authority over the entire Oil and Gas Mining sector delegated through legislation outlined in Law Number 22 of 2001 concerning Oil and Gas [1]. A heat transfer device is deemed effective in its application when it meets certain criteria, particularly the capability to transfer heat as required by the operational process within a fouling factor or $R_d$. Typically, the dirt factor of a heat exchanger is assessed over several periods. As this period elapses, the Heat Exchanger may struggle to operate efficiently due to contaminants accumulating on the shell and tube walls. To prevent this, periodic shutdowns and cleaning of the Heat Exchanger are necessary. Rd represents the maximum impact of dirt accumulation on the exterior of the shell and the interior of the tube walls, which, if left uncleansed, diminishes the heat transfer capacity [2]. Heat exchangers operate based on three fundamental modes of heat transfer: conduction, convection, and, in some cases, radiation. In shell and tube heat exchangers, conduction primarily occurs through the tube wall material, while convection dominates the heat exchange between the fluids and the tube surfaces. The performance of a heat exchanger depends largely on the overall heat transfer coefficient (U), which is influenced by the material thermal conductivity, fluid velocity, and the degree of surface cleanliness. The shell and tube type typically consists of a bundle of tubes enclosed within a cylindrical shell, where one fluid flows through the tubes and another fluid passes over the tubes within the shell side. Baffles are commonly installed to enhance turbulence and improve heat transfer efficiency by increasing the fluid mixing on the shell side.

The thermal design of a shell and tube heat exchanger aims to achieve a high rate of heat transfer while maintaining a reasonable pressure drop on both fluid sides. Key parameters influencing

its performance include the tube arrangement (triangular or square pitch), flow configuration (counter-flow, parallel-flow, or cross-flow), and the number of passes through the tubes. Among these, the counter-flow configuration generally offers the best thermal performance, as it maintains a higher mean temperature difference between fluids along the exchanger length. In industrial applications, however, the actual performance often deviates from design expectations due to fouling, corrosion, and partial blockage within the tubes or shell passages.

Fouling, defined as the accumulation of unwanted materials on heat transfer surfaces, can originate from multiple sources such as crystallization of salts, corrosion products, biological growth, or particulate deposition. Each fouling type contributes differently to thermal resistance and pressure loss. In hydrocarbon systems, especially in crude oil processing, the most common fouling issues arise from asphaltene and wax deposition, which can form hard layers on tube walls and significantly lower the overall heat transfer coefficient (U). The relationship between fouling and efficiency degradation is nonlinear, meaning even a small fouling layer can cause a substantial reduction in thermal performance.

Heat exchangers are increasingly being utilized in a variety of sectors to reduce and raise temper-atures in order to fulfill the technical requirements of different goods. Chemical plants, factories, office buildings, hospitals, and power plants are among the industries that employ heat exchangers [3]. In the oil and gas industry, heat exchangers are essential equipment for temperature regulation in processes such as crude oil stabilization, gas dehydration, and produced water treatment. Maintaining high thermal efficiency directly impacts the operational cost and safety of these processes. A decrease in heat transfer efficiency results in increased fuel consumption, production downtime, and potential operational hazards due to temperature deviations. Therefore, a periodic performance evaluation is crucial to ensure the exchanger continues to meet design expectations while minimizing energy losses. In the operational environment of Central Processing Areas (CPA), where crude oil and produced water are continuously processed, maintaining the heat exchanger's reliability is a crucial part of asset integrity management. Thermal inefficiencies not only lead to increased fuel consumption but can also disrupt separation efficiency in downstream units such as three-phase separators and dehydrators. Hence, predictive maintenance and periodic thermal performance assessments have become an integral practice in petroleum operations. The evaluation of fouling tendencies under real operating data, such as temperature and flow rate variations, provides valuable insights into the actual condition of the exchanger and helps determine the optimal cleaning intervals.

Furthermore, modern performance evaluations increasingly integrate computational methods such as process simulation or data-driven monitoring using digital twins. However, such systems must still rely on accurate field measurements to validate models. Thus, analytical evaluations—like those performed in this study—remain a vital step for ensuring operational safety and maintaining heat transfer performance within design specifications.

According to [4], the efficacy of the shell and tube of the Heat Exchanger with the COG Booster system was 37.4%. According to [5], the effectiveness value obtained on shell and tube of Heat Exchangers utilizing four baffles is 43%. The efficacy value found in the study by [6] on the Heat Exchanger with the Kern technique was 76.0613%. The Heat Exchanger then received a 47.77% efficacy rating in research conducted by [7]. In research done by [8], the efficacy of a shell and tube heat exchanger with baffles 15 cm apart was 82.13%. Whereas according to studies done by [9], the efficacy value for the shell and tube Heat Exchanger type BEM is 70%. The previous studies demonstrate a wide variation in efficiency among different shell and tube configurations, depending on baffle spacing, flow arrangement, and fouling accumulation. However, limited research has specifically addressed the performance of field-operated heat exchangers under real production conditions, particularly in upstream oil facilities. This research fills that gap by providing an in-depth evaluation of the HE-4000 unit operating in the Central Processing Area (CPA) of PT Pertamina EP Asset 4 Sukowati Field. The findings are expected to serve as a reference for optimizing maintenance intervals and improving operational reliability. Given the high operating temperature and the multiphase nature of crude oil streams, the HE-4000 heat exchanger is particularly vulnerable to fouling and scaling over extended operation periods. Factors such as variable crude composition, water cut, and intermittent shutdowns can accelerate fouling formation, resulting in a reduced effective heat transfer area. Therefore, continuous monitoring of temperature differentials between the shell and tube sides is essential for early detection of performance deterioration. Evaluating the actual fouling factor ($R_d$) relative to its design value enables engineers to determine whether the exchanger still operates within acceptable limits or requires immediate cleaning actions.

There is just one heat exchanger at CPA (Central Processing Area) PT. Pertamina EP Asset 4 Sukowati Field. The HE-4000 (Heat Exchanger

4000) receives crude oil and water from the well and functions as a heater to warm up the crude oil before it undergoes the FSO (Floating, Storage, and Offloading) process, preventing the product from gelling when transported from CPA to FSO. The type of heat exchanger used is Shell and Tube. The benefits of shell and tube Heat Exchanger are that the pressure drop can be varied according to the capacity of the heat exchanger, and maintenance is relatively easier because it can be dismantled and assembled [10].

The purpose of the study was to evaluate the performance of the Heat Exchanger (E-4000 in Pertamina EP Asset 4 Sukowati Field).

## MATERIAL AND METHODS

Metode Data collection is needed to evaluate the heat exchanger (E – 4000). The evaluation process involves both field data collection and analytical calculations. The performance of a heat exchanger can be assessed by comparing its actual thermal behavior to the design parameters. In this study, the analysis focuses on quantifying the extent of fouling accumulation through thermal resistance calculations. Therefore, the measured parameters include inlet and outlet temperatures of both fluids, flow rates, and the corresponding operating pressure on each side. These data were obtained directly from the CPA control system logs and daily operation records to ensure that they represent normal operating conditions. The data utilized is the heat exchanger (E – 4000) work data from August 17, 2021 to August 23, 2021. This information will subsequently be used to determine the Dirt Factor ($R_d$). Following the collection of these data, it is possible to determine whether or not the heat exchanger needs to be cleaned. All processes are represented using flow charts, which is meant to clarify the processes to be performed, to decision making from problem formulation. The flowchart illustrates the overall sequence of the analytical evaluation, starting from data acquisition, preprocessing, calculation of thermal parameters, and interpretation of results. The steps were carried out systematically using spreadsheet-based computation for efficiency and transparency.

The HE-4000 unit is a horizontal shell and tube heat exchanger installed at the Central Processing Area (CPA) of the Sukowati Field. The unit operates under continuous oil-water processing with water as the cooling medium in the tube side and crude oil as the hot fluid in the shell side. It is designed to prevent crude oil solidification during transfer to the Floating Storage and Offloading (FSO) facility. The heat exchanger is equipped with a removable tube bundle, enabling periodic mechanical cleaning when fouling exceeds design limits.

This design configuration makes it representative of typical field units used in upstream oil production, where both reliability and maintainability are key performance indicators.

Table 1 Tube and shell temperature

| Date | TUBE (WATER) | | SHELL (OIL) | |
|---|---|---|---|---|
| | IN (°F) | OUT (°F) | IN (°F) | OUT (°F) |
| **17/08/2021** | 219 | 216 | 117 | 150 |
| **18/08/2021** | 221 | 218 | 116 | 150 |
| **19/08/2021** | 223 | 219 | 116 | 149 |
| **20/08/2021** | 222 | 219 | 119 | 150 |
| **21/08/2021** | 223 | 220 | 117 | 148 |
| **22/08/2021** | 222 | 218 | 117 | 151 |
| **23/08/2021** | 222 | 219 | 118 | 150 |

Table 2. Tube and shell flow rate

| Date | TUBE (WATER) FLOW RATE (BWPD) | SHELL (OIL) FLOW RATE (BOPD) |
|---|---|---|
| **17/08/2021** | 35400 | 4306 |
| **18/08/2021** | 35400 | 4172 |
| **19/08/2021** | 35900 | 4124 |
| **20/08/2021** | 35200 | 4204 |
| **21/08/2021** | 36300 | 4135 |
| **22/08/2021** | 36500 | 4110 |
| **23/08/2021** | 36500 | 4175 |

The monitoring period was selected to represent a stable production window without any planned shutdowns, ensuring that the operating data reflected steady-state behavior. The data were then validated through cross-checking with historical averages to minimize anomalies caused by sensor drift or operational disturbances. The reliability of these data is essential because even a minor deviation in temperature readings can significantly affect the calculated heat transfer coefficient and fouling factor.

During the observation period, environmental conditions such as ambient temperature and cooling water temperature were relatively constant, with variations below ±2°F. Such stability ensures that changes in thermal performance can be primarily attributed to fouling effects rather than external factors.

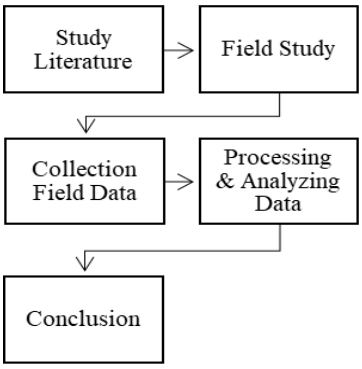


Figure 1. Research block diagram

## RESULT AND DISCUSSION

Based on the results of data processing, The evaluation began by comparing the measured operating data with the heat exchanger design specifications. These comparisons provide insight into how closely the field operation aligns with expected thermal behavior. The recorded data include daily variations in temperature and flow rate for both fluids, which directly influence the rate of heat transfer. Before detailed calculations were conducted, the data were plotted to visualize temperature trends and to identify any anomalies that may indicate operational disturbances. The data acquired in the form of real data and heat exchanger design data (E-4000) are presented in the following graph:

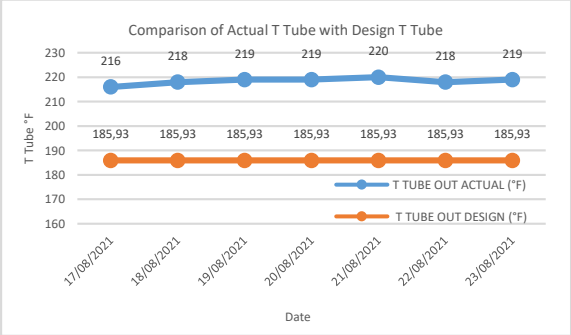


Figure 2 Comparison of actual T tube with design T tube

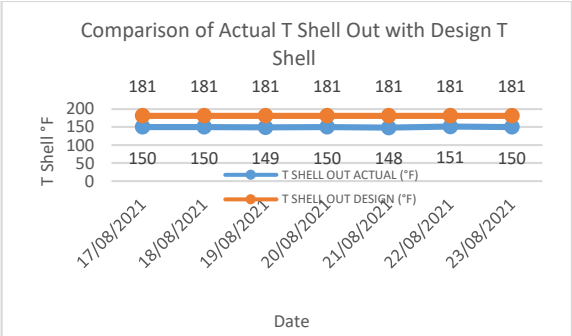


Figure 3 Comparison of actual T shell out with design T shell

As shown in Figure 2, the actual outlet temperature of the tube side (cooling water) exhibits a gradual decrease in comparison to the design value. This deviation suggests a reduced heat absorption capacity by the tube-side fluid, which may result from thermal resistance caused by fouling on the inner tube walls. Conversely, Figure 3 demonstrates that the shell-side outlet temperature (crude oil) remains slightly lower than design expectations, indicating that the intended heat delivery to the shell fluid is not fully achieved. The temperature difference between the shell and tube outlets (ΔT) can therefore serve as an indicator of the exchanger's decreasing performance over time.

The average deviation in tube outlet temperature during the observation period was approximately 2–3°F below design, while the shell-side outlet temperature was 1–2°F below design. These differences, though small numerically, can significantly affect the overall heat transfer rate due to the high flow rate and large surface area involved. In heat exchanger systems, even a few degrees of reduction in temperature differential may correspond to several percent loss in thermal efficiency.

The data collected from the field were then calculated through the following equations, the calculation of Fouling Factor (Rd) from Overall Coefficient (Uc) based on the first equations (Kern,1965)

$$U_C = \frac{h_{io} + h_o}{h_{io} \times h_o} \quad \text{.....(1)}$$

$U_c$ = Clean overall Coefficient, btu/hr.ft$^2$.°F
$h_o$ = Shell heat transfer coefficient,, btu/hr.ft$^2$.°F
$h_{io}$ = tube heat transfer coefficient, btu/hr.ft$^2$.°F

Design Overall Coefficient (Ud) calculated from the equations below

$$U_d = \frac{Q}{A \times \Delta T} \quad \text{.....(2)}$$

$U_d$ = Overall Heat Transfer Coefficient, btu/hr.ft$^2$.°F
A = Total surface

From the equations (1) & (2) then the fouling factor ($R_d$) could be determined as follow:

$$R_d = \frac{U_c - U_d}{U_c \times U_d} \quad \text{.....(3)}$$

The calculation results show that the clean overall heat transfer coefficient ($U_c$) is considerably higher than the design overall coefficient ($U_d$). This indicates that the exchanger's effective heat transfer area has been reduced by fouling layers. The fouling factor ($R_d$)acts as an additional thermal resistance in series with the metal wall and film resistances on both sides. As the thickness of the fouling layer increases, the overall heat transfer coefficient decreases exponentially.

In this study, the fouling factor reached an average value of 0.0079 ft²·hr·°F/Btu, which is significantly higher than the typical design range for shell-and-tube exchangers handling clean fluids (generally 0.001–0.002 ft²·hr·°F/Btu). Such high resistance values suggest substantial accumulation of deposits on the tube walls. The difference between Uc and Ud values also indicates a notable decline in heat transfer efficiency, approximately 40% below design performance.

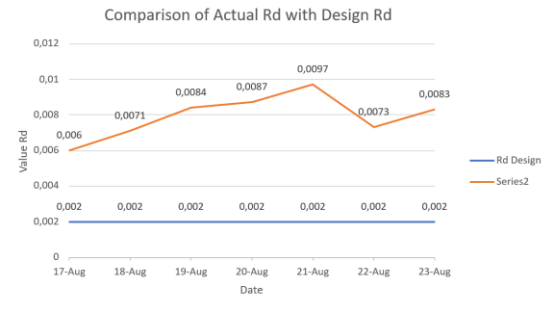


Figure 4. Comparison of actual $R_d$ with design $R_d$

The temperature for the tube and shell output does not match the design temperature, as shown in figure 1 and 2 from August 17, 2021 to August 23, 2021. The discrepancy in temperatures is due to the heat exchanger's high fouling factor. Figure 3 shows that the actual fouling factor ($R_d$) is higher than the design fouling factor ($R_d$). This indicates that the heat exchanger's inner and outer tube walls have crust, resulting in less efficient heat transmission from the heat exchanger. As a result, cleaning the heat exchanger is required to lower the value of Rd and increase the efficiency of heat exchange once more.

Overall, the results indicate that the HE-4000 unit operates below its optimal efficiency due to fouling accumulation. The thermal resistance value obtained suggests that the exchanger should be scheduled for mechanical cleaning within the next maintenance window. Implementing a predictive maintenance system based on continuous temperature and flow monitoring could prevent severe efficiency degradation. Furthermore, adjusting the cooling water flow rate or applying antifouling treatments may help delay the formation of deposits. These recommendations are expected to enhance the exchanger's operational lifespan and energy efficiency.

In addition to maintenance optimization, future improvement efforts could also involve material selection and design modification. Using corrosion-resistant or low-fouling tube materials such as stainless steel or titanium can reduce the rate of deposit buildup and extend cleaning intervals. Incorporating surface enhancement techniques, such as coating or micro-grooved surfaces, may further improve heat transfer by promoting turbulence and minimizing fouling adhesion. Moreover, regular chemical cleaning using environmentally friendly descaling agents could be integrated into the maintenance schedule to complement mechanical cleaning methods.

From an operational standpoint, data-driven monitoring systems offer a promising approach to manage heat exchanger performance. By combining historical data with real-time analytics, operators can predict fouling trends and determine the most cost-effective maintenance intervals. This integration of conventional engineering analysis with digital monitoring technologies supports the broader goal of achieving energy efficiency and sustainability in petroleum processing facilities.

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By calculation, the heat exchanger E-4000 has a lower heat transfer than the design due to the inhibiting factors such as crust on the inner and outer tube walls. The computed Rd value between Agustus 17, 2021 and Agustus 23, 2021 is higher than the design Rd value, indicating that the heat exchanger requires cleaning. The E-4000 heat exchanger is still usable in August 2021, but it will need to be cleaned to reduce the actual fouling factor and increase the heat transfer efficiency. In addition, the higher fouling factor shows that deposits on the tube surface significantly decrease the overall heat transfer coefficient (U). This condition leads to reduced energy efficiency and limits the exchanger's ability to achieve the desired outlet temperature for both shell and tube fluids. Regular maintenance and cleaning schedules are therefore needed to maintain performance close to design values. It is also recommended that performance monitoring be carried out periodically to detect early fouling

buildup, allowing corrective actions before severe efficiency loss occurs. The implementation of preventive measures—such as optimizing fluid velocity, maintaining stable operating conditions, and using appropriate antifouling chemicals—can further minimize fouling formation. By applying these strategies, the E-4000 unit is expected to operate more efficiently, extend its service life, and ensure reliable heat transfer performance in the long term.

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