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Original Article

Simulation of Plate Heat Exchanger with 30° Coguration Angle to Cool Oil

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Abstract *– The operation of valves in steam turbines, especially main stop valves and control valves, requires oil as a working fluid, which flows in the hydraulic system and then flows to the control oil radiator to be cooled. There is a disturbance in the control oil radiator, namely, the performance in cooling the oil is not optimal, so it is assisted by a blower, caused by damage to the fins due to corrosion. The radiator output oil temperature reaches 59 °C while the recommended temperature based on the design standard is 45 °C. One way to solve the problem is to install a Plate type Heat Exchanger (HE) to replace the control oil radiator, so that the HE installation is appropriate, a simulation is carried out for the HE, to get the HE characteristics. The simulation resulted in an oil fluid channel velocity of 0.15m/s, a water fluid channel velocity of 0.2 m/s, an oil pressure drop of 34000 (N/m²), a water pressure drop of 23557 (N/m²) with a plate configuration of 30° and an outlet oil temperature of 45 °C.*

Keywords *- Control valve, Heat Exchanger, Oil, Radiator, Hydraulic System, Water.*

1. Introduction

A control oil tank is an oil storage tank that has a capacity of 310 litres. The one used is Shell Turbo T 32, and for the operational process, the temperature must be maintained so that it can work optimally.

The oil that has been used as a medium for transmitting energy from the hydraulic system is then flowed to the control oil radiator to be cooled before being collected back into the control oil tank. The control oil radiator used is an air-cooled fan type whose cooling medium uses ambient air. The working principle is to transfer heat from the oil passing through the tube in the control oil radiator to the surrounding air. The control oil radiator will function as a cooler if the oil temperature is ≥ 55 °C, and in the control oil tank, there is a heater that will function as a heater if the oil temperature is ≤ 33 °C. Control valves that experience performance problems in cooling oil due to corrosion and long service life are replaced with heat exchangers.

Alternative technologies that aim to save energy often add heat exchangers [1-3]. Plate heat exchanger (PHE) is a suitable design because the main advantage is that the fluid is exposed to a much larger surface area, as the fluid is spread over the plates [4]. The distance between the plates is a function of the Reynolds number; changes in the distance between the plates will change the pressure drop on both the hot and cold sides of the PHE. Plate-type heat exchangers show good thermal performance, high heat transfer rate, and more adaptability and flexibility for real applications [5-6]. The plate design shows improved performance with effectiveness up to 83.1% [7]. The flat plate type PHE was able to increase the heat transfer coefficient from 0.053 to 0.064 kW/m2 °C [8].

This study aims to evaluate the replacement of a control oil radiator that has damaged fins due to corrosion. This corrosion affects the heat exchange process, so research is needed to find an alternative. The innovation of this research is to replace the control oil radiator with PHE, based on the advantages of PHE, namely, low production cost, easy maintenance, hygiene, high heat transfer coefficient, and fewer utility requirements than other types of HE. The method used in this research is simulation, and simulation results are compared with existing data. Simulation using HTRI and drawn with SketchUp Pro 2022 software. The software is an application suitable for calculating heat transfer, comparing calculations using equations to simulation results obtained, a value close to [9] and verifying heat exchanger design calculations [10].

1.1. Hydraulic System on Steam Turbine

The hydraulic system on this turbine uses oil to transfer power and operate the valves. In this system, if the oil temperature is not within the desired range, the oil radiator activates to cool the oil, and the heater turns on to warm it when the temperature is too low.

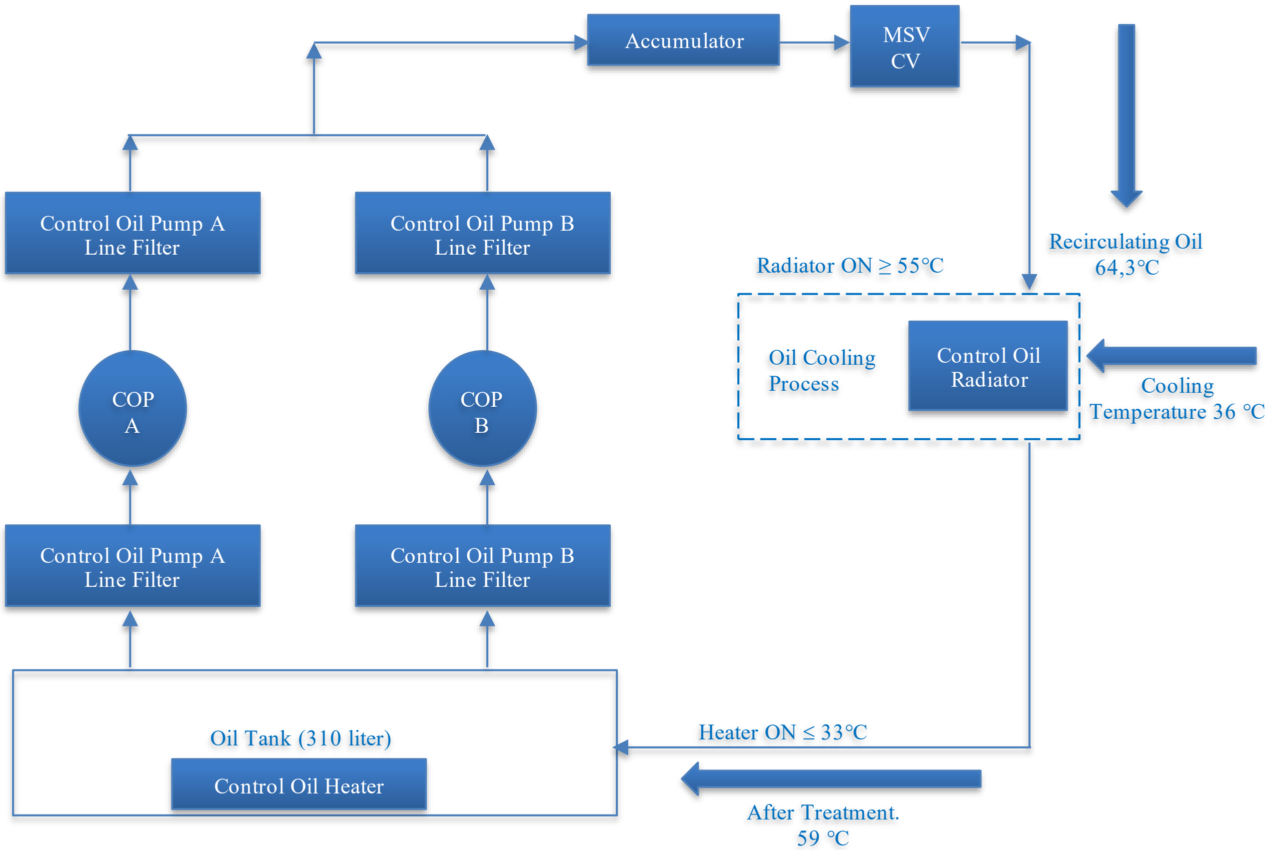


Fig. 1 Hydraulic system on steam turbine

The function of hydraulic oil is that it is a heat transfer medium because of its easy-flowing nature. In addition to its ability to move the valve, it can also be used to lubricate oil and cool the valve. Figure 1 shows the Hydraulic system on a steam turbine.

1.2. Software to Support Design

1.2.1. Application for simulation

The software used to perform the plate heat exchanger simulation is HTRI for research media on various heat transfer technologies and to determine the size of the heat exchanger. HTRI produces several parameters, such as geometry, by entering process parameters such as temperature, pressure, flow rate, tool material, and so on.

The use of HTRI has the main advantage of being able to save time doing calculations and designing complex tools that are in accordance with standards and safe, compared to when done by manual calculation. The scope of HTRI software is to design and simulate various kinds of heat exchangers, one of which is the plate heat exchanger.

HTRI software has several features to be used in designing plate heat exchangers, including when viewed from geometry specifications. HTRI software has a type of herringbone plate corrugation with chevron angles from 0 ° to 90 °, with two different flow directions. The number of flow passes from one to six, then HTRI software is flexible in inputting the specifications needed in the process, with the output that can be produced is a spreadsheet of design results with reports, along with 2D drawings of plate heat exchanger geometry. Some things that need to be done to validate manual calculations with software are as follows.

1. Selecting the type of heat exchanger in the HTRI tool
2. Entering operating conditions in the form of parameter data and hot and cold fluid properties
3. Fill in the plate geometry data with the appropriate data used in the equations in manual calculations, such as plate length, plate width, plate thickness, plate area, plate angle, plate material type with gaskets, number of channels in the plate, and so on.
4. Finally, view the summary of the output and result of the validation process.

1.2.2. SketchUp Pro 2022

SketchUp Pro 2022 is a design software used for drawing. The function of engineering drawings is to serve as a medium for conveying information and concepts about a plan. One of the outputs of the design results is an engineering drawing. In the context of designing a plate heat exchanger, SketchUp Pro 2022 provides several features that can help in making accurate design models and producing detailed engineering drawings.

2. Methods

The method used in this simulation is to draw the Plate Heat exchanger using SketchUp Pro 2022 software. This design is integrated with Auto CAD software and then simulated using HTRI. The research steps are described in Figure 1, with input data tabulated in Tables 1 and 2.

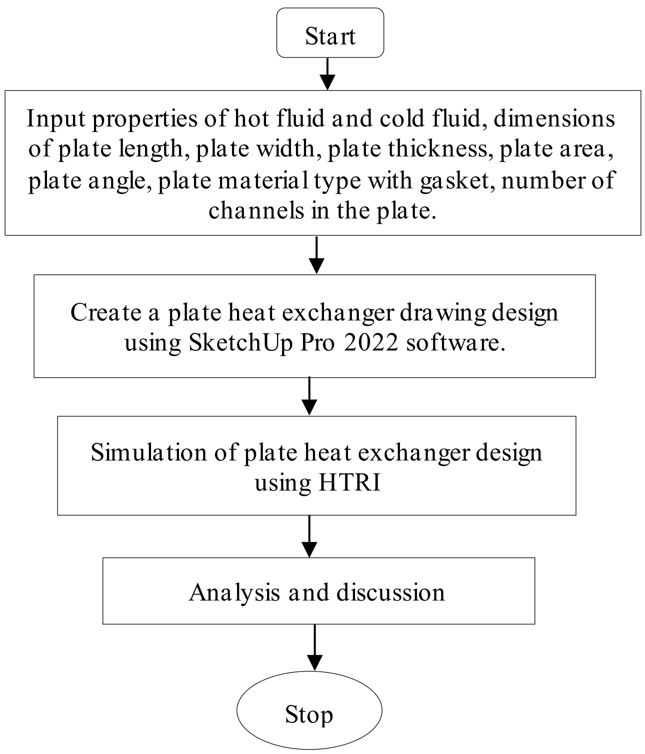


Fig. 1 Research flow chart

Table 1. Hot (oil) and cold (water) fluid properties data

Parameter	Value	Unit
Inlet oil temperature	337,3	K
Outlet oil temperature	318	K
Inlet water temperature	309	K
Oil mass flow rate	0,182	kg/s
Water mass flow rate	0,276	kg/s
Oil density	850	kg/m³
Water density	991,97	kg/m³
Oil viscosity	0,0172	kg/m. s
Water viscosity	0,00065	kg/m. s
Oil specific heat	2006	J/kg. K
Water specific heat	4174	J/kg. K
Oil thermal conductivity	0,131	W/m. K
Water thermal conductivity	0,632	W/m. K

Table 2. Design dimension data

Parameter	Value	Unit
Number of passes (1:1)	1	
Plate thermal conductivity (Stainless Steel 316)	16	W/m. K
Plate thickness (t)	0,00075	m
Plate length (L)	1,05	m
Plate width (W)	0,35	m
Plate distance (d)	0,002	m
Effective area of plate (A_{ef})	0,3675	m^2
Effective length (L_{ef})	1,15	m
Effective width (L_w)	0,25	m
Area enlargement factor	1,25	
Overall heat transfer coefficient	250- 450	W/m^2K
Assumed heat transfer coefficient range	300	W/m^2K
Port diameter	0,1	m

3. Discussion

3.1. Drawing Plate Heat Exchanger

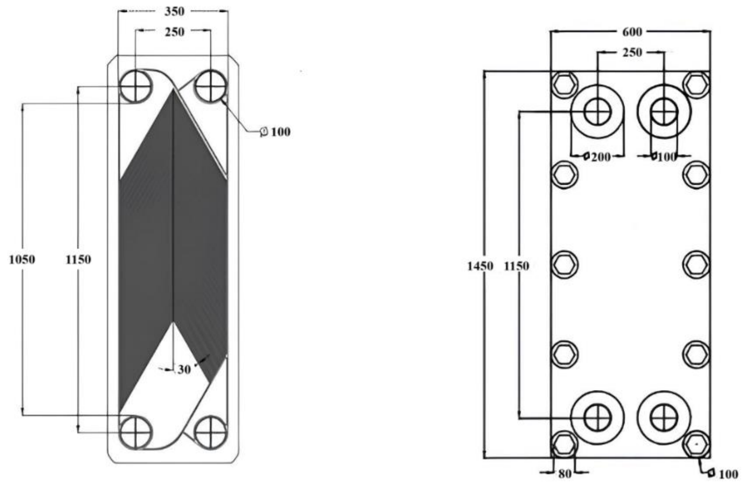
Figure 4 shows the Plate Heat Exchanger dimensions and features. The plate heat exchanger has four main fluid ports: two for hot fluid (inlet and outlet) and two for cold fluid (inlet and outlet). The diameter of the hot fluid holes is Ø200 mm, while the cold fluid holes are Ø100 mm. Distance between the axes of the two large (hot fluid) holes: 250 mm.

Horizontal distance between the centers of adjacent holes: 600 mm. Vertical distance from top to bottom holes: 1450 mm. Vertical distance between upper and lower groups of holes: 1150 mm. There are 12 bolt holes surrounding the plate, used to clamp the heat exchanger plates and ensure system tightness, typically with gaskets. Each bolt hole has a diameter of Ø100 mm. Total plate width: 600 mm. Height from the top to the bottom hole center: 1450 mm. Distance from the bottom hole center to the plate edge: 80 mm. The assembly includes a total of five heat exchanger plates.

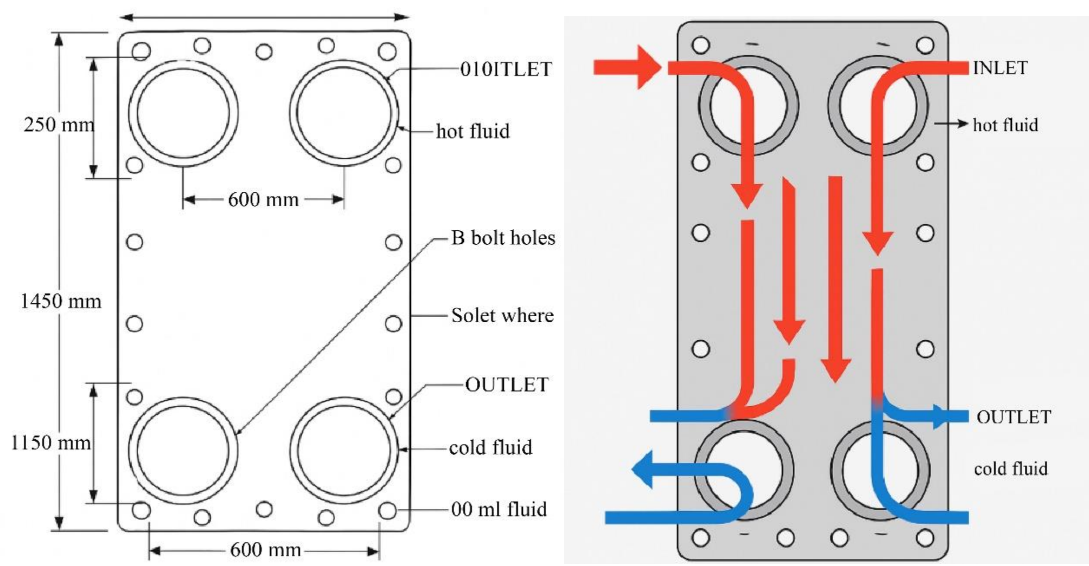
The process of heat transfer (Figure 5) can be explained as follows:

1. The top-left and top-right large holes are labeled “outlet hot fluid,” but contextually, one of them (usually the top-left) should serve as the inlet for the hot fluid, entering the system at high temperature. The hot fluid flows downward, guided between alternating plates inside the heat exchanger.

2. The bottom-left hole is for a cold fluid inlet, where a cooler fluid enters the exchanger. It flows upward, in the opposite direction to the hot fluid.



(a) (b)
Fig. 4 a. Plate Heat Exchanger b. Front-end plate Heat Exchanger



(a) (b)
Fig. 5 Plate Heat Exchanger (a) dimension, (b) flow inlet and outlet of fluid

3. The hot and cold fluids flow in opposite directions (counterflow), which maximizes the temperature gradient and increases heat transfer efficiency. They flow through alternating, thin, corrugated plates without mixing due to sealed flow channels.

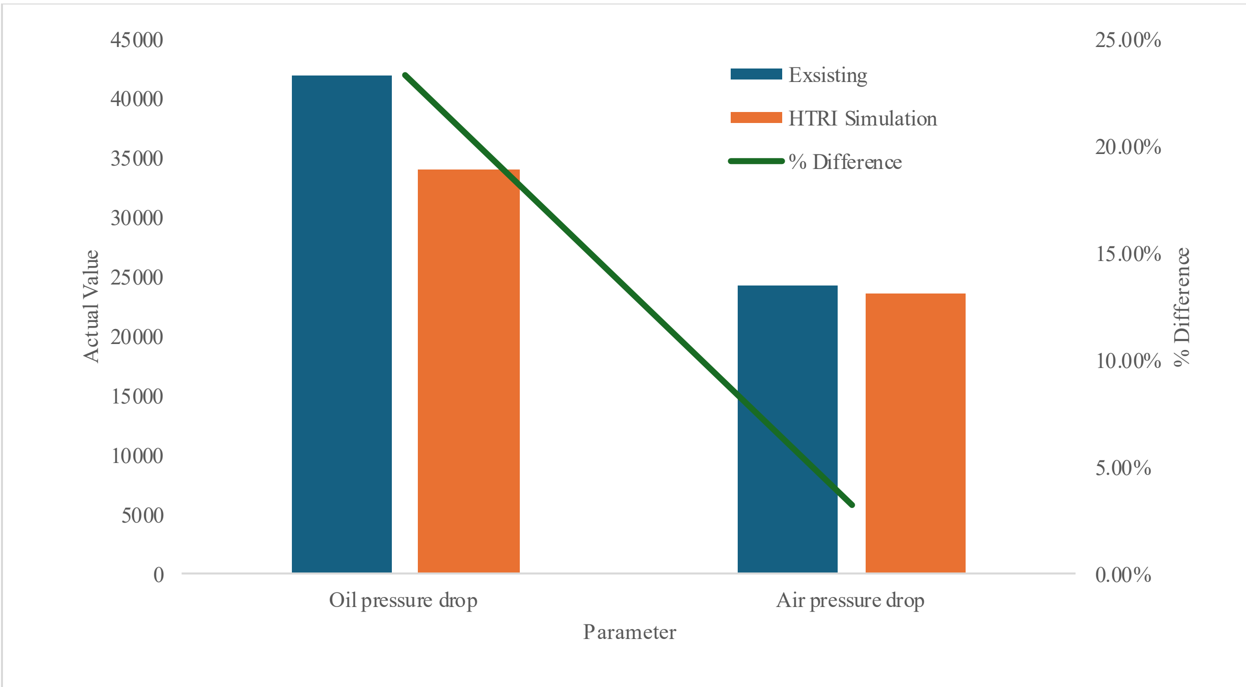
As the hot and cold fluids pass by each other in adjacent channels, heat transfers from the hot fluid to the cold fluid through the thin metal plates separating them. The metal plate conducts heat efficiently but prevents direct mixing of the two fluids.

The top-right hole (if not already used as an inlet) serves as the hot fluid outlet, where the now-cooled hot fluid exits. The bottom-right hole is the cold fluid outlet, where the now-heated cold fluid exits [11].

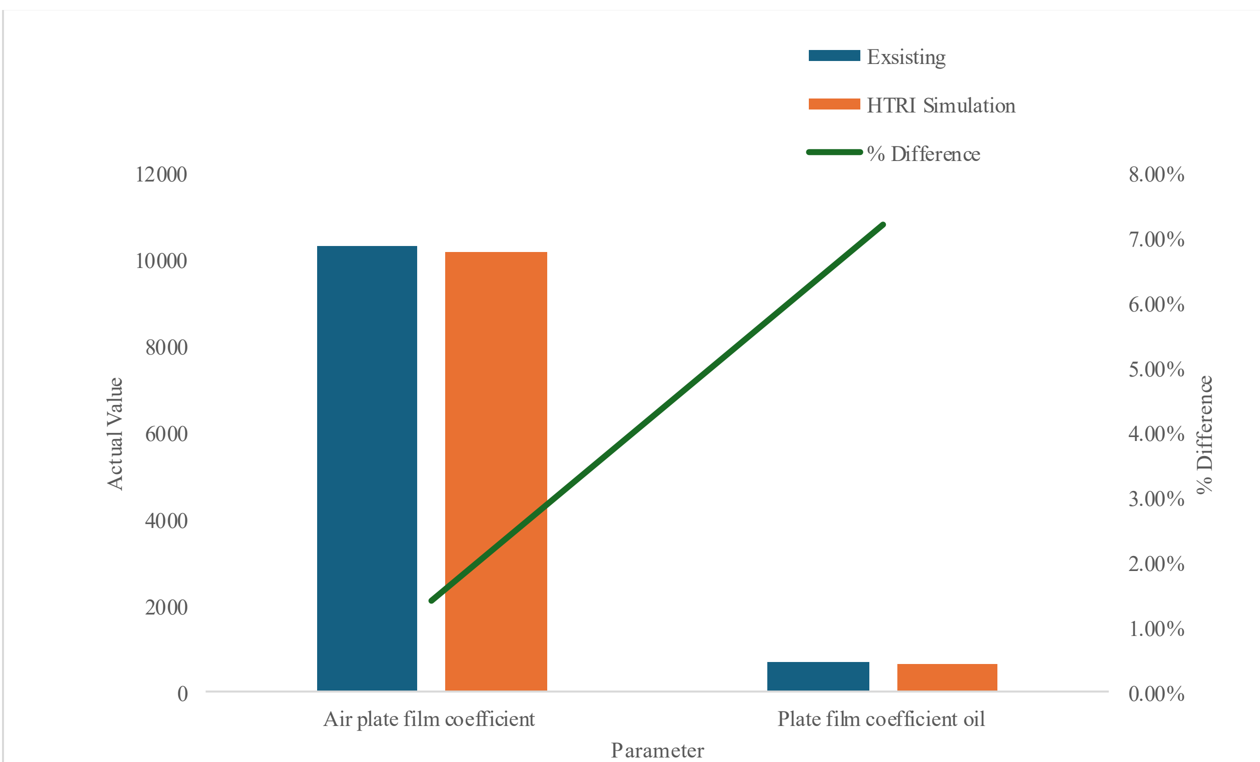
Bolt holes (12 total, evenly spaced around the perimeter) are used to clamp the plates tightly together, ensuring leak-free operation. Gaskets are usually placed between plates to prevent fluid mixing and direct leaks.

The results of the Plate Heat Exchanger (PHE) design are highly promising and warrant further development and implementation for the following logical and technical reasons:

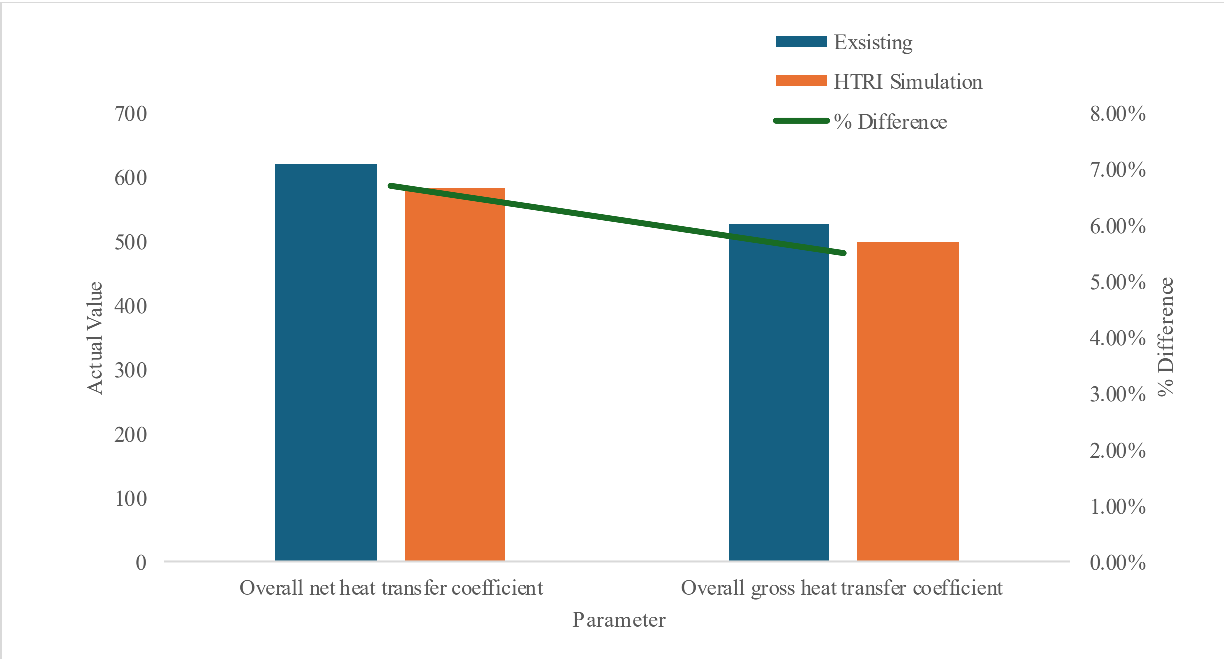
1. Validated Performance with Minimal Overdesign
   The comparison between existing conditions and HTRI software simulations shows a low over-design margin of 5.5 %, confirming that the calculated parameters are close to optimal. This ensures efficient use of materials and energy without excessive conservatism, making the design both cost-effective and high-performing.



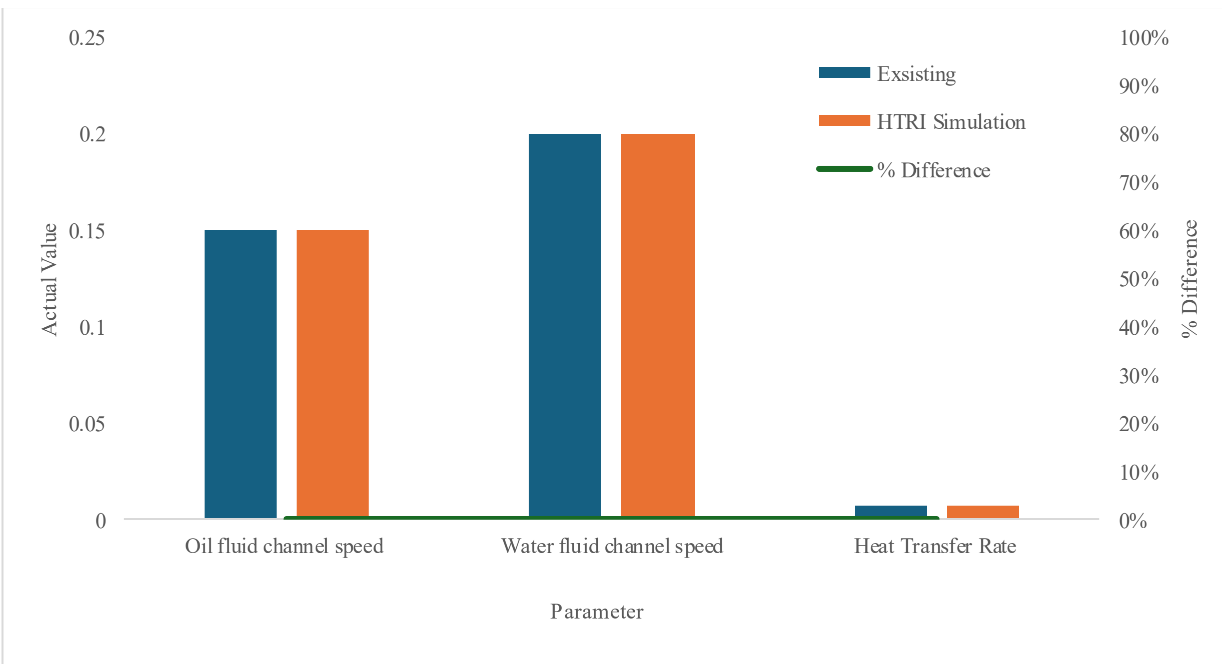
(a)



(b)



(c)



(d)

Fig. 6 Comparison between the existing and the simulation HTRI software (a) Pressure drop (b) Film Coefficient (c) Overall heat transfer (d) Rate

2. Optimized Heat Transfer Mechanism (Counter Flow Design) [12]. As depicted in Figure 5, the heat exchanger employs a counterflow arrangement, where hot fluid flows downward while cold fluid flows upward through alternating channels. This flow pattern maintains the maximum temperature gradient across the plates throughout the exchanger, significantly improving thermal transfer efficiency compared to parallel flow designs [13-14].
3. Effective Thermal Contact Without Fluid Mixing
   The design uses thin, corrugated metal plates that separate hot and cold fluids into sealed channels. These plates have excellent thermal conductivity, allowing efficient heat transfer while fully preventing direct mixing. Gaskets

between the plates and the use of 12 evenly spaced bolt holes ensure that leak-tight operation is an essential feature for safety, cleanliness, and system longevity.

4. Ease of Fabrication and Assembly
   The PHE is designed with precisely calculated and manufacturable dimensions: plate length of 1.05 m, width of 0.35 m, and port diameter of 0.1 m. These values are not only consistent with simulation outputs but also compatible with common manufacturing practices [15-17]. The model, designed in SketchUp Pro 2022, reflects practical engineering design standards and supports rapid prototyping or production.
5. Scalability and Maintenance Accessibility
   Plate heat exchangers are inherently modular. The bolt-based assembly allows for easy maintenance, cleaning, or future capacity expansion by adding more plates [19]. This flexibility increases the system's operational life and reduces long-term costs, making it suitable for industrial applications that demand durability and adaptability.
6. Enhanced Operational Safety and Efficiency
   By ensuring fluid separation, strong mechanical clamping, and reliable sealing, the system reduces the risk of cross-contamination, pressure loss, or leakage, common concerns in thermal exchange systems. This promotes safe operation even in demanding thermal environments.

The evaluation highlights both consistencies and deviations across thermal and hydraulic performance parameters. The heat transfer rate (q) exhibits a perfect match between the existing and simulated data, indicating a precise energy balance between the hot and cold fluid streams. This consistency confirms that the system effectively meets its thermal duty and validates the accuracy of the simulation in modeling the actual heat load.

The overall net heat transfer coefficient (U_c) obtained from the simulation is approximately 6.7% lower than the existing data. This slight reduction suggests minor underperformance, which may be attributed to fouling on the heat transfer surfaces or conservative assumptions embedded in the simulation algorithm. A lower U_c reflects increased resistance to heat transfer across the exchanger, potentially affecting thermal efficiency. Similarly, the overall gross heat transfer coefficient (U_d) shows a deviation of about 5.5%, with the simulation predicting a lower value. Since U_d accounts for the combined resistances, including fouling, wall conduction, and fluid-side resistances, this discrepancy may indicate aging effects or fouling not fully accounted for in the simulation parameters.

A notable deviation is observed in the oil-side pressure drop (ΔP_{oil}), where the simulated value is significantly lower—by approximately 23.3%—than the actual measurement. This substantial difference suggests the presence of additional hydraulic resistance in the actual system, likely due to fouling, partial obstructions, or changes in oil viscosity over time [19]. On the water side, the pressure drop (ΔP_{water}) shows a minor deviation of 3.2%, suggesting that the hydraulic model for the water channel closely reflects actual operating conditions. The small difference may result from the simulation assuming clean internal surfaces or steady flow conditions.

The plate film coefficient for oil (h_{oil}) in the simulation is 7.2% lower than the existing data. This difference may be because of temperature gradients, lower turbulence, or variations in oil viscosity that influence convective heat transfer at the wall. In practical operation, these factors often increase thermal resistance. For the plate film coefficient on the water side (h_{ater}), the simulation closely matches the existing data, with only a 1.4% difference. This indicates that the water-side heat transfer is well-captured by the simulation, likely due to stable flow properties and well-established correlations for water.

Both the oil and water fluid channel velocities (up) show perfect agreement between the existing and simulated values. This alignment confirms that the boundary conditions for mass flow rates and cross-sectional areas were accurately implemented in the simulation model. In summary, while most parameters show strong agreement, notable deviations—particularly in oil-side pressure drop and heat transfer coefficients—underscore the importance of accounting for operational fouling and aging effects when validating simulation models.

4. Conclusion

The validation between the existing system and the HTRI software simulation demonstrates a minimal over-design margin of 5.5 %, indicating strong alignment and reliability of the proposed plate heat exchanger (PHE) design. Utilizing Sketch Up Pro 2022, a detailed and manufacturability model of the PHE was developed with dimensions derived directly from engineering calculations: a plate length of 1.05 m, effective plate length of 1.15 m, plate width of 0.35 m, effective plate width of 0.25 m, plate angle of 30°, and a port diameter of 0.1 m. These optimized dimensions not only support ease of fabrication but also enhance thermal efficiency and operational reliability. With this foundation, the design paves the way for scalable innovations in heat exchanger technology, offering a practical yet forward-thinking solution for sustainable energy systems and industrial applications of the future.

The combination of validated simulation results, efficient thermal performance through counterflow operation, practical manufacturability, and operational reliability makes this PHE design both technically sound and economically viable. These strengths collectively justify their recommendation for real-world Application in energy systems, manufacturing, or process industries seeking compact and high-efficiency heat exchange solutions.

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