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Comprehensive Design and Implementation of Seawater-Cooled Heat Exchanger Networks for Marine Plant Operations in Offshore Oil and Gas Industrial Applications

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ABSTRACT: Efficient cooling systems are critical for marine plant operations on offshore oil and gas platforms where space, energy and environment constraints are significant. This project presents design and development of seawater-cooled heat exchanger networks to support sustainable thermal management in marine environments by using simplified calculations and free tools, key parameters including heat duty, heat transfer rate, seawater flow rate and effectiveness under clean and fouled conditions were determined. This study demonstrates how system designed properly for optimize energy usage, minimize operational cost and enhance reliability for offshore operations. Graphical representation and schematic diagrams illustrate the proposed network, highlight practical consideration for marine plant implementation. This project provides cost – effective and replicable methodology suitable for education purpose and preliminary engineering design in offshore industrial applications.

KEYWORDS: Seawater-cooled heat exchanger, Marine plant operation, Offshore oil and gas, Thermal management, Sustainable design, Heat transfer, Energy efficiency

I. INTRODUCTION

Marine plant operations particularly on offshore oil and gas platforms required reliable and efficient thermal management systems to ensure safety and continuous operation of machinery and process equipment. Cooling systems are essential for regulating temperature of compressors, generators, refrigeration units and other critical components. Among available cooling methods, seawater-cooled heat exchangers are widely preferred due to abundant availability of seawater, high heat transfer capacity and minimum operating costs.

The offshore environment presents unique challenges including limited space, fluctuating seawater temperature, corrosion and maintenance constraints. Therefore designing a seawater cooled heat exchanger network must be energy efficient, sustainable and capable of handling varying loads is crucial for the performance and longevity of marine plants.

This study focuses on the design and implementation of seawater cooled heat exchanger system for marine applications in offshore oil and gas industrial operations. The main objective is to provide a cost effective practical methodology for designing sustainable thermal management systems suitable for offshore industrial applications.

II. BACKGROUND

Seawater cooled heat exchangers are widely used in marine and offshore industrial applications due to their efficiency. They transfer heat from process fluid or refrigeration circuits to seawater which acts as a cooling medium.

Types of heat exchangers

Shell & Tube: Common in offshore platforms, compact and reliable

Plate: High heat transfer efficiency, smaller footprint

Tube-in-Tube: For small scale applications

Heat transfer principles

Heat absorbed or rejected = $m \cdot C_p \cdot \text{Temperature Difference}$

Difference

Overall heat transfer = $U \cdot A \cdot \text{LMTD}$

Seawater Properties

Density = 1025 kg/m³

Specific Heat = 4 kJ/kg. K

Typical Inlet Temperature = 28 to 32°C

Design Consideration

Space constraints on marine platforms

Corrosion resistance of materials

Fouling and maintenance schedule

Flow rates and pumping power

III. DESIGN STEPS AND METHODOLOGY

The design and development of heat exchanger network for marine plant operation begins with creating a schematic diagram of the system showing hot fluid inlet and outlet and the heat exchanger blocks. Key assumptions are made for the design hot fluid temperature, seawater inlet and outlet temperature, flow rate and overall heat transfer coefficient with consideration for fouling effect by using heat transfer equations. Calculations are carried out both clean and fouled condition to evaluate the impact on the system effectiveness. Graphical representations are prepared while schematic diagram are created. Finally the sensitivity checks are performed by varying seawater temperature and flow rate to access system robustness and all results are documented in tables and charts for inclusion in the report.

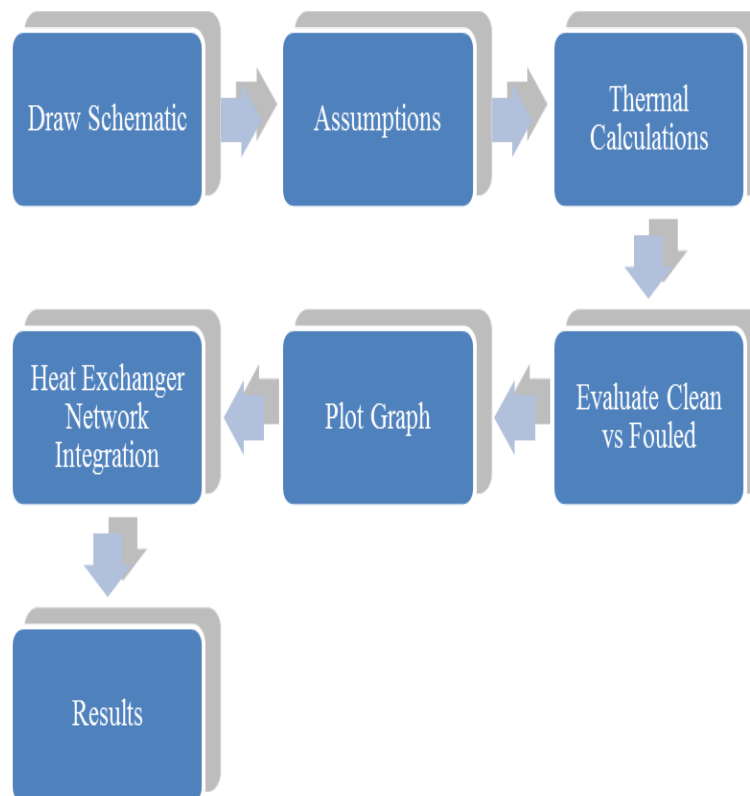


Figure 1: Process Flow Chart for Design and Development of Heat Exchanger System

Schematic Diagram



Figure 2: Schematic Diagram for Design and Development of Heat Exchanger System

It is schematic diagram of heat exchanger for seawater cooled shell and tube heat exchanger used in marine and offshore industrial applications.

Assumptions

Hot Fluid:	Process water
Mass Flow rate	= 5 kg/s
Specific Heat Capacity	= 4180 J/kg. K
Inlet Temperature	= 90°C
Outlet Temperature	= 40°C
Cold Fluid:	Seawater
Inlet Temperature	= 25°C
Specific Heat Capacity	= 3990 J/kg. K °C
Assumed Outlet Temperature Rise	= 10°C
Counter flow Arrangement correction Factor	= 1
Overall Heat Transfer Coefficient [Clean]	= 1200 W/m ² . K
Fouling resistances	
Hot Side	= 0.0001 m ² . K/W
Cold Side	= 0.0005 m ² . K/W

Thermal Calculations

Heat Duty

$$\begin{aligned} \text{Heat Duty (Q)} &= m_h \cdot C_{ph} \cdot (T_{h \text{ in}} - T_{h \text{ out}}) \\ &= 5 \cdot 4180 \cdot 50 = 1045 \text{ kW} \end{aligned}$$

Cold Side Flow

$$\begin{aligned} Q &= m_c \cdot C_{pc} \cdot (T_{c \text{ out}} - T_{c \text{ in}}) \\ m_c &= Q / C_{pc} \cdot (T_{c \text{ out}} - T_{c \text{ in}}) \\ &= 1.045 \cdot 10^6 / 3990 \cdot 10 = 2.62 \text{ kg/s} \\ \text{Cold Outlet temperature} &= 10 + 25 = 35^\circ\text{C} \end{aligned}$$

Log Mean Temperature Difference (LMTD)

$$\begin{aligned} \Delta T_1 &= T_{h \text{ in}} - T_{c \text{ out}} = 90 - 35 = 55^\circ\text{C} \\ \Delta T_2 &= T_{h \text{ out}} - T_{c \text{ in}} = 40 - 25 = 15^\circ\text{C} \\ \text{LMTD} &= \Delta T_1 - \Delta T_2 / \ln (\Delta T_1 / \Delta T_2) \\ &= 55 - 15 / \ln (55/15) = 30.78^\circ\text{C} \end{aligned}$$

Heat Transfer Area

Clean Condition

$$A_c = \frac{Q}{U_{\text{clean}} \cdot \text{LMTD}} = \frac{1.045 \cdot 10^6}{1200 \cdot 30.8} = 28.28 \text{ m}^2$$

Fouled Condition

$$\begin{aligned} \frac{1}{U_{\text{fouled}}} &= \frac{1}{U_{\text{clean}}} + R_{f_{\text{Hot}}} + R_{f_{\text{Cold}}} \\ R_{f_{\text{Hot}}} &= 0.0001 \text{ m}^2\text{K/W} \\ R_{f_{\text{Cold}}} &= 0.0005 \text{ m}^2\text{K/W} \\ U_{\text{fouled}} &= 697.67 \text{ W/m}^2\text{K} \\ A_f &= \frac{Q}{U_{\text{fouled}} \cdot \text{LMTD}} \\ &= 48.7 \text{ m}^2 \end{aligned}$$

Evaluation Clean vs. Fouled

If you fix area at the clean value (28.29 m²) and U falls because of fouling

$$\begin{aligned} Q &= U_{\text{fouled}} \cdot A_{\text{clean}} \cdot \text{LMTD} \\ &= 697.67 \cdot 28.28 \cdot 30.78 = 607.55 \text{ Kw} \end{aligned}$$

Table 1: Comparison between Clean and Fouled Conditions

Item	Clean Condition	Fouled Condition ($R_{f_{\text{hot}}} + R_{f_{\text{cold}}} = 0.0006 \text{ m}^2 \cdot \text{K/W}$)	Change
Overall Heat Transfer Coefficient (U)	1200 W/m ² K	697.7 W/m ² K	-41.9%
Required Heat Transfer Area (A)	28.29 m ²	48.65 m ²	71.97%
Cold Mass Flow	26.2 kg/s	26.2 kg/s	0%
Heat Duty If area fixed at clean value	1045 kW	607.55 kW	- 41.8% of Q

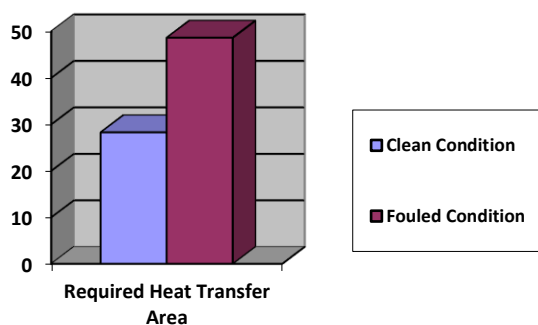


Figure 4: Required Heat Transfer Area Comparison

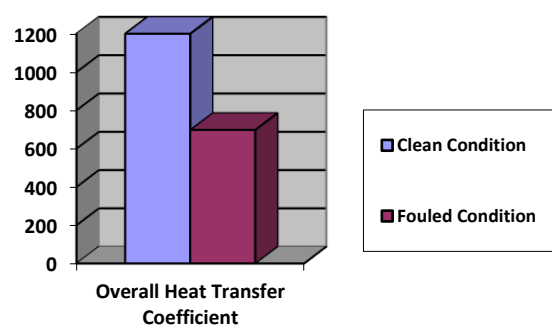


Figure 3: Overall Heat Transfer Comparison

The analysis of the seawater cooled heat exchanger network revealed that the system performs efficiently under clean conditions. Graph represents the Comparison of overall heat transfer coefficient and required heat transfer area on the both clean and fouled condition which shows the heat transfer performance on both working condition.

Heat Exchanger Network Integration

Design and developing two heat exchanger network from the results and give compact design and the practical recommendations.

LMTD	= 30.8°C	
Clean Condition:		
U_c	= 1200 W/m ² K	
$A_{tot,c}$	= 28.29 m ²	
$UA_{tot,c}$	= 1200*28.29	= 33,948 W/K
$Q_{tot,c}$	= 33,948*30.8	= 1,045,598.4 W

Fouled Condition:

U_f	= 697.7 W/m ² K	
$A_{tot,f}$	= 48.65 m ²	
$UA_{tot,f}$	= 697.7*48.65	= 33,943.10 W/K
$Q_{tot,f}$	= 33,943.10*30.8	= 1,045,447.63 W

Heat Exchanger Network Integration

Design and developing two heat exchanger network from the results and give compact design and the practical recommendations.

Parallel Counterflow Network (Equal Split)

Two identical counterflow heat exchangers in parallel. Each exchanger is a counterflow unit which means hot enter at one end while matched cold enters at the opposite end.

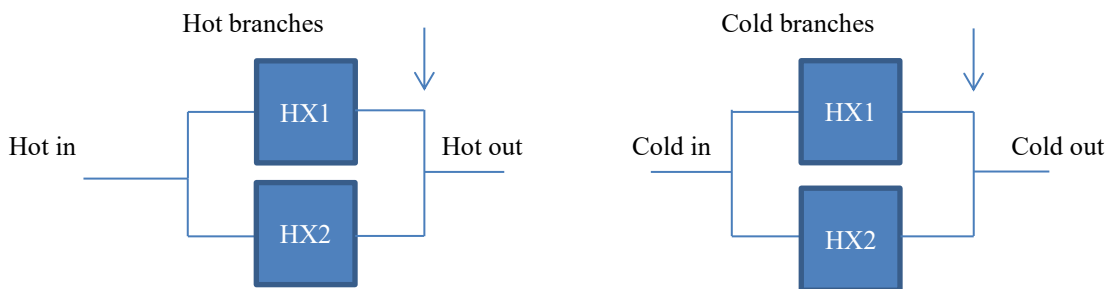


Figure 5: Parallel Counterflow Network

In each heat exchangers labeled HX1 and HX2 the hot and cold branch connections must be arranged so hot enters at the opposite to the cold inlet.

Total Q clean	= 1,045,598.4 W	
Each heat Exchanger Q each	= 522,799.2W	
Total Q fouled	= 1,045,447.63W	
Q each	= 522,723.815W	
Compute UA per exchanger		
Clean UA	= Qeach/LMTD	
	= 522,799.2/30.8	= 16,974W/K
Fouled UA	= Qeach/LMTD	
	= 522,723.81/30.8	= 16,971.55W/K
Compute area per exchanger		
Clean A each	= UA each/Uc	
	= 16,974/1200	= 14.14m ²
Fouled A each	= UA each/Uf	
	= 16,971.55/697.7	= 24.32 m ²
Check Totals For Clean	= 2*14.14	= 28.28m ²
For fouled	= 2*24.32	= 48.64 m ²

This network is best use for good reductancy, identical spare exchangers, easy isolation and cleaning.

Cascade Counterflow Network (70% / 30% Split)

Staged counterflow where a primary heat exchanger (HX1) takes the large share of duty and a polished exchanger (HX2) finishes heating. Both are counterflow units. Useful when process needs staged heating or when one stream is hotter.

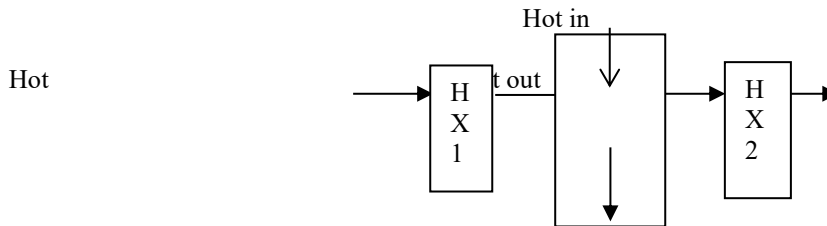


Figure 6: Cascade Counterflow Network

Duties (70/30)

Clean

$$Q_{HX1} = 731918.88W, \quad Q_{HX2} = 313,679.52W$$

Fouled

$$Q_{HX1} = 731813.34W, \quad Q_{HX2} = 313,634.28W$$

Compute UA per exchanger

$$\begin{aligned} \text{Clean } UA_{HX1} &= Q_{each}/LMTD \\ &= 731918.88/30.8 \\ &= 23,763.6 \text{ W/K} \end{aligned}$$

$$\begin{aligned} \text{Clean } UA_{HX2} &= Q_{each}/LMTD \\ &= 313,679.52/30.8 \\ &= 10,184.4 \text{ W/K} \end{aligned}$$

$$\begin{aligned} \text{Fouled } UA_{HX1} &= Q_{each}/LMTD \\ &= 731813.34/30.8 \\ &= 23,760.17 \text{ W/K} \end{aligned}$$

$$\begin{aligned} \text{Fouled } UA_{HX2} &= Q_{each}/LMTD \\ &= 313,634.28/30.8 \\ &= 10,182.93 \text{ W/K} \end{aligned}$$

Compute area per exchanger

$$\begin{aligned} \text{Clean } A_{each \text{ HR1}} &= UA_{each}/U_c \\ &= 23,763.6/1200 \\ &= 19.80 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Clean } A_{each \text{ HR2}} &= UA_{each}/U_c \\ &= 10,184.4/1200 \\ &= 8.48 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Fouled } A_{each \text{ HR1}} &= UA_{each}/U_f \\ &= 23,760.17/697.7 \\ &= 34.05 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Fouled } A_{each \text{ HR2}} &= UA_{each}/U_f \\ &= 10,182.93/697.7 \\ &= 14.59 \text{ m}^2 \end{aligned}$$

This network is best use for stage heating, one primary exchanger that carries most of the duty and smaller polishing exchanger.



Figure 7: Computed Area Per Exchanger at both Condition

This graph shows clean and fouled condition performance of heat exchangers, showing a slight decrease in heat transfer efficiency under fouled condition which was reflected in increased required heat transfer area.

IV. RESULTS AND FUTURE SCOPE

The heat exchanger network consisting of two counterflow heat exchangers was successfully designed and analyzed for both clean and fouled conditions. The calculated heat duties for exchangers ensured that required energy transfer between the hot and cold streams achieved efficiently. The LMTD values for each exchanger confirmed proper temperature profile while the heat transfer areas indicated that fouling slightly reduced thermal performance, necessitating larger areas compare to the clean condition. Schematic diagrams of network illustrate the configuration and integration of exchanger, highlighting optimum flow arrangements to maximize energy recovery. Overall the study demonstrate that the designed heat exchanger network can effectively meet thermal requirements while accounting for fouling effects, ensuring both operational efficiency and reliability in practical applications.

The designed heat exchanger network can be further enhanced and optimized for practical application in several ways. Future work could include implementing advanced fouling mitigation techniques such as surface coating or periodic cleaning strategies. Computational fluid dynamics simulation can be employed to analyze detailed flow and temperature distribution it may enabling more accurate prediction of performance under varying operation conditions. Additionally integrating energy recovery optimization algorithms can further reduce operational cost and environmental impact. The network also be extend to multi stream or hybrid configuration combining different types of heat exchangers to meet complex industrial demands. Finally experimental validation using pilot scale setup would provide valuable data for refining the design and ensuring reliability in real world marine and offshore applications.

V. CONCLUSION

The study successfully designed and analyzed a seawater cooled heat exchanger for optimum energy recovery between hot and cold streams. The project highlights the importance of considering fouling effect in design and provides a solid foundation for further optimization and practical application in marine and offshore oil and gas industry. The results underscore the potential for improving operational efficiency, energy savings and long term reliability in practical heat exchanger systems.

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