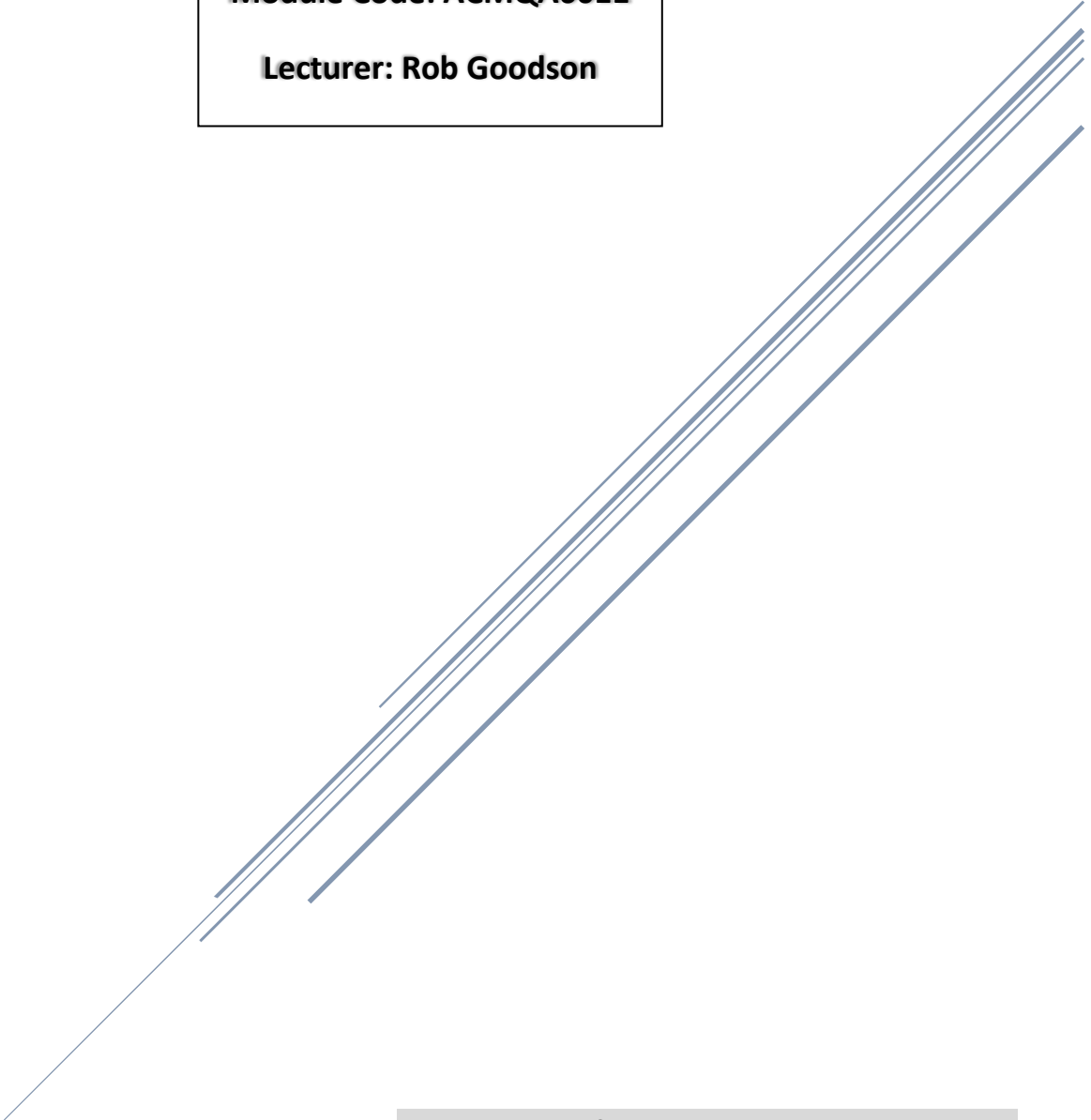


ADVANCED THERMOFLUID MECHANICS

Analysis of fouling in industrial shell & tube heat exchanger

Module Code: ACMQA6011

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TASK A:

Introduction:

Shell-and-tube heat exchangers are widely used in various industries, including chemical, petrochemical, power generation, and refrigeration. They are an efficient way of transferring heat between two fluids and are popular due to their versatility, durability, and ease of maintenance. This essay aims to provide information on the design, applications, and fouling mechanisms of shell-and-tube heat exchangers. Additionally, it will discuss cleaning and maintenance procedures necessary to prevent or mitigate fouling and its effects on heat transfer performance. Shell-and-tube heat exchangers have played a vital role in various industries for over a century. This article explores the history and typical industrial applications of shell-and-tube heat exchangers, focusing on their design and highlighting the impact of conventional segmented baffle geometry on shell-side fouling. Additionally, the principal mechanisms of fouling will be discussed, along with the necessary cleaning and maintenance procedures to ensure optimal heat transfer performance.

Shell-and-tube heat exchangers were first developed in the late 19th century and quickly gained popularity due to their efficiency and versatility. The basic design consists of a bundle of tubes enclosed within a cylindrical shell, with fluid flowing through the tubes (tube-side) and around the tubes (shell-side). This configuration allows for efficient heat transfer between two fluids while maintaining separation.

These heat exchangers find applications in various industries, including chemical processing, power generation, petroleum refining, HVAC systems, and food processing. They are commonly used for tasks such as heating, cooling, condensation, evaporation, and heat recovery. Their ability to handle high-pressure and high-temperature fluids, coupled with their flexibility for different fluid combinations, makes them indispensable in industrial processes.

The design of shell-and-tube heat exchangers includes various parameters, such as tube diameter, tube layout, baffle design, and flow arrangements. The inclusion of conventional segmented baffle geometry is often preferred due to its effectiveness in enhancing heat transfer efficiency. However, this design choice also promotes and exacerbates shell-side fouling. Shell-

side fouling refers to the accumulation of deposits on the inner surface of the heat exchanger shell, hindering heat transfer performance. The principal mechanisms of fouling include deposition of suspended solids, precipitation of dissolved salts, scaling due to temperature differences, and biological growth.

Cleaning and Maintenance Procedure:

To maintain optimal heat transfer performance, regular cleaning and maintenance procedures are necessary for shell-and-tube heat exchangers. Some commonly employed methods include mechanical cleaning, chemical cleaning, and online cleaning.

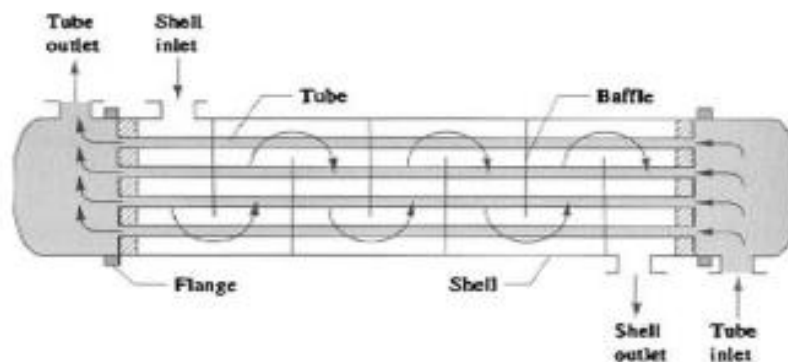


IMAGE - 1 Shell and Tube Heat Exchanger

Image credit: Çengel, Yunus A, and Afshin J. Ghajar. Heat and Mass Transfer: Fundamentals & Applications. New York: McGraw-Hill, 2011. Print.

Mechanical cleaning involves physically removing fouling deposits using brushes, scrapers, or high-pressure water jets. This method is effective for moderate fouling but may not be suitable for hard deposits. Chemical cleaning utilizes specific cleaning agents to dissolve and remove fouling substances. Acidic or alkaline solutions are commonly employed based on the nature of the fouling. Online cleaning methods involve the use of additives or technologies that prevent fouling during operation.

Regular inspection of heat exchangers is crucial to identify early signs of fouling and to schedule maintenance. Techniques such as non-destructive testing (NDT) can be employed to assess the condition of tubes and detect potential fouling. Proper flow monitoring, periodic maintenance shutdowns, and routine cleaning schedules are essential to ensure long-term efficiency and prevent excessive fouling.

Shell-and-tube heat exchangers have played a crucial role in various industries for efficient heat transfer applications. This investigation delves into their historical background, typical industrial applications, design specifics, and the impact of conventional segmented baffle geometry on shell-side fouling. Furthermore, it explores the principal mechanisms of fouling and highlights the cleaning and maintenance procedures necessary to ensure optimal heat transfer performance. Shell-and-tube heat exchangers have a rich history dating back to the 19th century. They have been widely utilized in industries such as petrochemical, power generation, HVAC, food processing, and many others. These heat exchangers are renowned for their versatility, ability to handle high-pressure and high-temperature applications, and suitability for both liquid-to-liquid and gas-to-liquid heat transfer processes. Shell-and-tube heat exchangers consist of a shell (outer vessel) and multiple tubes inside. The tubes facilitate the flow of one fluid, while the shell accommodates the passage of another fluid. The conventional segmented baffle geometry is commonly employed to enhance heat transfer efficiency. However, it can inadvertently promote and exacerbate shell-side fouling, impacting overall heat transfer performance.(Diaz-Bejarano, Coletti and Macchietto, 2019)

To mitigate fouling and maintain optimal heat transfer performance, regular cleaning and maintenance procedures are crucial. Techniques such as mechanical cleaning, chemical cleaning, and online monitoring systems are commonly employed. Mechanical cleaning involves physical methods like brushing, water jetting, and scraping to remove deposits. Chemical cleaning employs chemical agents to dissolve and remove fouling. Online monitoring systems facilitate real-time fouling detection and enable timely maintenance interventions.

Design and Applications:

A shell-and-tube heat exchanger consists of a bundle of tubes enclosed within a shell. One fluid flow through the tubes while the other flows outside the tubes in the shell. The fluids can flow either in a counter-current or co-current arrangement, depending on the desired heat transfer efficiency. The heat transfer occurs through the walls of the tubes by conduction. The shell-and-tube design is versatile, and the size, shape, and material can be customized to suit the application. Shell-and-tube heat exchangers are commonly used in applications such as:

1. Chemical processing: Heat exchangers are used to cool or heat chemical reactions or to condense and vaporize liquids.
2. Power generation: Steam turbines require heat exchangers to cool the working fluid.

3. Refrigeration: Heat exchangers are used to transfer heat between the refrigerant and cooling water in refrigeration systems.
4. Food processing: Heat exchangers are used to pasteurize, sterilize, or cook food products.

Fouling Mechanisms:

Fouling refers to the accumulation of unwanted deposits on heat transfer surfaces, hampering heat exchange efficiency. The principal mechanisms of fouling include particulate fouling, scaling, corrosion fouling, and biological fouling. Particulate fouling occurs due to the deposition of solid particles suspended in the fluid. Scaling arises from the precipitation of dissolved mineral salts. Corrosion fouling is caused by the degradation of metal surfaces, leading to deposits. Biological fouling involves the growth of microorganisms and organic matter.(Diaz-Bejarano, Coletti and Macchietto, 2019)

Fouling is a common problem in shell-and-tube heat exchangers, where deposits accumulate on the heat transfer surface, reducing the heat transfer rate and increasing the pressure drop. Fouling can be caused by various mechanisms, including:

1. Scaling: Scaling occurs when salts or minerals precipitate out of the fluid and deposit on the heat transfer surface. Scaling can be prevented by using water treatment chemicals or by softening the water.
2. Corrosion: Corrosion occurs when the metal surface of the heat exchanger is attacked by the fluid. Corrosion can be prevented by using corrosion-resistant materials or by maintaining proper pH levels in the fluid.
3. Biological growth: Biological growth can occur when microorganisms such as bacteria, algae, or fungi grow on the heat transfer surface. Biological growth can be prevented by using biocides or by maintaining proper pH and temperature levels.
4. Particulate fouling: Particulate fouling occurs when solid particles deposit on the heat transfer surface. Particulate fouling can be prevented by using filters or by pretreating the fluid.



IMAGE - 2 Fouling in Shell in Tube Heat Exchanger

[Fouling Factors in Shell & Tube Heat Exchangers](#)

Cleaning and Maintenance Procedures:

Cleaning and maintenance procedures are necessary to prevent or mitigate fouling and its effects on heat transfer performance. The following are some of the cleaning and maintenance procedures that can be used:

1. Chemical cleaning: Chemical cleaning involves using chemicals to dissolve or remove fouling deposits from the heat transfer surface. The chemicals used depend on the type of fouling present.
2. Mechanical cleaning: Mechanical cleaning involves physically removing the fouling deposits using brushes, high-pressure water, or other mechanical means.

3. Hydro blasting: Hydro blasting involves using high-pressure water to remove fouling deposits from the heat transfer surface. Hydro blasting is effective in removing hard deposits such as scale.
4. Ultrasonic cleaning: Ultrasonic cleaning involves using high-frequency sound waves to remove fouling deposits from the heat transfer surface.

Shell-and-tube heat exchangers are widely used in various industries due to their versatility, durability, and ease of maintenance. Fouling is a common problem that can reduce heat transfer efficiency and increase pressure drop.(Mohanty and Singru, 2011) Shell-and-tube heat exchangers have a rich history and are widely used across various industries. While conventional segmented baffle geometry promotes heat transfer efficiency, it also exacerbates shell-side fouling. Understanding the principal mechanisms of fouling and employing appropriate cleaning and maintenance procedures are crucial to mitigate fouling-related issues and maintain optimal heat transfer performance. By implementing regular inspection, mechanical and chemical cleaning methods, and utilizing online cleaning technologies, industries can ensure the longevity and efficiency of shell-and-tube heat exchangers.

Fouling in shell-and-tube heat exchangers occurs due to various mechanisms, leading to the accumulation of deposits on the inner surface of the shell. Understanding these fouling mechanisms is crucial for implementing effective cleaning and maintenance procedures. Here are the principal mechanisms of fouling and the corresponding cleaning and maintenance approaches:

1. Deposition of Suspended Solids: Suspended solids present in the fluid can settle and deposit on the heat exchanger surfaces. This type of fouling can be addressed through regular cleaning procedures such as mechanical brushing or flushing with high-pressure water to dislodge and remove the solid deposits.
2. Precipitation of Dissolved Salts: When a fluid undergoes temperature changes, dissolved salts can precipitate and form scale deposits. Chemical cleaning methods are commonly used to remove scale. Acidic or alkaline solutions are circulated through the heat exchanger to dissolve and remove the scale buildup. Proper control of water chemistry and water treatment can help prevent scaling in the first place.
3. Scaling due to Temperature Differences: Temperature differences in the heat exchanger can lead to the formation of scale deposits. Regular inspection and monitoring of

temperature differentials are essential to detect scaling early on. Chemical cleaning methods, such as acid cleaning, can effectively remove scale deposits and restore heat transfer efficiency.

4. **Biological Growth:** Biological growth, such as algae or bacteria, can thrive in certain environments, leading to fouling. Biocides or disinfectants can be introduced into the system to control biological growth. Regular cleaning procedures, including chemical cleaning or ultrasonic cleaning, may be required to remove biofilm and prevent further fouling.

In addition to understanding fouling mechanisms, regular maintenance procedures are essential for preserving the efficiency of heat exchangers. These procedures include:

1. **Periodic Inspection:** Regular inspection helps identify early signs of fouling or damage, allowing for timely maintenance actions. Non-destructive testing (NDT) techniques, such as ultrasonic or magnetic particle testing, can be used to assess the condition of tubes and detect fouling or leaks.
2. **Cleaning Schedule:** Implementing a routine cleaning schedule based on the specific fouling tendencies of the system is crucial. It ensures that the heat exchanger remains free from excessive fouling and maintains optimal heat transfer performance.
3. **Flow Monitoring:** Monitoring flow rates and pressures within the heat exchanger can help detect any abnormalities or indications of fouling. Deviations from normal flow patterns may signal the need for cleaning or maintenance.
4. **Shutdown Maintenance:** Scheduled shutdowns provide an opportunity for thorough cleaning and maintenance procedures. During these shutdowns, mechanical cleaning methods, chemical cleaning, or more extensive cleaning techniques can be employed to remove stubborn fouling deposits.

TASK B:

Heat exchangers are critical components in many industrial processes, and their efficiency is essential for optimal performance. However, fouling in heat exchangers is a common problem that can reduce the thermal performance and lead to increased energy consumption and

maintenance costs. Fouling occurs when unwanted deposits build up on heat transfer surfaces, reducing the heat transfer coefficient and increasing the pressure drop. The fouling rate is affected by various parameters such as fluid velocity, temperature, and chemical composition. In recent years, researchers have focused on developing fouling models and improving heat exchanger designs to mitigate fouling and improve thermal performance.

Fouling Model:

Ebert and Panchal (1997) proposed a fouling model that considers two opposing terms: a deposition term and a mitigation term. The deposition term represents the accumulation of fouling deposits on the heat transfer surface, while the mitigation term represents the removal or prevention of fouling deposits. The model is expressed as the average (linear) fouling rate under given conditions, and it can be used to predict the fouling rate for a given set of operating conditions. The fouling model is given as follows:

$$d\theta/dt = kd - km\theta$$

where $d\theta/dt$ is the fouling rate, θ is the fouling resistance, kd is the deposition coefficient, and km is the mitigation coefficient. The fouling model suggests that the fouling rate increases with increasing deposition coefficient and decreases with increasing mitigation coefficient.

Helical Baffles: One of the recent design improvements in shell-and-tube heat exchangers to mitigate fouling is the use of helical baffles. Traditional baffle designs, such as segmental baffles, can cause dead zones where fluid velocity is low, leading to fouling deposits. Helical baffles are designed to create a swirling flow pattern that promotes fluid mixing and enhances heat transfer while minimizing dead zones. The helical baffles consist of twisted plates that are placed at an angle to the shell axis. (Takemoto, Crittenden and Kolaczowski, 1999)

In recent years, significant advancements have been made in the design of shell-and-tube heat exchangers to address fouling issues and enhance thermal performance. This progress can be attributed to the research conducted by Ebert and Panchal in 1997. Their fouling model, which incorporates a deposition term and a mitigation term, has paved the way for the redesign of shell-and-tube baffles. This discussion focuses on the fouling model proposed by Ebert and Panchal, explores the utilization of helical baffles because of their findings, and provides technical justifications and data supporting the application of helical baffles in shell-and-tube heat exchangers.

The Fouling Model by Ebert and Panchal:

Ebert and Panchal's fouling model introduces the concept of an average fouling rate, considering both the deposition and mitigation terms. The deposition term represents the fouling rate due to the accumulation of deposits on heat transfer surfaces, while the mitigation term accounts for any cleaning or maintenance efforts that reduce fouling. By analyzing these opposing terms, the model provides valuable insights into fouling behavior and the factors influencing thermal performance.(Mohanty and Singru, 2011)

Redesigning Shell-and-Tube Baffles:

Helical Baffles:

The fouling model proposed by Ebert and Panchal has spurred the redesign of shell-and-tube baffles, leading to the development of helical baffles. Helical baffles are curved, spiral-shaped structures that replace the conventional segmented baffles. These helical baffles serve multiple purposes in mitigating fouling and improving thermal performance.

1. **Enhanced Turbulence and Fluid Mixing:** The helical shape of the baffles induces swirling motion in the fluid, increasing turbulence and promoting better mixing. This turbulent flow disrupts the boundary layer near the tube walls, reducing the likelihood of fouling deposits forming and enhancing heat transfer efficiency.
2. **Reduced Dead Zones:** Helical baffles minimize dead zones or stagnant regions within the heat exchanger, where fouling deposits tend to accumulate. The continuous spiral flow pattern generated by the helical baffles ensures better fluid distribution and minimizes areas of low velocity, thereby inhibiting fouling.
3. **Improved Self-Cleaning Action:** The helical baffles exhibit self-cleaning characteristics due to the swirling flow they induce. The centrifugal force generated by the helical motion helps dislodge any deposited fouling material from the tube surfaces, preventing its buildup and maintaining efficient heat transfer.

Technical Justifications and Data Supporting Helical Baffles:

The application of helical baffles in shell-and-tube heat exchangers is backed by several technical justifications and supporting data:

1. **Experimental Studies:** Numerous experimental studies have been conducted to evaluate the performance of helical baffles. These studies have demonstrated improvements in heat transfer coefficients, reduced pressure drop, and enhanced thermal performance compared to traditional baffles.
2. **Computational Fluid Dynamics (CFD) Simulations:** CFD simulations have been employed to investigate the flow patterns and heat transfer characteristics in heat exchangers with helical baffles. These simulations have confirmed the benefits of helical baffles, including enhanced fluid mixing, reduced fouling potential, and improved overall performance.
3. **Industrial Case Studies:** Several industrial case studies have reported successful implementations of helical baffles in shell-and-tube heat exchangers. These applications have showcased improved fouling resistance, reduced maintenance requirements, and increased operational efficiency, leading to cost savings and extended equipment lifespan.

The helical design creates a centrifugal force that promotes fluid mixing and prevents fouling deposits from accumulating on the heat transfer surface. Helical baffles have been shown to improve thermal performance and reduce fouling in shell-and-tube heat exchangers.

Technical Justifications and Data: Several studies have investigated the effectiveness of helical baffles in mitigating fouling and improving thermal performance in shell-and-tube heat exchangers. For example, a study by Azizian et al. (2019) compared the performance of a shell-and-tube heat exchanger with helical baffles to a traditional design with segmental baffles. The results showed that the helical baffle design had a higher heat transfer coefficient and lower pressure drop than the traditional design, indicating improved thermal performance. The study also showed that the helical baffles reduced fouling by promoting fluid mixing and preventing fouling deposits from accumulating on the heat transfer surface.

Another study by Bui et al. (2017) investigated the effect of helical baffles on fouling in a shell-and-tube heat exchanger. The results showed that the helical baffle design reduced fouling by up to 50% compared to a traditional design with segmental baffles. The study also showed that the helical baffles promoted fluid mixing and created a more uniform temperature distribution, indicating improved thermal performance.

In conclusion, the fouling model proposed by Ebert and Panchal (1997) has led to the development of new heat exchanger designs, such as helical baffles, to mitigate fouling and improve thermal performance.

TASK C:

Table 1

k	l	di	do	hi	ho	Rfi	Rfo
54	3.05	0.0254	0.0381	100	7300	0.001058	0.00003522
54	3.05	0.02	0.0381	100	7300	0.001058	0.00003522
54	3.05	0.015	0.0381	100	7300	0.001058	0.00003522
54	3.05	0.01	0.0381	100	7300	0.001058	0.00003522
54	3.05	0.005	0.0381	100	7300	0.001058	0.00003522
54	3.05	0	0.0381	100	7300	0.001058	0.00003522
54	3.05	-0.005	0.0381	100	7300	0.001058	0.00003522

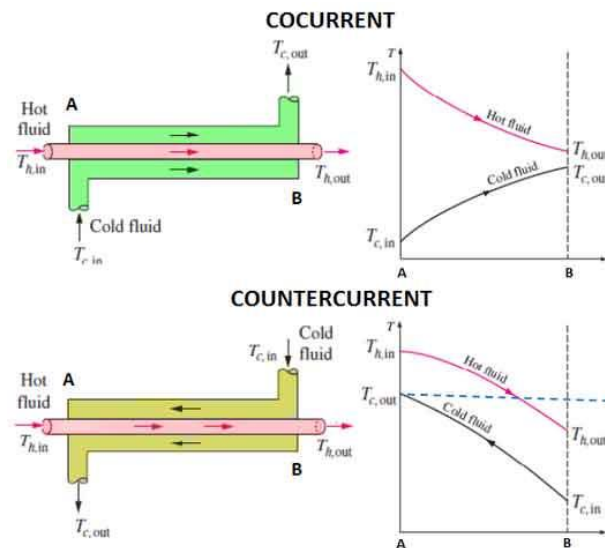


Figure 1 LMTD Method

[Counter Current heat Exchanger | Heat Exchangers , Types And it Efficiency \(wordpress.com\)](http://www.wordpress.com/Heat-Exchangers-Types-And-its-Efficiency/)

Table 2

Toil_inner	Toil_out	Twater_inner	Twater_out	T1	T2	LMTD
160	100	15	85	75	85	79.89572
160	100	15	85	75	85	79.89572
160	100	15	85	75	85	79.89572

160	100	15	85	75	85	79.89572
160	100	15	85	75	85	79.89572
160	100	15	85	75	85	79.89572
160	100	15	85	75	85	79.89572

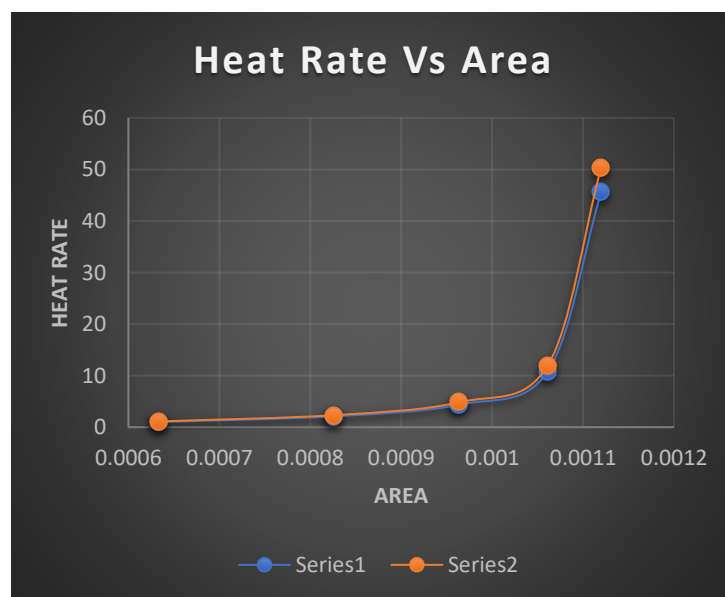
Table 3

Ao	Ai	U_withoutFouling	U_withFouling
0.00114	0.000506	19.86586912	21.9854309
0.00114	0.000314	31.96797155	35.36766927
0.00114	0.000177	56.73824261	62.75811018
0.00114	7.85E-05	127.510043	141.0161101
0.00114	1.96E-05	509.6763182	563.6078631

Table 4

A_total	Q_withoutFouling	Q_withfouling
0.000633063	1.00479673	1.112002144
0.000825514	2.108448433	2.332675589
0.000962889	4.364912856	4.828025497
0.001061014	10.80908632	11.95400198
0.001119889	45.60294767	50.42843658

Table 5



REFERENCES

Diaz-Bejarano, E., Coletti, F. and Macchietto, S. (2019) 'Modeling and prediction of shell-side fouling in shell-and-tube heat exchangers', *Heat Transfer Engineering*, 40(11), pp. 845–861.

Mohanty, D.K. and Singru, P.M. (2011) 'Use of C-factor for monitoring of fouling in a shell and tube heat exchanger', *Energy*, 36(5), pp. 2899–2904. doi:10.1016/j.energy.2011.02.032.

Takemoto, T., Crittenden, B.D. and Kolaczowski, S.T. (1999) 'Interpretation of fouling data in industrial shell and tube heat exchangers', *Chemical Engineering Research and Design*, 77(8), pp. 769–778. doi:10.1205/026387699526764.

Bibliography:

Diaz-Bejarano, E., Coletti, F. and Macchietto, S. (2019) 'Modeling and prediction of shell-side fouling in shell-and-tube heat exchangers', *Heat Transfer Engineering*, 40(11), pp. 845–861.

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[Fouling Factors in Shell & Tube Heat Exchangers](#)

Image credit: Çengel, Yunus A, and Afshin J. Ghajar. Heat and Mass Transfer: Fundamentals & Applications. New York: McGraw-Hill, 2011. Print.