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Analysis of the Efficiency of Shell and Tube, and Spiral Heat Exchangers

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Abstract

Population growth, industrialisation, and urbanisation have all contributed to a significant increase in energy consumption, mostly from fossil fuels, which accounted for more than 80% of the total energy supply between 2000 and 2018. This study examines how heat exchangers used in power production, manufacturing, and HVAC systems might help enhance energy efficiency. The study seeks to improve the efficiency and performance of shell and tube and spiral heat exchangers by looking at their design and operational issues. Methodologically, the study entails developing a problem statement, examining literature, selecting models, and performing tests to determine heat transfer efficiency, Logarithmic Mean Temperature Difference (LMTD), and heat transfer coefficient. Results show that spiral heat exchangers outperform shell and tube ones in terms of heat transfer coefficient, demonstrating higher LMTD values and higher heat transfer rates, making them more suitable for educational and practical applications. The study helps improve energy efficiency and sustainability, boosts industrial competitiveness by addressing maintenance and productivity issues, and broadens the knowledge base in thermal engineering, ultimately assisting in developing more efficient and sustainable thermal solutions across various sectors.

1. Introduction

Population expansion, industrialisation, and urbanisation have increased energy usage in recent decades. This has led to a growth in the usage of fossil fuels, including coal, oil, natural gas, and nuclear power to generate electricity. The International Energy Agency states that between 2000 and 2018, global energy consumption increased by more than 20%, with fossil fuels accounting for more than 80% of total energy supply [1]. Researchers have been charged with inventing energy-saving strategies and new renewable energy sources to combat increased energy use. One possible alternative is to develop more efficient thermal systems, such as heat exchangers. Heat exchangers transfer heat between two or more fluids and are used in various applications, including power production, manufacturing, and HVAC systems [2-4]. There are several heat exchangers, each with unique design and operating features, such as the Shell and Tube Heat Exchanger, Spiral Heat Exchanger, Plate Heat Exchanger, and Concentric Heat Exchanger [2, 4]. This study will focus on Shell and Tube Heat Exchanger (STHE) and Spiral Heat Exchanger (SHE).

Previous research on energy consumption and thermal solutions is critical for understanding current energy use and the need for more sustainable energy sources. Research shows that heat exchanger design and operation modifications can result in significant energy savings, ranging from 10% to 30% [5]. The current study intends to offer a complete assessment of current energy consumption patterns and the need for energy-saving solutions, focusing on the role of heat exchangers in supporting more sustainable energy use. It also emphasises the need for more sustainable and efficient energy sources. The study delves deeper into the many thermal solutions being created to minimise energy consumption, such as heat exchangers, which are compact and efficient, making them suitable for use in homes, companies, and industries [3, 4, 6].

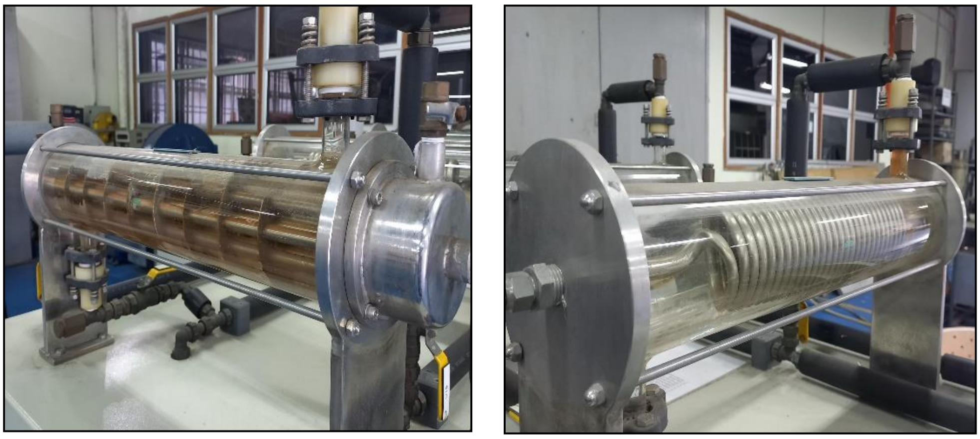
Heat exchangers, widely employed in industrial and commercial applications, are often fraught with challenges such as fouling, corrosion, and thermal performance loss. This study aims to address these concerns by focusing on shell and, tube and spiral heat exchangers, investigating their design, operation, and potential solutions to improve efficiency and performance [5]. The research findings will be valuable for academics, researchers, and industry professionals involved in heat exchanger development and implementation, ultimately contributing to enhanced energy efficiency and sustainability [2-4].

This study aims to find the relationship between heat transfer and heat loss with heat exchanger efficiency, investigate the Logarithmic Mean Temperature Difference (LMTD) for different types of heat exchangers and study the heat transfer coefficient in heat exchangers.

This study holds significant implications for improving energy efficiency and sustainability across industries by addressing heat exchanger design and performance challenges. The research can potentially optimise heat exchanger operation, reducing energy consumption and lowering greenhouse gas emissions. Additionally, the findings can enhance industrial competitiveness by identifying solutions to fouling and corrosion, resulting in lower maintenance costs and greater productivity [5]. Lastly, the comprehensive analysis will expand the knowledge base in heat transfer and thermal engineering, benefiting researchers, academics, and industry experts in heat exchanger development and applications [5, 7].

2. Materials and method

This study systematically evaluates and analyses various aspects of heat exchangers, aiming to inform engineering practices and promote energy-efficient solutions. The research design consists of three key objectives: assessing heat transfer and efficiency, investigating the Logarithmic Mean Temperature Difference (LMTD), and studying the heat transfer coefficient in different configurations, including Shell and Tube Heat Exchanger (STHE) and Spiral Heat Exchanger (SHE). The study also explores using liquid air as a sustainable heat exchange medium. Experiments are conducted to evaluate and compare the thermal performance, energy efficiency, and system characteristics under various operating conditions, with the findings expected to influence heat exchanger selection and design based on specific requirements, contributing to advancements in thermal management technology.



(a) (b)

Fig. 1 *Figure description (a) Shell and Tube Heat Exchanger; (b) Spiral Heat Exchanger*

3. Results and Discussion

Table 1 and Table 2 provide performance data for a counter-current shell and tube heat exchanger, with the one fluid stream (FT1) flow rate constant at 10 LPM. As the flow rate of the other fluid stream (FT2) increases from 2 to 10 LPM, the temperature differences between the inlet and outlet of the heat exchanger generally decrease, indicating improved heat transfer efficiency.

Table 1 *Counter-current Shell and Tube Heat Exchanger (FT1 Constant = 10LPM)*

FT1 (LPM)	FT2 (LPM)	TT1 (°C)	TT2 (°C)	TT3 (°C)	TT4 (°C)	DPT1 (mmH_2O)	DPT2 (mmH_2O)
10	2	68.4	33.2	43.2	61.7	33.2	61.7
10	4	69.7	32.9	46.0	63.6	32.9	63.6
10	6	68.0	33.2	43.0	61.6	33.2	61.6
10	8	68.2	33.2	41.4	60.7	33.2	60.7
10	10	68.4	32.6	40.0	60.4	32.6	60.4

The temperature values represent the heat transfer between the two fluid streams, with the FT1 stream being cold and the FT2 stream being hot. By analysing the data in this table, we may learn about the spiral heat exchangers' performance characteristics, such as the link between flow rates and temperature variations.

Table 2 *Counter-current Spiral Heat Exchanger (FT1 constant = 5LPM)*

FT1 (LPM)	FT2 (LPM)	TT1 (°C)	TT2 (°C)	TT3 (°C)	TT4 (°C)
5	2	70.8	33.9	46.2	63.3
5	3	68.4	33.7	43.5	61.9
5	4	68.3	34.3	41.8	61.2
5	5	69.0	34.7	41.3	61.8

$$LMTD = \frac{\Delta T1 - \Delta T2}{ln\frac{\Delta T1}{\Delta T2}} \quad (1)$$

Fig 2 illustrates a graph of the inverse relationship between the heat transfer rate and the heat transfer coefficient for two different heat exchangers: Shell and Tube Heat Exchangers (STHE) and Spiral Heat Exchangers (SHE). As the heat transfer rate increases, the heat transfer coefficient decreases for both heat exchangers, suggesting that higher heat transfer rates reduce overall heat transfer efficiency. SHE exhibits a significantly higher maximum heat transfer rate of approximately 14,040 W compared to STHE, and correspondingly, SHE also demonstrates a higher maximum heat transfer coefficient of around 551.96 $W/m^2\cdot K$, indicating that SHE represents a more optimised or efficient heat exchanger design capable of achieving higher overall thermal performance. This inverse relationship between heat transfer rate and heat transfer coefficient is a fundamental characteristic of heat exchangers, as the design and operating conditions play a crucial role in determining the overall thermal performance of the system.

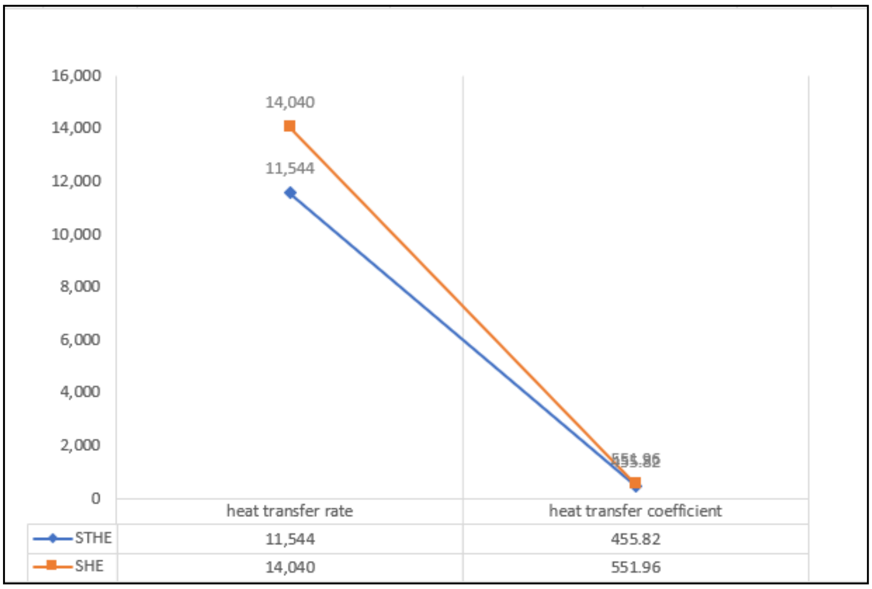


Fig. 2 *Relationship between Heat Transfer Rate and Heat Transfer Coefficient*

The results in Fig 3 show that the spiral heat exchanger (SHE) outperforms the shell and tube heat exchanger (STHE). As the Logarithmic Mean Temperature Difference (LMTD) increases, the SHE achieves significantly higher heat transfer rates, reaching a maximum of around 14,040 W compared to the STHE lower maximum. This indicates the SHE design is more efficient and optimised, enabling excellent heat transfer performance.

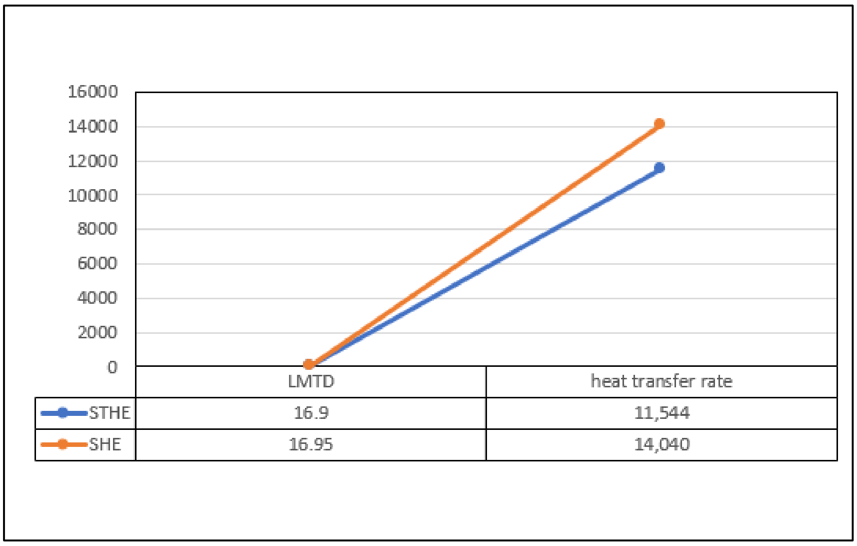


Fig. 3 *Relationship between LMTD and Heat Transfer Rate.*

4. Conclusion

The research study using the HE 158C model found that the spiral heat exchanger (SHE) outperformed the shell and tube heat exchanger (STHE). The SHE achieved a higher maximum heat transfer coefficient of 551.96 W/m^2·K compared to the STHE 455.82 W/m^2·K. Additionally, the SHE reached a peak heat transfer rate of approximately 14,040 W at an LMTD of 16.95°C, indicating superior efficiency. These findings demonstrate the SHE design is more optimised for high-performance applications. Therefore, the spiral heat exchanger proved to be the better choice for achieving the desired educational and efficiency objectives in this context.

Some recommendations to ensure accurate and successful results in the heat exchanger experiment include verifying equipment condition, removing air bubbles, taking stable system readings, avoiding parallax error, properly insulating the exchanger, recording steady temperature readings, maintaining constant conditions, and implementing an alert system to notify when to take readings. Following these precautions can help provide reliable data for the study.

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Conflict of Interest

The authors declare no conflict of interest regarding the paper's publication.

References

[1] International Energy Agency (IEA). (2019). World Energy Outlook 2019. Paris, France: IEA.

[2] Kakaç, Sadik, Hongtan Liu, and Anchasa Pramuanjaroenkij. Heat exchangers: selection, rating, and thermal design. CRC Press, 2002.

[3] Cengel, Y. A. (2002). Heat transfer: a practical approach (Vol. 409). New York: McGraw-Hill.

[4] Çengel, Y. A., & Ghajar, A. J., Heat and mass transfer: fundamentals and applications. McGraw-Hill, 2011.

[5] Shah, Ramesh K., and Dusan P. Sekulic. Fundamentals of heat exchanger design. John Wiley & Sons, 2003.

[6] Whitman, Alan M. Thermodynamics: basic principles and engineering applications. Springer, 2020.

[7] Sharma, K. V., P. K. Sarma, W. H. Azmi, Rizalman Mamat, and K. Kadirgama. "Correlations to predict friction and forced convection heat transfer coefficients of water-based nanofluids for turbulent flow in a tube." International Journal of Microscale and Nanoscale Thermal and Fluid Transport Phenomena 3, no. 4 (2012): 1-25.