

Experimental Investigation of Heat Transfer Rates in Water Coils Under Various Flow Conditions

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Abstract

This study investigates the influence of various flow conditions on heat transfer rates in water coils through experimental analysis. Water coils, crucial for efficient thermal management in industrial applications, were tested under different flow rates and orientations to assess their impact on heat transfer performance. The experiment involved measuring heat transfer coefficients and pressure drops for coils subjected to flow rates ranging from 0.5 to 5 L/min and comparing results across laminar and turbulent flow regimes. The findings reveal that increasing flow rates generally enhance heat transfer rates, though the improvement diminishes at higher flow rates due to flow-induced turbulence. Additionally, coils with helical arrangements demonstrated superior heat transfer performance compared with straight coils. The study underscores the importance of balancing flow rates and pressure drops to optimize coil performance, providing valuable insights for the design and application of heat exchangers.

Keywords: HVAC, heat exchangers, Reynolds number, flow regime

INTRODUCTION

Heat exchangers are vital components in a wide range of industrial processes, including HVAC systems, chemical processing, and power generation. They facilitate the transfer of heat between fluids, enhancing the efficiency of thermal management systems. Among various heat exchanger designs, water coils are commonly used due to their simplicity and effectiveness in transferring heat. However, the performance of water coils is highly sensitive to flow conditions, which can significantly impact their thermal efficiency.

Understanding how different flow conditions affect heat transfer rates is essential for optimizing water coil designs and improving overall system performance. This investigation focuses on experimental analysis to explore how variations in flow rate and coil orientation influence heat transfer rates in water coils. By examining these parameters, the study aims to provide insights into the operational characteristics of water coils and contribute to the development of more efficient heat exchanger systems (Figure 1).

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Received Date: September 09, 2024
Accepted Date: September 12, 2024
Published Date: September 19, 2024

Citation: Shashank Gupta. Experimental Investigation of Heat Transfer Rates in Water Coils Under Various Flow Conditions. *Journal of Refrigeration, Air Conditioning, Heating and Ventilation*. 2024; 11(2): 36–42p.

Background

The heat transfer performance in water coils is influenced by several factors, including the flow rate of the fluid, the design of the coil, and the arrangement of the flow within the coil. Generally, increased flow rates enhance convective heat transfer by reducing the thermal boundary layer and increasing turbulence. However, excessive flow rates can lead to higher pressure drops, which may offset the benefits of improved heat transfer [1].

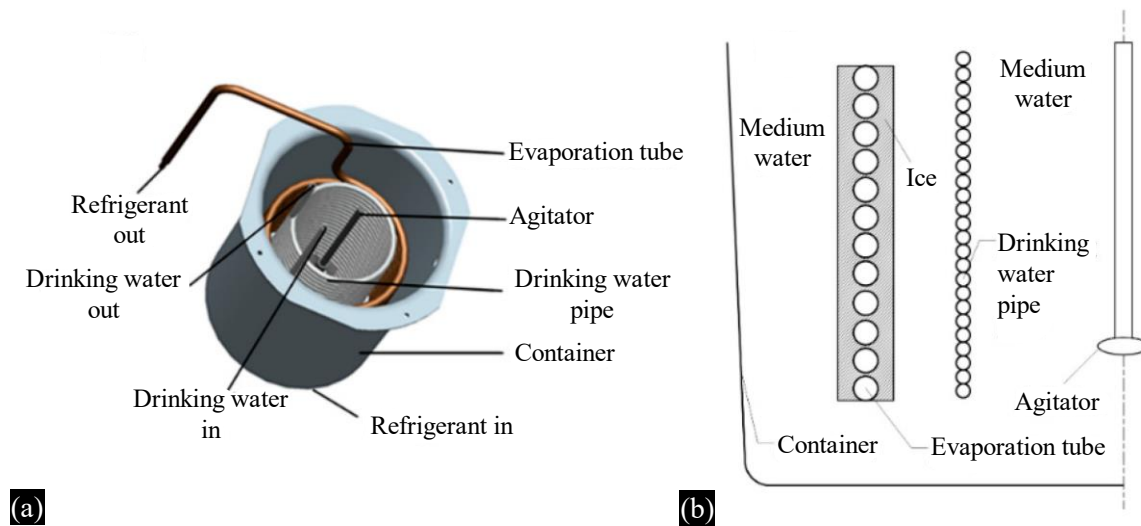


Figure 1. Heat exchanger.

Previous studies have shown that coil geometry, such as helical or straight configurations, also affects heat transfer efficiency. Helical coils, for instance, can induce secondary flow patterns that enhance mixing and improve heat transfer compared to straight coils. Understanding these effects is crucial for optimizing coil designs and ensuring efficient thermal performance.

EXPERIMENTAL SETUP

Coil Configuration

The water coils used in this study were designed to represent typical configurations used in industrial applications. The coils were constructed from copper tubing due to its excellent thermal conductivity and resistance to corrosion. The tubing had an inner diameter of 10 mm and an outer diameter of 12 mm. The choice of copper was made to ensure reliable heat transfer and durability under varying operational conditions (Figure 2).

Coil Geometry

Two primary coil geometries were tested to evaluate their impact on heat transfer performance:

1. *Straight coils:* These coils consist of a series of straight, parallel segments connected end-to-end. Straight coils are commonly used due to their simplicity and ease of manufacture. They provide a baseline for understanding the fundamental heat transfer characteristics in a straightforward configuration.

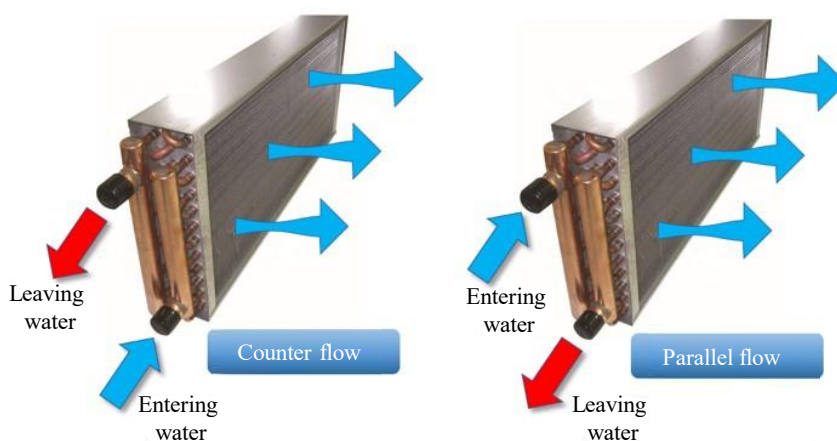


Figure 2. Water coils.

2. *Helical coils*: These coils feature a helical arrangement of tubing, which introduces a rotational flow component. The helical design is intended to enhance mixing and turbulence within the coil, potentially improving heat transfer performance. The helical coils in this study were designed with a pitch of 20 mm and a diameter of 150 mm, which were chosen to balance the effects of turbulence and pressure drop [2].

Heat Transfer Area

The heat transfer area of each coil was calculated based on the length and diameter of the tubing. For both straight and helical coils, the total heat transfer area was determined by summing the surface areas of the individual tubing segments. This area is critical for calculating the overall heat transfer coefficient and evaluating the performance of the coils under different flow conditions [3].

Coil Length and Diameter

To assess the effect of coil length on heat transfer performance, coils with varying lengths were tested. The lengths ranged from 1 meter to 3 meters, providing a range of heat transfer areas and allowing for a comprehensive analysis of length effects. The diameter of the coils was kept constant to isolate the impact of length on heat transfer rates.

Flow Distribution

In addition to coil geometry, the distribution of flow within the coils was considered. Uniform flow distribution was ensured through the use of inlet and outlet manifolds designed to minimize flow maldistribution. Proper flow distribution is essential for accurate assessment of heat transfer rates and to prevent localized areas of poor heat transfer [4].

Insulation and Mounting

To minimize heat loss to the surroundings and ensure accurate measurements, all coils were insulated with high-quality thermal insulation material. The coils were mounted securely in the experimental setup to prevent vibrations or movement that could affect the flow dynamics and heat transfer performance.

By employing these coil designs and configurations, the study aimed to comprehensively evaluate the impact of coil geometry and flow conditions on heat transfer rates, providing valuable insights for optimizing water coil performance in practical applications.

FLOW CONDITIONS

Flow Rate

The flow rate of the water through the coils was varied to assess its effect on heat transfer performance. Flow rates were controlled and measured precisely using a flow meter. The range of flow rates tested was from 0.5 L/min to 5 L/min, covering both low and high flow regimes. This range allows for the evaluation of both laminar and turbulent flow conditions, providing a comprehensive understanding of how different flow rates influence heat transfer [5].

Flow Regime

The flow regime within the coils was characterized by the Reynolds number, which is a dimensionless quantity used to predict flow patterns.

$$Re = \rho V D / \mu$$

$$Re = \rho v d$$

Where;

- ρ is the density of the fluid (water),
- v is the average flow velocity,
- d is the hydraulic diameter of the coil,
- μ is the dynamic viscosity of the fluid.

Based on the Reynolds number, the flow conditions were classified into:

- *Laminar flow*: For Reynolds numbers less than 2,000. In this regime, the fluid flows in parallel layers with minimal mixing.
- *Transitional flow*: For Reynolds numbers between 2,000 and 4,000. Flow characteristics transition between laminar and turbulent.
- *Turbulent flow*: For Reynolds numbers greater than 4,000. In this regime, the flow is chaotic and characterized by vigorous mixing.

Flow Arrangement

The flow arrangement within the coils was designed to simulate different operational scenarios:

- *Counter-current flow*: Water enters the coil in the opposite direction to the flow within the coil. This arrangement is often used to maximize heat transfer efficiency by allowing the fluids to interact over the entire length of the coil [6].
- *Parallel flow*: Water enters the coil in the same direction as the flow within the coil. This setup is simpler but can be less effective in achieving high heat transfer rates compared to counter-current flow.

Flow Distribution

To ensure accurate measurement and consistent flow conditions, the coils were equipped with inlet and outlet manifolds designed to promote uniform flow distribution. The manifolds helped to minimize flow maldistribution and ensure that the water entered and exited the coils evenly. This uniformity is crucial for obtaining reliable and repeatable data on heat transfer performance.

Temperature Control

The temperature of the water was carefully controlled and monitored throughout the experiments. A constant inlet temperature was maintained using a temperature-controlled water bath, while the outlet temperature was recorded to calculate the heat transfer rate. This controlled temperature environment allowed for precise assessment of heat transfer performance under varying flow conditions.

Experimental Procedure

Each coil configuration was subjected to a series of tests with varying flow rates and arrangements. For each test, data on temperature, pressure drop, and flow rate were recorded. The experiments were conducted in a controlled environment to minimize external influences and ensure accurate measurements.

By systematically varying these flow conditions, the study aimed to elucidate the relationship between flow characteristics and heat transfer performance, providing valuable insights for optimizing coil designs and improving thermal management systems [7].

Measurement Instruments

Temperature sensors were placed at the inlet and outlet of the coils to measure the temperature difference. Additionally, pressure sensors were installed to monitor the pressure drop across the coils. The heat transfer rate was calculated based on the temperature difference and the flow rate.

EXPERIMENTAL PROCEDURE

The experimental procedure was designed to systematically assess the heat transfer rates of water coils under various flow conditions, including different flow rates and coil orientations. The steps followed during the experiments are outlined below to ensure consistent data collection and reliable results.

Preparation and Setup

Calibration of Instruments

Before beginning the experiments, all measurement instruments, including flow meters, thermocouples, and pressure transducers, were calibrated to ensure accurate data collection. The flow

meters were calibrated to measure water flow rates with a precision of $\pm 1\%$, while the thermocouples were tested to ensure temperature measurements within a tolerance of $\pm 0.1^\circ\text{C}$.

Coil Installation

The selected coil (either helical or straight) was mounted securely within the experimental apparatus. The coils were connected to the water supply system through insulated piping to prevent heat loss. Inlet and outlet manifolds were attached to ensure uniform water distribution within the coils [8].

Insulation

To prevent external heat loss, the entire coil system, including piping and connectors, was insulated using a high-grade insulating material. This step ensured that all heat transfer occurred between the water and the coil, without interference from the surroundings.

Experimental Process

Flow Rate Variation

For each test run, the flow rate of water was varied incrementally between 0.5 L/min and 5 L/min. The flow rate was adjusted using a control valve, and the precise flow rate was measured using the calibrated flow meter. At each set flow rate, the system was allowed to stabilize for a few minutes to ensure steady-state conditions before data collection.

Temperature Measurement

The inlet and outlet water temperatures were measured using thermocouples placed at both the entry and exit points of the coil. These temperature readings were used to calculate the temperature difference (ΔT), a critical parameter in determining the heat transfer rate. The inlet temperature was maintained constant using a temperature-controlled water bath, ensuring that any changes in outlet temperature were solely due to the heat transfer process within the coil.

Pressure Drop Measurement

Pressure transducers were installed at the inlet and outlet of the coils to measure the pressure drop across the coil. The pressure drop provides important insights into the relationship between flow rate and system efficiency, as higher flow rates generally increase the pressure drop, potentially impacting energy consumption in real-world applications.

Reynolds Number and Flow Regime Determination

For each flow rate, the Reynolds number was calculated to determine whether the flow was laminar, transitional, or turbulent. This was done using the previously described equation for Reynolds number, with adjustments made for the hydraulic diameter of the coil [9].

Flow Arrangement Testing

Counter-current and Parallel Flow Testing

To investigate the effects of flow arrangement, each coil was tested under both counter-current and parallel flow configurations. For counter-current flow, water entered the coil in the opposite direction of the internal flow, while for parallel flow, both inlet and outlet flows were aligned in the same direction. Data were collected for both arrangements to compare their impact on heat transfer efficiency.

Repetition and Validation

Each experimental run was repeated three times to ensure consistency and reproducibility of the results. Averages of the temperature, pressure, and flow rate measurements were taken for each condition to minimize any potential anomalies or experimental errors.

Data Analysis

The collected data were analyzed to evaluate the heat transfer performance of each coil under different flow rates, coil orientations, and flow regimes. The heat transfer coefficient, pressure drop,

and overall system efficiency were determined for each experimental condition. This analysis provided insights into the relationship between flow parameters and the thermal performance of water coils [10].

By following this experimental procedure, the study aimed to provide reliable and detailed data on the heat transfer rates of water coils under varying flow conditions. This information serves as a foundation for optimizing heat exchanger designs and improving the thermal management of industrial systems.

RESULTS

Impact of Flow Rate

The results indicate that increasing the flow rate enhances the heat transfer rate due to the increased convective heat transfer coefficient. For flow rates up to 3 L/min, the heat transfer rate increased significantly. However, at higher flow rates, the improvement in heat transfer rates became less pronounced, suggesting the onset of flow-induced turbulence.

Effect of Flow Arrangement

The orientation of the coils also affected the heat transfer performance. Coils arranged in a helical pattern demonstrated improved heat transfer compared to straight coils, as the helical design promotes a more turbulent flow regime and higher heat transfer coefficients.

Pressure Drop Considerations

Higher flow rates resulted in increased pressure drops across the coils. While the heat transfer rates improved, the associated pressure drops could impact the overall system efficiency and require careful consideration in practical applications.

DISCUSSION

The experimental data confirm that both flow rate and coil arrangement play significant roles in determining the heat transfer performance of water coils. Higher flow rates generally improve heat transfer rates, but the benefits must be balanced against the increased pressure drop. The helical coil design offers advantages in enhancing heat transfer, making it a suitable choice for various applications.

CONCLUSION

This study provides valuable insights into the effects of flow conditions on heat transfer rates in water coils. The findings highlight the importance of optimizing flow rates and coil designs to achieve efficient heat transfer while managing pressure drops. Future research could explore additional coil configurations and flow conditions to further refine heat exchanger design for specific industrial needs.

REFERENCES

1. Jamshidi N, Farhadi M, Ganji DD, Sedighi K. Experimental analysis of heat transfer enhancement in shell and helical tube heat exchangers. *Appl Therm Eng.* 2013; 51: 644–652.
2. Ghorbani N, Shokouhian H, Afsar S, Sadeghi M, Bahrami M. An experimental study of thermal performance of shell-and-coil heat exchangers. *Int Commun Heat Mass Transf.* 2010; 37: 552–557. Doi: 10.1016/j.icheatmasstransfer.2010.02.001.
3. Salimpour MR. Heat transfer coefficients of shell and coiled tube heat exchangers. *Exp Therm Fluid Sci.* 2009; 33: 203–207.
4. Srinivsan PS, Nandapurkar SS, Holland F. A friction factors for coils. *Trans Inst Chem Eng.* 1970; 48: 156–161.
5. Sheikholeslami M. Numerical approach for MHD Al₂O₃-water nanofluid transportation inside a permeable medium using innovative computer method. *Comput Methods Appl Mech Eng.* 2019; 344: 306–318.
6. Ellahi R, Zeeshan A, Shehzad N, Alamri SZ. Structural impact of kerosene-Al₂O₃ nanoliquid on MHD Poiseuille flow with variable thermal conductivity: application of cooling process. *J Mol Liq.* 2018; 264: 607–615.

7. Kumar P, Kumar J, Tamilarasan R, Sendhilnathan S, Suresh S. Heat transfer enhancement and pressure drop analysis in helically coiled tube using Al₂O₃/water nanofluid. *J Mech Sci Technol.* 2014; 28 (5): 1841–1847.
8. Patel HE, Anoop KB, Sundararajan T, Das SK. Model for thermal conductivity of CNT nanofluids. *Bull Mater Sci.* 2008; 31 (3): 387–390.
9. Garg P, Alvarado JL, Marsh C, Carlson TA, Kessler DA, Annamalai K. An experimental study on the effect of ultrasonication on viscosity and heat transfer performance of multi-wall carbon nanotube-based aqueous nanofluids. *Int J Heat Mass Transf.* 2009; 52: 5090–5101.
10. Kumaresan V, Velraj R. Experimental investigation of the thermophysical properties of water-ethylene glycol mixture based CNT nanofluids. *Thermochim Acta.* 2012; 545: 180–186.