ALKU Journal of Science 2024, Sayı 6(3): 272-282
e-ISSN: 2667-7814

Original Article

Comparative Analysis of Heat Transfer Coefficient Using Experimental Data and Empirical Expressions

Birkut Güler [1*]
[1]*Makine ve Metal Teknolojileri, Bulancak Meslek Yüksekokulu, Giresun Üniversitesi, Giresun, Türkiye.*
* *birkut.guler@giresun.edu.tr*

Abstract

This study focuses on determining the heat transfer coefficient by making a comparative analysis of experimental data and empirical expressions. The experiments were carried out to evaluate the heat transfer performance of water flowing through a polyethylene hose. The heat transfer coefficient obtained by experimental methods was determined as 48.30 W/(m² K), while this value was calculated as 53.44 W/(m² K) by empirical calculation. These results show minor differences due to small errors in experimental applications and assumptions in empirical models. The closeness between experimental and empirical values supports the validity of empirical correlations in estimating heat transfer coefficients for similar configurations. However, the study is not limited to comparing heat transfer coefficients but also emphasizes the accuracy of experimental methods and the applicability of empirical models. In conclusion, this research sheds light on the complexity of heat transfer processes and reveals the importance of integrating experimental and empirical approaches in engineering applications. These findings contribute to the development of more efficient engineering practices and provide important information that experimental and empirical methods can be used together in the calculation of heat transfer coefficients.

Keywords: Heat transfer, convection, validation, experimental

Deneysel Veriler ve Ampirik İfadeler Kullanılarak Isı Transfer Katsayısının Karşılaştırmalı Analizi

Özet

Bu çalışma, deneysel veriler ile ampirik ifadelerin karşılaştırmalı analizini yaparak ısı transfer katsayısının belirlenmesine odaklanmaktadır. Deneyler, polietilen bir hortum içerisinden akan suyun ısı transfer performansını değerlendirmek amacıyla gerçekleştirilmiştir. Deneysel yöntemler aracılığıyla elde edilen ısı transfer katsayısı 48,30 W/(m²·K) olarak belirlenmişken, ampirik hesaplama ile bu değer 53,44 W/(m²·K) olarak hesaplanmıştır. Bu sonuçlar, deneysel uygulamalardaki minör hatalar ve ampirik modellerdeki varsayımlara bağlı olarak küçük farklılıklar göstermektedir. Deneysel ve ampirik değerler arasındaki yakınlık, benzer konfigürasyonlar için ampirik korelasyonların ısı transfer katsayılarını tahmin etme konusundaki geçerliliğini desteklemektedir. Ancak, çalışma yalnızca ısı transfer katsayılarının karşılaştırılması ile sınırlı kalmamış, aynı zamanda deneysel yöntemlerin doğruluğunu ve ampirik modellerin uygulanabilirliğini de vurgulamaktadır. Sonuç olarak, bu araştırma, ısı transfer süreçlerinin karmaşıklığına ışık tutmakta ve mühendislik uygulamalarında deneysel ile ampirik yaklaşımların entegrasyonunun önemini ortaya koymaktadır. Bu bulgular, daha verimli mühendislik uygulamalarının geliştirilmesine katkıda bulunmakta ve ısı transfer katsayılarının hesaplanmasında deneysel ve ampirik yöntemlerin birlikte kullanılabileceğine dair önemli bilgiler sunmaktadır.

Anahtar Kelimeler: Isı transferi, taşınım, doğrulama, deneysel veriler

Geliş/Received: 20 Ağustos/20 August
Kabul Ediliş/Accepted: 22 Ekim/22 October

1. INTRODUCTION

Heat transfer is a fundamental phenomenon that plays a crucial role in various industrial and engineering applications. Understanding the heat transfer properties of fluids is essential for increasing energy efficiency, optimizing system performance, and developing innovative technologies. In this study, we focus on determining the heat transfer coefficient through both experimental methods and empirical expressions, aiming to demonstrate that the results obtained from these two approaches are not significantly different.

The heat transfer coefficient (h) varies depending on factors such as fluid flow rate and pipe geometry. Various theoretical models and empirical expressions can be used to directly calculate this coefficient. However, experimental results are critical to verify the accuracy of theoretical predictions and provide practical guidance for industrial applications. The primary goal of this study is to determine whether the heat transfer coefficients calculated from experimental data align with those obtained from empirical expressions in the literature.

The results from this analysis contribute to a better understanding of the heat transfer properties of fluids and the development of more efficient heat transfer systems. In the following sections, we will present the methodology used, analyze the findings obtained, and discuss the implications of the results. We believe that the information obtained from this study will be valuable for researchers and professionals working in the field of heat transfer.

Optimizing energy consumption and improving the performance of heat exchangers are crucial efforts in various industrial processes [1, 2]. Heat exchangers, which are vital in energy and heat transfer systems, have been the subject of extensive research to shorten heat transfer time and increase efficiency [1, 3, 4]. Recent advances in heat transfer fluids such as nanofluids have shown promising results in improving heat exchanger performance [1, 5, 6]. Nanofluids, engineered fluids with nanoparticles dispersed in a base fluid, exhibit superior heat transfer properties compared to conventional heat transfer fluids [5-7]. Its potential applications span a variety of industries including refrigeration, electronics, and renewable energy systems [6]. Experimental studies of heat transfer phenomena have been crucial in advancing our understanding of thermal processes [1, 8]. Studies focusing on convective heat transfer in microchannel heat sinks have described empirical correlations and verified their accuracy through experimental and simulation studies [5, 9, 10]. These studies have revealed the importance of factors such as flow distribution and convective thermal resistance in optimizing heat transfer efficiency [5, 9, 10]. Additionally, studies on the boiling heat transfer coefficients of hydrocarbons in two-phase flow have provided valuable information regarding the performance of heat transfer equipment [2]. By analyzing experimental data and comparing them with existing correlations, researchers aimed to develop more accurate prediction methods for flow boiling properties [2]. In addition to fluid dynamics, studies have also investigated the effect of geometric configurations on heat transfer performance [11]. Experimental studies on longitudinal fins have demonstrated the effectiveness of different fin designs in dissipating heat under natural convection conditions [11]. These findings underline the importance of innovative design approaches in optimizing heat transfer efficiency [11, 12]. Additionally, numerical simulations have contributed to the understanding of the influence of parameters such as the Prandtl number on flow and heat transfer properties [12]. Such studies provide valuable information about the fundamental mechanisms governing heat transfer in various geometries and flow regimes [12]. There are studies aiming to contribute to the existing knowledge by investigating the effects of connectors between microchannels on heat transfer coefficients [7]. Drawing on knowledge gained from previous research on nanofluids and heat transfer enhancement techniques, the studies aim to elucidate the role of connectors in optimizing heat transfer efficiency [7]. It also aims to provide valuable insights into the design and optimization of microchannel heat transfer systems through experimental investigations and analysis of flow dynamics. Experimental-numerical methods are also suggested for determining heat transfer coefficients in cross-flow heat exchangers. Using experimental data, liquid, and air side coefficients can be optimized by the Levenberg-Marquardt method. Error uncertainty in determining correlations can be evaluated by Gauss's rule [12]. If the methods of heat transfer coefficient measurement are classified, the methods are divided into five main groups: direct, transient, Wilson, heat/momentum/mass transfer analogy, and boundary layer thickness method. Each method has its applications, limitations, and accuracies. All methods have a certain level of uncertainty [13].

This study presents an innovative approach to determine the heat transfer coefficient using experimental methods and empirical expressions, compared to previous studies in the literature. While existing studies usually focus on theoretical models or specific fluid types, this study examines heat transfer under different flow conditions with experimental measurements. For example, the studies conducted by Y. Li et al. [5]. on nanofluids suggest using alternative fluids to improve heat transfer performance; however, the experimental data presented in this study provide a broader perspective on determining heat transfer coefficients in conventional fluids. In addition, the comparison of the empirical correlations developed by E. N. Sieder and G. E. Tate [13] with the experimental results obtained in this study allows for evaluating the validity of theoretical predictions in practical applications. The results support the reliability of heat transfer coefficients based on existing literature studies and aim to provide a more comprehensive and applicable understanding for industrial applications.

2. METHODOLOGY

he methodology employed in this study revolves around an in-depth exploration of the heat transfer dynamics observed during the flow of water through a hose and its interaction with the surrounding air. The primary objective is to ascertain the heat transfer coefficient by integrating both empirical data and dimensionless parameters. The experimental setup encompasses the meticulous preparation of 1 liter of water alongside the assembly of the requisite apparatus. This includes a polyethylene hose featuring a 6 mm diameter, a heating mechanism, a pumping system, precise thermometric devices for temperature monitoring, and an air blower for regulating airflow conditions. The procedural steps commence with the controlled pumping of water through the hose at a predetermined flow rate facilitated by the pump mechanism. Concurrently, one end of the hose is elevated by 1 meter while the opposing end is lowered by an equivalent length, thus establishing a vertical flow orientation. Temperature readings at the hose outlet and the airflow velocity are meticulously recorded using the designated thermometric apparatus. Integral to this methodology is the calculation of essential dimensionless numbers, notably the Reynolds (Re), Prandtl (Pr), and Nusselt (Nu) numbers, derived from the acquired experimental data. These dimensionless quantities play a pivotal role in delineating the flow characteristics and discerning the intricacies of heat transfer phenomena. Leveraging the Nusselt number (Nu), the heat transfer coefficient (h) is subsequently computed, representing a pivotal metric indicative of the efficacy of heat exchange between the flowing water and the ambient air. A comprehensive analysis ensues, integrating the experimental datasets, dimensionless parameters, and the derived heat transfer coefficient. Any discernible variances or disparities between empirical observations and computed values are critically examined and elucidated. Ultimately, this meticulous process culminates in insightful conclusions regarding the nuanced heat transfer mechanisms governing water flow within the hose under the stipulated experimental parameters.

The main purpose of this study is to determine the heat transfer coefficient results obtained by experimental methods by comparing them with empirical expressions. However, the majority of such studies are limited to only one experimental or empirical method. In this study, a comprehensive comparison was made by considering the existing empirical models and experimental data as well as the existing CFD analysis results in the literature. With this approach, the accuracy and reliability of the experimental and empirical results were tried to be increased by using the in-depth insights provided by CFD analyses. For example, the CFD analyses conducted by [10] and [9] made significant contributions to the better understanding of heat transfer processes and the validation of empirical models. In this study, such CFD analysis results were compared with the existing experimental data to expand the accuracy and application areas of existing empirical models.

Strict controls were applied to ensure the accuracy and repeatability of the experimental design. In particular, boundary conditions such as water inlet temperature, air flow rate, and temperature were carefully controlled and kept constant. Each experiment was repeated multiple times under the same conditions and the consistency of the obtained data was verified. In addition, the laboratory environment was kept at a constant temperature and humidity to minimize the influence of environmental factors during the experiment.

2.1 Boundary Conditions

The boundary conditions implemented in this experimental study are crucial for establishing a controlled environment conducive to accurate heat transfer analyses. Several key boundary conditions were meticulously defined and maintained throughout the experimental procedure. Firstly, the water inlet temperature was rigorously controlled and set at a constant value of 50°C. This initial temperature condition ensured consistency and reproducibility in the experimental setup, serving as a baseline for measuring heat transfer variations. Secondly, the airflow rate and temperature at the hose outlet were carefully regulated. The airflow rate, maintained at 5.1 m/s, facilitated consistent air-water interaction throughout the experiment. The air temperature at the outlet, set at 14°C, represented the ambient conditions affecting heat dissipation from the water stream. Additionally, the vertical orientation of the hose, with one end elevated by 1 meter and the other end lowered by an equivalent length, established a gravitational influence on the flow dynamics. This vertical configuration imposed a gravitational head on the water flow, impacting the flow velocity and pressure distribution within the hose. Furthermore, the material properties of the polyethylene hose, including its thermal conductivity and surface characteristics, were considered as boundary conditions influencing heat transfer. The thermal conductivity of the hose material, specified at 0.46 W/(m·K), played a significant role in determining the heat conduction through the hose walls. Lastly, the duration of the pumping process, set at 8 minutes and 5 seconds, ensured a consistent and adequate duration for capturing steady-state conditions and minimizing transient effects during data acquisition. These meticulously defined boundary conditions collectively provided a controlled and standardized experimental framework, essential for accurate heat transfer coefficient calculations and insightful analyses of water-air interaction dynamics within the hose system. The schematic representation of the experimental setup used in the study is given in Figure 1.

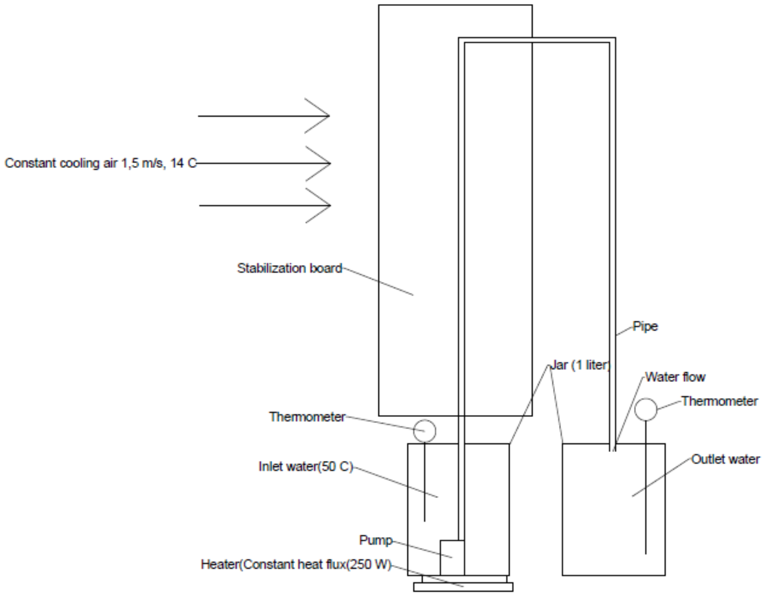

Figure 1. Boundary conditions for the present study

2.2 Experimental Procedure

The experimental design devised for this investigation was meticulously structured to systematically scrutinize the intricate heat transfer phenomena manifesting during the flow of water through a hose under precisely controlled parameters. The following delineates the fundamental constituents of the experimental design framework. The experimental setup featured a precisely calibrated polyethylene hose, boasting a standardized diameter of 6 mm, alongside a thermal control unit for regulating water temperature, a precision pump to modulate water flow rates, thermometric instrumentation for accurate temperature readings, and an air modulation mechanism for controlling airflow patterns surrounding the hose assembly. Imposing stringent boundary conditions played a pivotal role in ensuring the veracity and reproducibility of experimental outcomes. These constraints included a consistently maintained water inlet temperature fixed at 50°C, an airflow rate of 5.1 m/s meticulously regulated at the hose outlet, and an ambient air temperature of 14°C meticulously sustained throughout the experimental duration. The experimental configuration encompassed the deliberate vertical positioning of the hose assembly, wherein one terminus was meticulously elevated by 1 meter while its counterpart was correspondingly lowered, thereby engendering a discernible gravitational influence on the water flow dynamics and associated heat transfer phenomena. Integral experimental parameters such as water flow rates, inlet and outlet temperatures of the water stream, airflow velocities, and the duration of the pump operation were vigilantly monitored, recorded, and meticulously documented at pre-defined intervals throughout the experimental timeframe. The data acquisition methodology adhered to a meticulous and systematic approach, facilitating the capture of steady-state conditions conducive to comprehensive heat transfer analyses. The duration of the pump operation was judiciously set at 8 minutes and 5 seconds, ensuring optimal data acquisition without compromising experimental integrity. To ensure the robustness and credibility of the experimental findings, the experiment was meticulously repeated under identical conditions, enabling data validation and fostering result reproducibility. Statistical analysis techniques were subsequently employed to assess data consistency, coherence, and overall reliability. A stringent regimen of safety protocols was rigorously implemented throughout the experimental proceedings, encompassing comprehensive electrical safety measures, meticulous equipment handling guidelines, and mandatory personnel training to mitigate potential hazards and ensure a safe experimental environment. The meticulously crafted experimental design framework delineated above underscored the systematic, structured, and methodical approach adopted in this investigation, poised to yield profound insights into the intricate heat transfer dynamics governing water flow within the stipulated hose system parameters. Table 1 lists the equipment used in the study.

Table 1**.** Equipment list

Equipment	**Purpose of Usage**	**Brand**	**Model**
Heater	Constant heat flux	Local manufacture	
Cooling fan	Constant air velocity	Arçelik	APPSB-OLA0
Thermometer	Measure temperature	Testo	830-T2
Anemometer	Measure velocity	Sinometer	AM802
Pump	Water flow	TLS Robotic	

Figure 2 shows the experimental study setup.

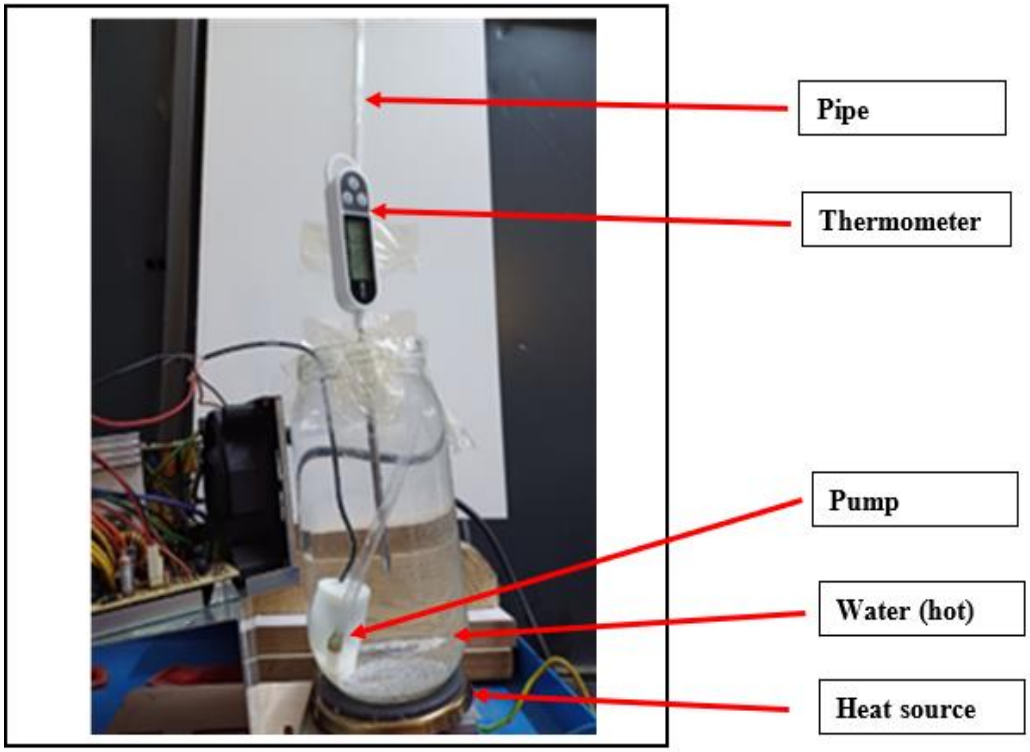

Figure 2. Experimental setup

2.3 Experimental Analysis

We delve into the calculation methodology utilizing the experimental data gathered from the conducted experiments. The focus of this analysis is to determine the heat transfer coefficient (h) based on the specific parameters measured during the experimental setup. By employing the collected data, including water inlet and outlet temperatures, airflow rates, and other pertinent variables, we aim to calculate the heat transfer coefficient (h) using established formulas and analytical methods. This calculation process is integral to understand the heat transfer dynamics within the hose system under experimental conditions and will provide valuable insights into the efficiency of heat exchange in this setup.

Provided data:

Table 2. Provided data for experimental setup

Water volume (V)(m^3)	0,001
Time (pump working) (t)(s)	485
Water temperature(inlet) ^{0}C	50
Water temperature(outlet) ^{0}C	42
Ait temperature ^{0}C	14
Air velocity (m/s)	5,1
Diameter (Hose inner)(m)	0,006
Diameter (Hose outer)(m)	0,008
Length (Hose)(L)(m)	2
Thermal conductivity(Polyethylene)(k)(W/mK)	0,46

Mass Flow Rate (m^3):

$$m'=\frac{V}{t} \tag{1}$$

The density of water is approximately 1000 kg/m³;

Heat Transfer

$$(Q):Q = m.C_p(T_{in} - T_{out}) \tag{2}$$

Here, the specific heat capacity of water, C_p, is approximately 4181 J/(kg·K).

Hose Thermal Conductivity (R_{cond}):

$$R_{cond}=\frac{\ln\left(\frac{d_o}{d_i}\right)}{2\pi kL} \tag{3}$$

Log Mean Temperature Difference (LMTD): is an important parameter representing the temperature difference that drives the heat exchange process. This value reflects the average of the temperature differences at the inlet and outlet of the heat exchanger system.

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \tag{4}$$

Total Heat Transfer Resistance (R_total):

$$R_{total} = R_{cond} + \frac{1}{hA} \tag{5}$$

$$A = \pi d_o L \qquad Q = \frac{\Delta T_{lm}}{R_{total}} \tag{6}$$

2.4 Empirical Analysis

Reynolds Number (Re) Calculation

The Reynolds number determines whether the flow is turbulent or laminar and evaluates the airflow on the outer surface.

$$Re = \frac{\rho v D}{\mu} \tag{7}$$

Prandtl Number (Pr) Calculation

The Prandtl number describes the relationship between momentum and thermal diffusivity in the air.

$$Pr = \frac{\rho C_p}{k} \tag{8}$$

Nusselt Number (Nu) Calculation

The Nusselt number is used to calculate the convective heat transfer coefficient. For laminar flow, an appropriate correlation should be applied. In this case, the Sieder-Tate equation for laminar flow can be used (Sieder & Tate, 1936):

$$Nu = 0.664.Re^{0.5}Pr^{0.33} \tag{9}$$

Calculation of Convective Heat Transfer Coefficient (h)

Using the Nusselt number, we can calculate the convective heat transfer coefficient

$$Nu = \frac{hD}{k} \tag{10}$$

2.5 Extended Parameter Range

The single set of experimental conditions used in this study optimized for a specific application area. However, it is recommended that future studies use a wider range of parameters, including variables such as different water inlet temperatures, hose orientations, and flow rates. This will increase the generalizability of the results and provide a wider data set for different industrial applications. Accordingly, repeating the experiments under different flow rates, temperatures, and hose configurations will enable a more comprehensive analysis of the heat transfer coefficient.

3. RESULTS AND DISCUSSIONS

In this section, the findings of the experimental studies are presented and the relationship between the obtained data and empirical correlations is examined. Experimental data are based on measurements performed under certain conditions and these measurements play an important role in the evaluation of heat transfer performance. Factors such as heat transfer coefficients, temperature differences, and fluid properties are critical elements that determine the effectiveness of heat transfer.

When the experimental results are compared with the values calculated for a specific fluid (such as air), the validity of the empirical correlations is questioned and the applications of these correlations in real-world conditions are evaluated. The obtained data cover both the experimental results and the empirical models found in the literature and demonstrate the consistency between them.

3.1 Summary of Experimental Calculations

$$m'=\frac{0.001m^3}{485\,s}=2.06.10^{-6}\,\frac{m^3}{s}$$

$$m'\left(\frac{kg}{s}\right)=2.06.10^{-6}\,\frac{m^3}{s}.\,1000\,\frac{kg}{m^3}=0.00206\frac{kg}{s}$$

$$Q=0.00206\,\frac{kg}{s}.\,4181\,\frac{J}{kgK}.(50-42)$$

$$Q=68{,}90\,W$$

$$R_{cond}=\frac{\ln\left(\frac{0.008}{0.006}\right)}{2\pi 0.46.2}$$

$$R_{cond}=0.0498\text{ K/W}$$

$$\Delta T_1=T_{in}-T_{air}=50\ {}^0\text{C}-14\ {}^0\text{C}$$

$$\Delta T_2=T_{out}-T_{air}=42\ {}^0\text{C}-14\ {}^0\text{C}$$

$$\Delta T_{lm}=\frac{36-28}{\ln\left(\frac{36}{28}\right)}$$

$$\Delta T_{lm}=31.83\,K$$

$$A=\pi\ 0.008m.\,2\text{m}=0.0503\,m^2$$

$$68.97\,W=\frac{31.83\,K}{0.0498+\frac{1}{hA}}$$

$$\text{h}=48.30\,\frac{W}{m^2K}$$

The experimental setup and calculations yielded the following results:

Heat Transfer Rate (Q): 68.90 W

Log Mean Temperature Difference (LMTD): 31.83 K

Heat Transfer Coefficient (h): 48.30 W/(m^2·K)

3.2 Analysis with Dimensionless Numbers

The dimensionless numbers were calculated based on the experimental conditions:

Where:

- ρ: Air density (approximately 1.225 kg/m³ at 14°C)
- v: Air velocity (1.5 m/s)
- D: Outer diameter of the pipe (0.008 m)
- μ: Dynamic viscosity of air (1.81 x 10-5Pa.s at 14°C)

$$Re = \frac{(1.225).(1.5).(0.008)}{(1.81)\,.10^{-5}} = 812$$

Reynolds Number (Re): 812

Where:

- Cp: Specific heat capacity of air (approximately 1005 J/(kg·K))
- μ: Dynamic viscosity of air (1.81 x 10-5 Pa.s)
- k: Thermal conductivity of air (0.0262 W/(m.K) at 14°C)

$$Pr = \frac{1005.1.81.10^{-5}}{0.0262} = 0.694$$

Prandtl Number (Pr): 0.694

$$Nu = 0.664.812^{0.5}0.694^{0.33} = 16.44$$

Nusselt Number (Nu): 16.44

$$16.44 = \frac{h.0.008}{0.0262}$$

Convection heat transfer (h) is calculated as 53,44 W/m2K

h=53,44 W/m2K

Heat Transfer Coefficient (h): 53.44 W/(m²·K)

3.3 Heat Transfer Coefficient

The heat transfer coefficient calculated from the experimental data was 48.30 W/(m²·K). In comparison, the heat transfer coefficient derived from the empirical Sieder-Tate equation was 53.44 W/(m²·K). The slight discrepancy between these values can be attributed to several factors. Experimental measurements are prone to minor errors, including inaccuracies in temperature readings, flow rate measurements, and physical properties of the materials. The empirical correlation used for the Nusselt number assumes a specific flow regime and ideal conditions, which may not perfectly match the actual experimental setup. The boundary conditions such as air velocity, ambient temperature, and hose orientation play a significant role in heat transfer dynamics. Any variations in these conditions could lead to deviations in the calculated heat transfer coefficient.

In experimental studies, thermophysical properties, especially the properties of fluids, may vary depending on the conditions of the experiment. However, in empirical correlations, these properties are generally considered constant. This may cause differences between experimental and theoretical (empirical) results. In experimental studies, especially in heat transfer calculations, these errors may become more pronounced if thermophysical properties are assumed constant.

If the following formula is used to calculate the relative error:

$$Relative\ error = \frac{|Theoretical\ result - Experimental\ result|}{Theoretical\ result} \text{x}100 \tag{11}$$

$$Relative\ error = \frac{|5{,}14-53{,}44|}{53{,}44} \text{x}100 = 9{,}62\ \% \tag{12}$$

The consistency between the experimental and empirical values of the heat transfer coefficient indicates that the experimental setup and methodology were reliable. The close agreement validates the use of empirical correlations, such as the Sieder-Tate equation, for predicting heat transfer coefficients in similar configurations.

Understanding the heat transfer coefficient is crucial for designing efficient heat exchangers. The findings of this study can aid in optimizing heat exchanger performance by providing accurate predictions of heat transfer rates. Improved heat transfer efficiency directly impacts energy consumption in industrial processes. By validating empirical correlations with experimental data, industries can enhance the energy efficiency of their systems.

In the literature, empirical statements were attempted to be verified with experimental data in a similar way, and agreement was achieved with a 10% deviation [9]. When the heat transfer coefficients were obtained from the experimental data and the Nusselt number was correlated with the experimental data, compatible results were obtained [10]. Some studies developed correlations for heat transfer coefficients and Nusselt numbers using the experimental data obtained [3].

Although strict controls were applied to ensure the accuracy and reproducibility of the experimental design, the use of a wider range of parameters would increase the generalizability and accuracy of the results obtained. Future studies should aim to increase the validity of the present findings by performing a more comprehensive analysis of the heat transfer coefficient under different experimental conditions. In this context, repeating the experiments in a wider range will provide more reliable and comprehensive data sets for different application areas.

4. CONCLUSION

The comparative analysis of the heat transfer coefficient calculated from inlet and outlet temperatures with values obtained from empirical expressions demonstrated good agreement. The study confirms the reliability of using empirical correlations for practical applications and highlights the importance of experimental validation in heat transfer research. The results provide valuable insights for optimizing heat transfer processes in various industrial and engineering applications.

5. FUTURE WORK

To further enhance the accuracy and applicability of the findings, future studies could focus on:

Extended Parameter Range: Conducting experiments over a wider range of flow rates, temperatures, and fluid types to generalize the results.

Advanced Measurement Techniques: Utilizing more precise instrumentation and data acquisition methods to minimize uncertainties.

Numerical Simulations: Complementing experimental studies with computational fluid dynamics (CFD) simulations to gain deeper insights into the heat transfer mechanisms.

REFERENCES

[1] R. Gugulothu, K. Akkiraju, S. Somanchi, and V. K. Reddy, “ScienceDirect A Review on Enhancement of Heat Transfer in Heat Exchanger with Different Inserts A Review on Enhancement of Heat Transfer in Heat Exchanger with Different Inserts,” 2016. [Online]. Available: www.sciencedirect.com

[2] M. ElFaham and C. C. Tang, “A Comparative Analysis of Two-Phase Flow Boiling Heat Transfer Coefficient and Correlations for Hydrocarbons and Ethanol,” Aug. 01, 2023, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/en16165931.

[3] H. Shi, N. Di Miceli Raimondi, M. Cabassud, C. Gourdon, and C. Gourdon Experimen, “Experimental study of heat transfer coefficient in heat exchanger reactors with square millimetric zigzag channels,” *Chemical Engineering and Processing*, vol. 182, 2022, doi: 10.1016/j.cep.2022.109194ï.

[4] Y. Xuan and Q. Li, “Investigation on convective heat transfer and flow features of nanofluids,” *J Heat Transfer*, vol. 125, no. 1, pp. 151–155, Feb. 2003, doi: 10.1115/1.1532008.

[5] Y. Li, M. Li, Y. Li, W. Cai, and L. Yao, “Experimental investigation on the heat transfer performance of falling film evaporation with lubrication oil on horizontal tubes having different structures,” *International Journal of Thermal Sciences*, vol. 160, Feb. 2021, doi: 10.1016/j.ijthermalsci.2020.106669.

[6] S. Kim, S. Kang, and J. Lee, “High-Thermal-Conductivity and High-Fluidity Heat Transfer Emulsion with 89 wt % Suspended Liquid Metal Microdroplets,” *ACS Omega*, vol. 8, no. 20, pp. 17748–17757, May 2023, doi: 10.1021/acsomega.3c00487.

[7] K. Apmann, R. Fulmer, B. Scherer, S. Good, J. Wohld, and S. Vafaei, “Nanofluid Heat Transfer: Enhancement of the Heat Transfer Coefficient inside Microchannels,” *Nanomaterials*, vol. 12, no. 4, Feb. 2022, doi: 10.3390/nano12040615.

[8] Y. Zhai, G. Xia, Z. Li, and H. Wang, “Experimental investigation and empirical correlations of single and laminar convective heat transfer in microchannel heat sinks,” *Exp Therm Fluid Sci*, vol. 83, pp. 207–214, 2017, doi: 10.1016/j.expthermflusci.2017.01.005.

[9] S. S. Pawar and V. K. Sunnapwar, “Experimental studies on heat transfer to Newtonian and non-Newtonian fluids in helical coils with laminar and turbulent flow,” *Exp Therm Fluid Sci*, vol. 44, pp. 792–804, Jan. 2013, doi: 10.1016/j.expthermflusci.2012.09.024.

[10] V. M. Hameed, M. A. Hussein, and H. T. Dhaiban, “Investigating the effect of various fin geometries on the thermal performance of a heat sink under natural convection,” *Heat Transfer*, vol. 49, no. 8, pp. 5038–5049, Dec. 2020, doi: 10.1002/htj.21866.

[11] S. Yu, T. Tang, J. Li, and P. Yu, “Effect of prandtl number on mixed convective heat transfer from a porous cylinder in the steady flow regime,” *Entropy*, vol. 22, no. 2, Feb. 2020, doi: 10.3390/e22020184.

[12] D. Taler, “Experimental determination of correlations for average heat transfer coefficients in heat exchangers on both fluid sides,” *Heat and Mass Transfer/Waerme- und Stoffuebertragung*, vol. 49, no. 8, pp. 1125–1139, 2013, doi: 10.1007/s00231-013-1148-5.

[13] T. A. Moreira, A. R. A. Colmanetti, and C. B. Tibiriçá, “Heat transfer coefficient: a review of measurement techniques,” Jun. 01, 2019, *Springer Verlag*. doi: 10.1007/s40430-019-1763-2.