FAIRFIELD UNIVERSITY

School of Engineering

Department of Mechanical Engineering

MEEG 4350L

ENERGY TRANSFER

Laboratory

Laboratory Experiment No. 3

Title: Convective Heat Transfer Coefficient in Forced Convection

Date Experiment Conducted: September 30, 2024

Date Report Submitted: October 7, 2024

Instructor: Dr. Naser Haghbin

We have proofread the report and all the data in this report is from our experiments conducted in the lab.

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Abstract

This experiment aimed to investigate the relationship between power input and surface temperature in a forced convection system, focusing on calculating the convective heat transfer coefficient. Forced convection enhances heat transfer by increasing the velocity of airflow, which is critical in many engineering applications, such as heat exchanger design. The main objective was to observe how varying air velocities affect the surface temperature of a finned heat exchanger and improve heat transfer efficiency. The setup involved controlling air velocity at different levels from 0.0 m/s to 1.5 m/s, while maintaining a constant power input of 80 W. Temperature measurements were taken using a thermistor, and the heat transfer coefficient was calculated based on the surface area and recorded temperature differences between the heated surface and ambient air. Results showed that as air velocity increased, the temperature difference between the heat exchanger surface and the surrounding air decreased significantly, from 47.1°C to 28.1°C. Correspondingly, the convective heat transfer coefficient increased, indicating more efficient heat transfer with higher airflow. The coefficient values ranged from 11.84 W/m²°C at zero airflow to 19.85 W/m²°C at 1.5 m/s. This result aligns with the expectations, confirming that forced convection significantly improves heat transfer by enhancing the film coefficient. The findings confirmed that increased air velocity enhances the efficiency of heat transfer. Comparing these results to those from free convection showed that forced convection leads to a notably higher heat transfer coefficient. Minor discrepancies were likely due to measurement uncertainties or environmental factors, but overall, the experiment highlighted the crucial role of forced convection in optimizing heat transfer processes.

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1. Introduction

1.1. Background/Theory

In convective heat transfer, the movement of fluid plays a critical role in determining how efficiently heat is transferred from a solid surface to the surrounding fluid. In free convection, the heat transfer is driven by natural fluid movement caused by temperature differences, which leads to slow and limited air movement. This restricts the rate of heat transfer. However, in forced convection, external mechanisms like fans or pumps are used to increase the velocity of the fluid. This forced movement accelerates the transfer of heat, as higher fluid velocities promote turbulent flow. Turbulent flow disrupts the boundary layer, leading to a higher film coefficient, which measures the fluid's resistance to heat flow. The film coefficient is crucial for heat transfer efficiency, as it depends on the direction of fluid flow and the characteristics of the fluid itself. Under the same power input, forced convection systems exhibit lower surface temperatures than free convection systems due to the enhanced heat removal enabled by the higher film coefficient. This makes forced convection far more effective in transferring heat in industrial systems like heat exchangers [1].

1.2. Application in Industry

Convective heat transfer in forced convection within a car radiator occurs when an external force, such as a fan or pump, drives airflow over the radiator's surface. As shown in Fig. 1, as hot coolant circulates through the radiator tubes, the forced air, either from the vehicle's motion or a dedicated fan, increases the heat transfer efficiency. This cools the engine coolant as heat is transferred to the passing air, ensuring that the coolant can effectively absorb more heat from the engine once recirculated. Forced convection significantly improves cooling by enhancing the heat transfer rate compared to natural convection [2].

In a convection oven, as shown in Fig. 2, convective heat transfer occurs when heated air circulates around the food, transferring heat. This process is powered by forced convection, in which fans inside the oven actively move the air. The movement of air improves heat transfer by reducing the boundary layer, a thin layer of stagnant air that protects the food, and increasing the rate at which heat reaches the food's surface. The moving air, heated by the oven's heating elements, transfers energy to the food via convection and radiation. The forced air movement accelerates the cooking process by distributing heat evenly and maintaining a high temperature difference between the air and the food surface, resulting in more efficient heat transfer [3].

In an air conditioning system, as shown in Fig. 3, convective heat transfer is crucial for moving heat between the air and the system's heat exchangers. In forced convection, a fan or pump drives the air over the evaporator and condenser coils, enhancing the heat transfer process. As the air passes over these coils, it either releases heat to the refrigerant in the evaporator or absorbs heat from the refrigerant in the condenser, depending on whether the system is cooling or heating the air. Forced convection increases the heat transfer rate compared to natural convection, making the process more efficient [4].

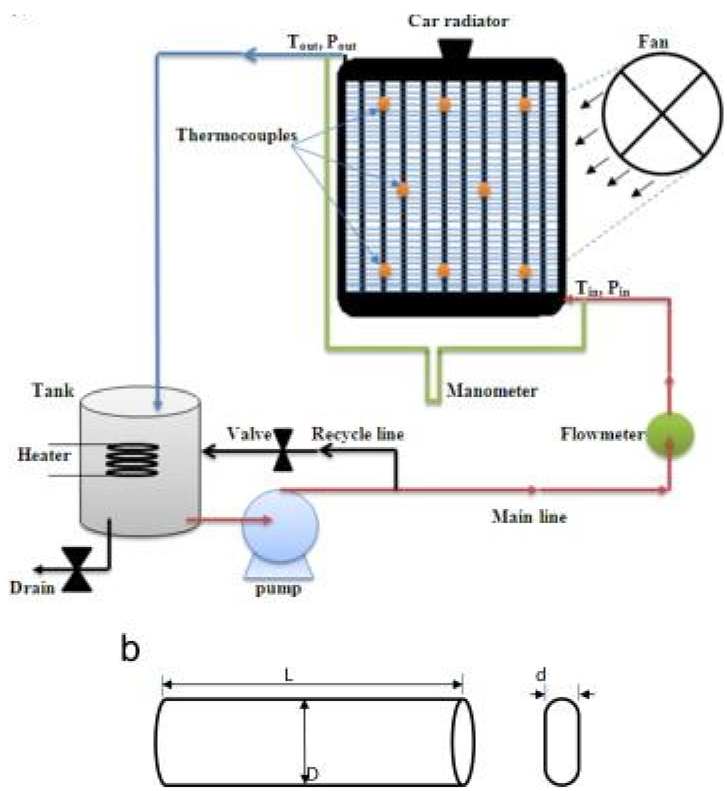

Fig. 1. Car radiator system featuring several key components. It includes a tank with a heater that maintains the fluid temperature and a pump that circulates this fluid through the radiator. Thermocouples are utilized to measure fluid temperatures at both the inlet and outlet, while a manometer monitors pressure drop, and a flowmeter tracks flow rate. Additionally, a fan enhances cooling by increasing airflow over the radiator [5].

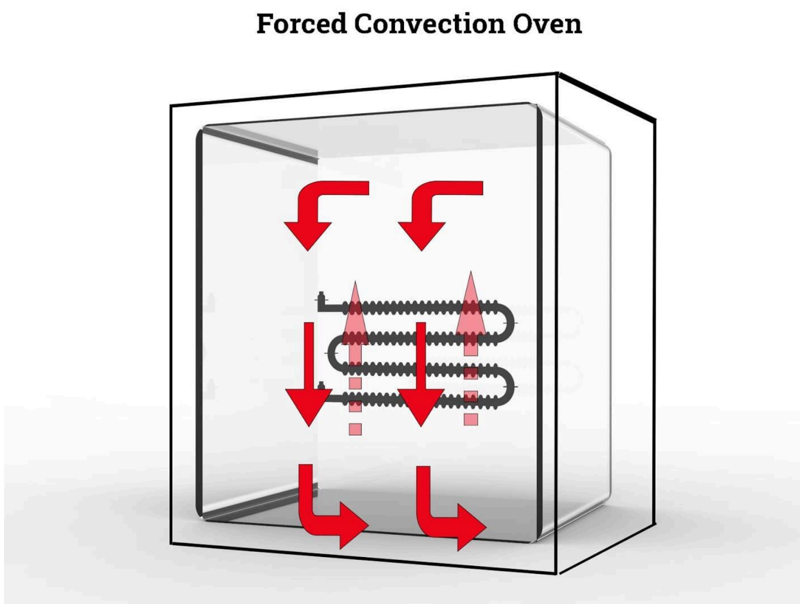

Fig. 2. Forced convection oven, where hot air is actively circulated by a fan or blower. The red arrows indicate the directional flow of heated air, which is distributed evenly throughout the chamber, ensuring uniform temperature and efficient heating [6].

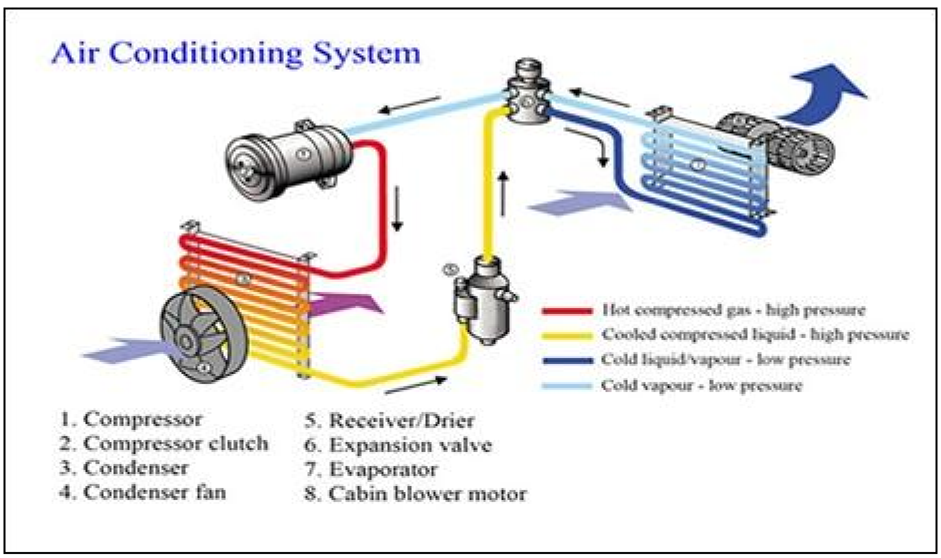

Fig. 3. Air conditioning system showing refrigerant flow through stages of compression, condensation, and evaporation. Key parts include the compressor, the compressor clutch, the condenser fan, the expansion valve, the evaporator, and the cabin blower motor. Color-coded lines represent different refrigerant states: red for hot gas, blue for cold vapor, and yellow for cold liquid [7].

1.3. Purpose of Experiment

The purpose of the experiment is to demonstrate the relationship between power input and surface temperature within a forced convection system. By investigating how forced convection enhances heat transfer efficiency compared to free convection, we will produce accurate data sheets, conduct systematic error analyses, and derive correct conclusions regarding heat losses. The study ultimately aims to provide insights into calculating the heat transfer coefficient at various air velocities.

1.4. Governing Equations

The main equation being used in this experiment is the equation for heat flow:

$$q = hA\Delta t \tag{1}$$

where q is the amount of heat transferred in joules, h is the heat transfer coefficient in $W/m^2 \cdot {}^{\circ}C$, which quantifies the heat transfer per unit area per unit temperature difference, A is the surface area through which heat is being transferred in m^2, and Δt is the temperature difference between the two bodies or environments in degrees Celsius or Kelvin. The equation for power input into the heat exchanger is also needed, which will cause the temperature of the heat exchanger to rise:

$$P(W) = q \tag{2}$$

where P represents the power input in watts (W), and q denotes the heat transfer rate. This relationship indicates that the power supplied to the heat exchanger contributes to the thermal energy increase within the system.

1.5. Discovery Questions

In this experiment, we will be evaluating the behavior of the convective heat transfer coefficient in forced convection. We will examine the relationship between air velocity and temperature. We will also calculate the values for the convective heat transfer coefficient, h, and compare those results to the h values from the free convection experiment. This comparison will discuss how different airflow conditions affect the heat transfer coefficients and their implications for convection theory. Our hypothesis is that increasing the air velocity around the heatsink will improve heat dissipation up to a certain point, but beyond that, the heat transfer coefficient may level off or increase only marginally, regardless of further increases in fan speed.

2. Methods

2.1. Experimental Overview

This experiment aims to determine the convective heat transfer coefficient by examining the relationship between power input and surface temperature in a free convection system. The heat transfer area is calculated and the ambient temperature is recorded using a finned heat exchanger and the Armfield Free & Forced Convection Heat Transfer Apparatus. At 80 Watts, and once steady-state conditions are reached, the air velocity is gradually raised (0, 0.5, 1, 1.5 m/s), and the corresponding base temperature of the heat exchanger is monitored. After that, the convective heat transfer coefficient is computed, examined, and shown graphically.

2.2. Apparatus and Equipment Table

A vertical heating element surrounded by temperature sensors and probes to detect temperature at various heights is the centerpiece of the Armfield Free & Forced Convection Heat Transfer Apparatus, as seen in Fig. 4. By directing airflow over the heater, a fan at the top replicates forced convection. The control unit receives the temperature readings and uses a wattmeter to measure power usage, a heater power control, and an "ON" switch to turn the unit on. This unit facilitates comprehension of the effects of forced and free convection on heat transport. The wind speed and temperature are measured using the airflow anemometer/thermometer apparatus, as seen in Fig. 5. The anemometer component measures the air movement in meters per second (m/s) to calculate the airflow speed. The portion of the thermometer measures the air temperature.

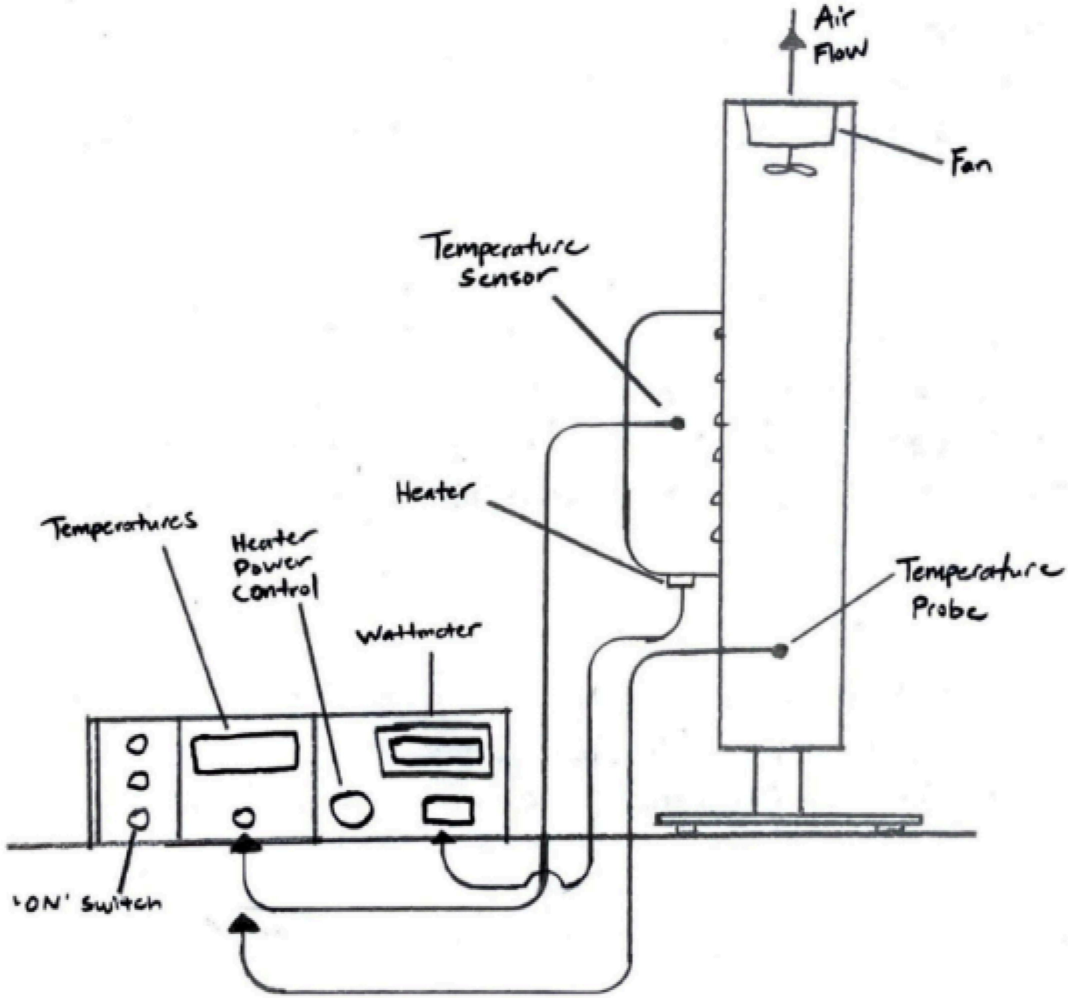

Fig. 4. Diagram of the Armfield H71-B Free & Forced Conversion Heat Transfer Apparatus, along with the Armfield HT6-B Power Supply, is shown. The heat transfer apparatus features a temperature probe, temperature sensor, heater, and a fan for airflow control. The power supply includes a heater power control, a wattmeter, and a temperature display.

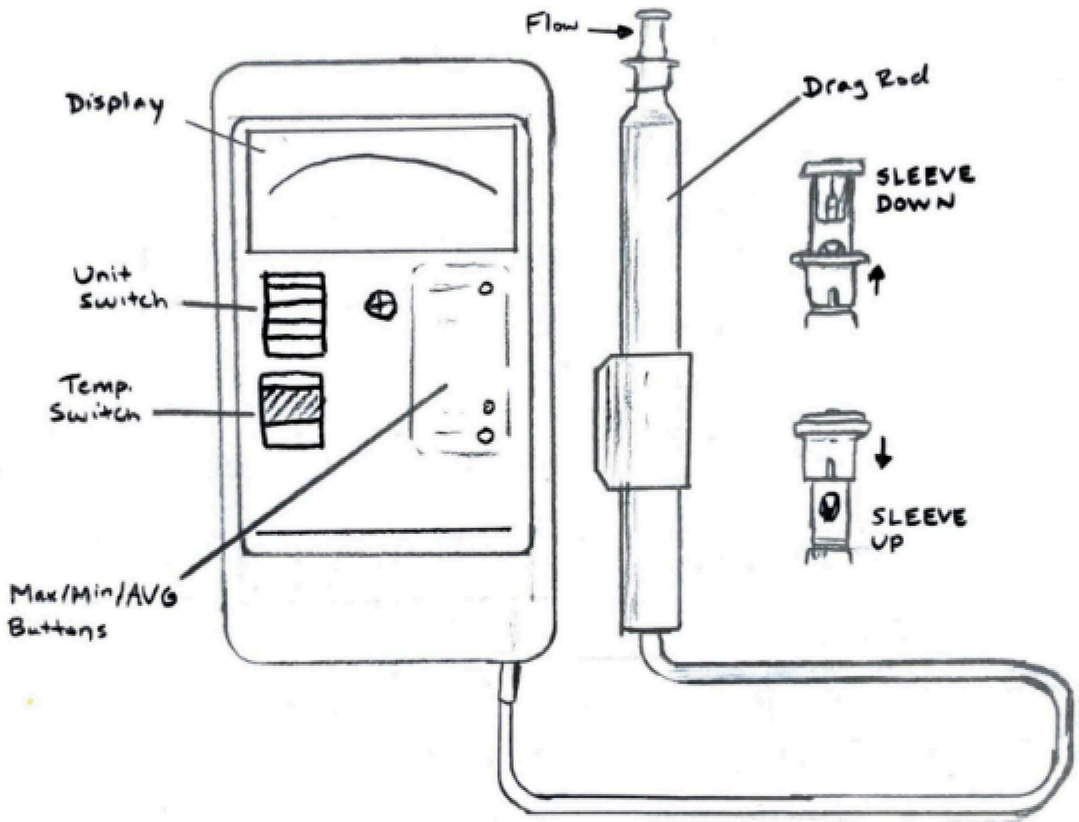

Fig. 5. Diagram showing the drag rod-operated airflow anemometer/thermometer device. The gadget has buttons to measure the maximum, lowest, and average readings in addition to a display, unit, and temperature switches. The device's functioning can be changed by adjusting the sleeve positions ('sleeve up' and ' sleeve down'). The drag rod located on the right is utilized for measuring flow.

Table 1. The apparatus and equipment table shows the components utilized in the experiment. The vertical heater of the Armfield Free & Forced Convection Heat Transfer Apparatus is equipped with sensors that allow temperature readings at different elevations. A fan blows air over the heater to replicate forced convection. This configuration illustrates the effects of forced and free convection on heat transport. While a thermometer tests the temperature of the air, an anemometer measures the speed of airflow.

Equipment and Instrumentation Used	**Accepted Value**
Armfield Free & Forced Conversion Heat Transfer Apparatus – H71-B	Volume: 0.2m³, Gross Weight: 24kg, Dimensions: 0.35m x 0.30m x 0.95m. [8]
Armfield Power supply – HT6-B	Measuring range: +/- 103.42 kPa Accuracy: 0.3% Operating Voltage: 24vDC power supply Dimensions: 0.385. x 0.314m x 0.249m [9]
Airflow Anemometer/Thermometer – TA2	Range: velocity 0-30 m/s, flow rate 0-2700m3/s Accuracy: velocity: ±3% of reading ± 1 digit or ± 0.06 m/s ±1 digit whichever is the greater; flow rate: ±3% of reading ± 1 digit or ± (0.06*input area) m3/s ±1 digit whichever is the greater Dimension: 194mm x 930mm x 13mm [10]

2.3. Procedure

1.) Calibrate the anemometer for velocity measurement and load the finned heat exchanger
2.) Set the pin to 80 *Watts* and wait 15 minutes so the heat exchanger can reach an ambient temperature
3.) Connect the thermistor sensor and measure TH
4.) Turn on the anemometer, and, through the power supply, set the fan speed to 0.5 *m/s*
5.) Wait 15 minutes so the system can reach a steady state then measure the new TH value.
6.) Repeat for 1.0, and 1.5 *m/s*

3. Results

The primary objective of this experiment was to determine the convective heat transfer coefficient, *h*, in a forced convection system and analyze how it varies with different air velocities. This experiment also sought to compare the findings with those from a previous free convection experiment. The power input was set to 80 watts throughout the experiment, and air velocities ranging from 0 to 1.5 m/s were examined. The heat transfer equation, Eq. (1), was used to calculate the convective heat transfer coefficient, where *A* is the surface area of the heat exchanger, and *q* is the power input. With the fan off, the air velocity in the test duct was zero, and the temperature difference was recorded at 47.1°C. When the fan was turned on, the air velocity increased incrementally, and the temperature difference decreased accordingly, as shown in Fig. 6. This behavior aligns with the theoretical expectation that as air velocity increases,

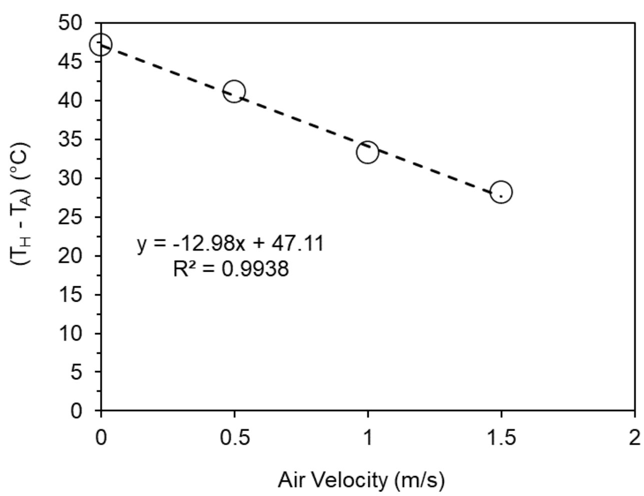

Fig. 6. Relationship between air velocity and temperature difference. The temperature difference decreases as air velocity increases, indicating more efficient heat transfer. The line of best fit accurately represents the relationship between the two variables as the coefficient of determination is close to 1.

heat is transferred more efficiently, causing a drop in the temperature difference. The data revealed a nearly linear decrease in temperature difference as air velocity increased, which is indicative of the enhanced convective heat transfer at higher air velocities. The heat transfer coefficient was calculated for each air velocity using Eq. (1). As the air velocity increased, *h* also increased, as demonstrated in Fig. 7. This trend is expected since higher air velocities enhance

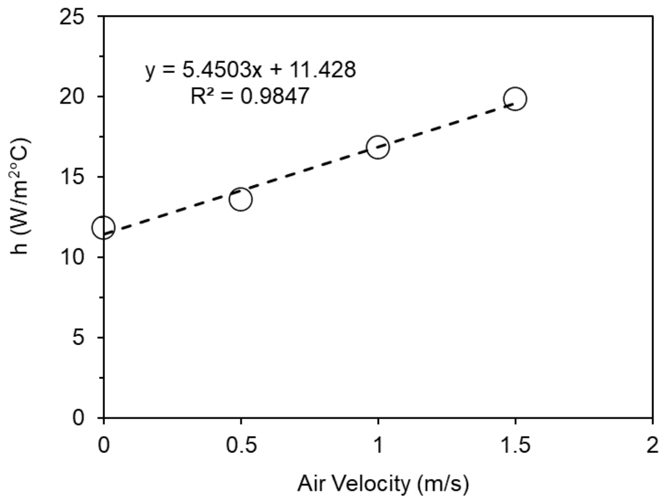

Fig. 7. Variation of the heat transfer coefficient with air velocity. As air velocity increases, the heat transfer coefficient rises, enhancing the convective heat transfer process. The coefficient of determination demonstrates an accurate linear relationship.

the movement of cooler air over the heated surface, leading to greater heat transfer efficiency. At an air velocity of 0 m/s, the heat transfer coefficient was 11.84 W/m²°C, whereas at 1.5 m/s, it increased to 19.85 W/m²°C. These results suggest that the heat transfer coefficient is strongly influenced by the airflow over the heat exchanger. In comparing the forced convection results with those from the free convection experiment, it is evident that the forced convection system exhibited much higher heat transfer coefficients. In the free convection experiment, the heat transfer coefficient ranged from 8.81 to 8.99 W/m²°C. This stark difference can be attributed to the fact that forced convection introduces external airflow, which significantly improves the rate of heat transfer. In contrast, free convection relies solely on the natural movement of air, resulting in a much lower heat transfer coefficient. The data obtained in this experiment underscore the effectiveness of forced convection in enhancing heat transfer rates.

4. Discussion

Looking at Fig. 6 the linear correlation between the difference in ambient and heatsink temperature and the fluid velocity can be seen. As the fluid velocity increases, the difference between ambient and heatsink temperature decreases. This is expected as by the time the heated molecules of air surrounding the heatsink reach a temperature higher than the environments, it is quickly replaced by the cooler air molecules the fan blows over said heatsink. Therefore one can expect that as air velocity increases, the heat sink itself reaches temperatures close to that of the air that is blown by the fan or in this case, ambient air. Important to note as well that the wattage supplied (80W) was an independent variable and remained constant throughout all trials. This made the temperature difference and value for *h* the only dependent variables in this experiment. Looking at Fig. 7 we can see the results of increasing fan speed on the heat transfer coefficient. As expected, the heat was more easily transferred to other entities away from the heatsink therefore increasing the heat transfer coefficient values. As the fan speed increased, the hot air around the heatsink was more quickly moved then again increasing the heat transfer rate and ergo *h*. Throughout these trials there was very little error recorded. We did not ascertain a theoretical value to compare our experimental results to but the experimental trends followed the theoretical trends. Nonetheless, some possible sources of error could have been slight fluctuations in the fan speed as a result of changing air density and possible instrumental error with the thermistor. Important to note however that the error these sources would cause would be slight in this scenario. There is also the aspect of free convection also occurring. We were even able to note this when the fan was completely off. Although not seen on the instrumentation in our trials, the lab instructor explained to us that the free convection of the heat transfer was something that caused there to be a non-zero value for velocity. This makes sense as the changes in air density cause this movement which can then be assigned a value for velocity. It is possible that in our case the air was just moving too slowly for the sensors to sense it but it should be noted that this free convection also imparted a velocity on the surrounding air. To really quantify the differences between free and forced convection, we can relate the values found in this experiment to those found in a previously done free convection experiment. Working with the same fluid and heatsink, we can compare the two heat transfer coefficient values. In the free convection experiment *h* was found to be 8.839 $W/m^2{}^\circ C$ at 80 watts and in this case it was found to be 11.842 $W/m^2{}^\circ C$ at the same wattage and air velocity (0 m/s). This results in a 29% difference between these two numbers. By looking at the data the temperature difference between the heatsink and environment in the free convection experiment was much higher than that of the one during the forced experiment. Not allowing enough time for the heatsink to heat up before recording the temperature could be the source of this discrepancy. Nonetheless, we can still note the higher *h* values when the fluid underwent forced convection. In this experiment *h* reached a maximum value of 19.849 W/m²°C. This is more than double than the *h* value recorded in the free convection experiment. This is to be expected as the fan force can much more easily overcome the inertia of the molecules of air when compared to the buoyant force created by the heat during free convection.

5. Conclusion and Future Work

The heat flow equation was used to determine both the relationship between air velocity and temperature difference and the relationship between the heat transfer coefficient and the air velocity. Both relationships followed the theoretical expectations. The temperature difference between the heatsink and the ambient air decreased as the air velocity increased and resulted in a 19°C temperature difference between an air velocity of 0 m/s and 1.5 m/s. The heat transfer coefficient increased as the air velocity increased resulting in a 8 W/m²°C difference between the *h* value at 0 m/s and 1.5 m/s. Important to note that when the fan was set to push air at 0 m/s the heatsink was undergoing free convection heat transfer. This difference in density between the air particles should theoretically produce a velocity value that could be picked up by the equipment sensors but was unfortunately not; This was most likely due to equipment limitations. When the *h* values were compared with a previously done free convection lab, there was a discrepancy when comparing the values for *h* when both air velocities were at 0 m/s. The two values were not the same and there was approximately a 29% difference between the two values of 8.839 W/m²°C(free convection experiment) and 11.842 W/m²°C(forced convection experiment). This could be attributed to not waiting long enough for the heatsink to reach equilibrium with the heating plate supplying it with heat.

Further experimentation could be done to attain a more accurate value for *h* and also prove or disprove the hypothesis. Unfortunately theoretical values for *h* were not attained and therefore the experimental values could not be compared to any other values but themselves. More trials where air speed increased past 1.5 m/s could help with proving or disproving the hypothesis but unfortunately the limitations of the experiment procedure limited this endeavor.

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Appendix

Table A.1 Air Velocity vs. Temperature

Air Velocity (m/s)	Heat Exchanger Temp (°C)	(T_H - T_A) (°C)	h (W/m2°C)
0	69.7	47.1	11.84247964
0.5	63.7	41.1	13.57130878
1	55.8	33.2	16.80062624
1.5	50.7	28.1	19.84985021