YEDİTEPE UNIVERSITY

DEPARTMENT OF MECHANICAL ENGINEERING

ME324 HEAT TRANSFER LABORATORY

Convective Heat Transfer From a Wire

Final Report

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1. Abstract

This experiment investigates how heat transfer from a nichrome wire changes under natural and forced convection. By monitoring the wire's electrical resistance and temperature during heating with a DC power source, we examined convective heat transfer in different air conditions using a wind tunnel. We calculated the Nusselt (Nu) numbers to plot against the Rayleigh (Ra) numbers and compared them with literature values. Results were derived for both free convection (0.5 A, 0.6 A, 0.8 A) and forced convection (1.4 A, 1.7 A, 2.1 A), and are detailed in Tables 8 and 9.

2. Introduction

This experiment explores convective heat transfer over a heated nichrome wire in varying air conditions (steady and fast air) using a wind tunnel setup. Observations led to calculations and graphical comparisons with existing literature. Starting from a reference current (0.15 A), steps were taken for both free and forced convection. The resistance, a function of temperature, was calculated using:

$$R = R_0[1 + \alpha(T - T_0)]$$

Equation 1

Using a DAQ system, air flow along the wire was monitored by measuring voltage (V) and current (I). Nichrome's temperature coefficient of resistance is α = 0.0004 K^{-1}, as illustrated for currents of 0.5 and 0.6 Amperes.

$$T = T_0 + \frac{1}{\alpha}\left(\frac{R}{R_0} - 1\right)$$

Equation 2 : Formula That helped us to find Tsurface

2.1 Step We Used while calculating

Steps we have used while calculating reference values :

1) $R_0 = \frac{V}{I} \rightarrow R \rightarrow R_{average} = R_{reference}$
2) $T_1(102℃)_{average}$
3) $T_2(103℃)_{average}$
4) $T_0 = \frac{(T_1(102℃)_{average} + T_2(103℃)_{average})}{2} \rightarrow T_{reference}$

- Steps we have used for Free Convection :

1) $T = T_o + \frac{1}{\alpha}\left(\frac{R}{R_o} - 1\right) \longrightarrow T_{Surface}$

2) $Q_{total} = VI$

3) $Q_{rad} = \varepsilon\sigma A\left(T_s^4 - T_\infty^4\right)$

4) $Q_{net} = Q_{total} - Q_{rad}$

5) $Q_{net} = hA(T_s - T_\infty)$

6) $h = \frac{Q''}{(T_s - T_\infty)}$

> - $\varepsilon = \frac{(0{,}65+0{,}79)}{2}$
> - $\sigma = 5{,}7 * 10^{-8}$
> - Area $(m^2) = \pi * D\ (Diameter) * L\ (Length)$

7) $Nu_d = \frac{h * d}{k_{Air}}$

8) $Ra_d = \frac{g * \beta * \Delta T * d^3}{v^2}$

Free Convection: Nu = f(Gr, Pr) = f(Ra)

- Steps we have used for Forced Convection :

1) $\Delta P = (100) * \frac{\mathrm{I} - 4}{20 - 4}$

2) $T = T_o + \frac{1}{\alpha}\left(\frac{R}{R_o} - 1\right) \longrightarrow T_{Surface}$

3) $Q_{total} = VI$

4) $Q_{rad} = \varepsilon\sigma A\left(T_s^4 - T_\infty^4\right)$

5) $Q_{net} = Q_{total} - Q_{rad}$

6) $Q_{net} = hA(T_s - T_\infty)$

> - $\varepsilon = \frac{(0{,}65+0{,}79)}{2}$
> - $\sigma = 5{,}7 * 10^{-8}$
> - Area $(m^2) = \pi * D\ (Diameter) * L\ (Length)$

7) $h = \frac{Q''}{(T_s - T_\infty)}$

8) $Nu_d = \frac{h * d}{k_{Air}}$

9) $Re_d = \frac{\rho * U_\infty * d}{\mu}$

Forced Convection: Nu = f(Re, Pr)

3. Procedure

The primary goal is to determine R_0 at T_0 (Reference Temperature):

• With air at temperature T_0 and adequate airflow, apply 0.15A.

3.1 Calculating Forced Convection:

Measure Re and Nu for forced convection at:

• 3m/s with 1.4 A

• 6 m/s with 1.7 A

• 12 m/s with 2.1 A

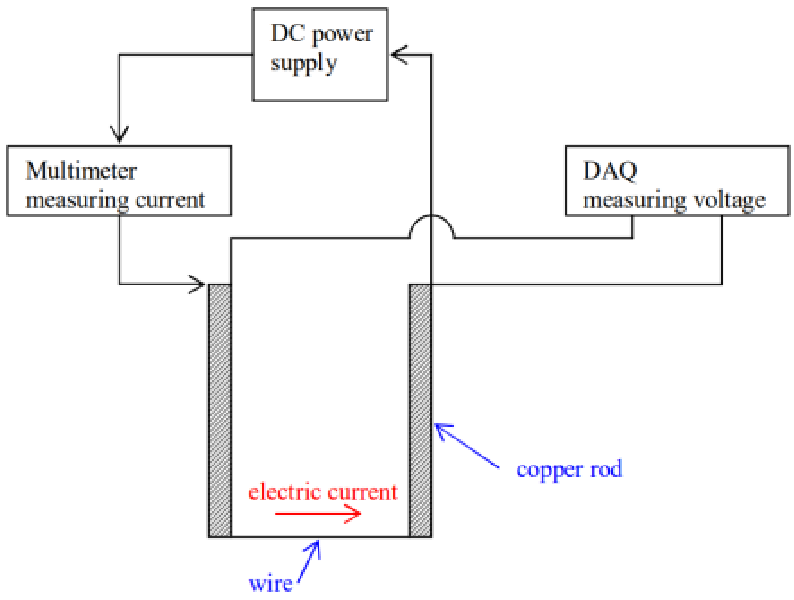
3.2 Calculating Free Convection:

Measure Nu and Rayleigh numbers for free convection at:

- 0.5 A
- 0.6 A
- 0.8 A

4. Experimental Setup

This experiment utilized eight different equipment elements to measure heat transfer:



➢ Nichrome Wire

- Diameter: 0.41mm, Length: 0.10m, Temperature Coefficient of Resistance: 0.0004 K^{-1}

➢ Data Acquisition (DAQ) System – Agilent 34972A

- Measures voltage across the nichrome wire, pressure sensor output from a Pitot tube for air velocity in the wind tunnel, and air temperature using a T-type thermocouple.

➢ Multimeter – Agilent 34410A

- Measures the wire's current flow.
- Synchronizes current and voltage measurements with the DAQ system to determine heat produced and wire temperature.

➢ Wind Tunnel

- No air flow for natural convection; air flow for forced convection controlled by a frequency converter, ranging from 1 m/s to 15 m/s.

➢ Pitot Tube

- Connected to a differential pressure sensor to monitor air flow speed.

➢ Differential Pressure Sensor

- Measures between 0 and 100 Pa, outputs 4 mA to 20 mA, powered by 12 to 36 volts, linked to the DAQ system.

➢ T-type Thermocouple

- Measures air flow temperature in the wind tunnel, connected to the DAQ system.

➢ DC Power Supply

- Provides power to the pressure sensor and wire (note: maximum current for Agilent 34410A is 3 A).

5. Presentation Of Data

In this experiment, we used the formulas from Figure 5 to calculate the Nusselt (Nu) and Rayleigh (Ra) numbers for free convection (0.5 A, 0.6 A, 0.8 A) using the reference values in Figure 4. For forced convection (1.4 A, 1.7 A, 2.1 A), we calculated the Nu and Reynolds (Re) numbers using the formulas in Figure 6 and the same reference values from Figure 4.

5.1 Calculations Reference

R_Reference	T reference
0.8722989	22.51737097

Table 1. The data is gathered by measuring the reference values and applying the data to solve the reference phases

For our reference value calculations, we first added the Channel 1 (ADC) data from the 0.15 Ampere/mm measurements to our 0.15 Ampere file. We then calculated the R values for all scan values using the first formula in Figure 4. The $RReference$ values were obtained by averaging these calculated R values. We calculated separate averages for all scan values at 102 degrees and 103 degrees. Finally, we determined our $TReference$ point using the fourth formula in Figure 4.

5.2 Free Convection Calculations

R_Average		T_Air	T_Surface	Q_Total_Average	Q_Radyan	Q_Net	Q"	h	T_Film_Temperate	Nu	Ra
0.882		**23.076**	**52.120**	**0.2175**	**0.0184**	**0.1990**	**1545.150**	**53.200**	**37.598**	**0.7707**	**0.1768**
									310.598		
0,15 Amper Calculations							**Table Air**				
T_Reference	**R_Reference**	**Alpha (α)**	**Diameter**	**Emissivity (ε)**	**Boltzman**	**Area**	**k_Air**	**Beta**	**g**	**k_Viscosity**	**Pr**
22.51700	0.87200	0.0004	0.00041	**0.720**	**0.000000057**	**0.0001288**	0.0283	0.00322	9.81	0.0000159	0.706

Table 2. The calculated values of 0.5 A for the free convection

R_Average		T_Air	T_Surface	Q_Total_Average	Q_Radyan	Q_Net	Q"	h	T_Film_Temperate	Nu	Ra
0.886		**23.114**	**61.953**	**0.3154**	**0.0259**	**0.2895**	**2247.687**	**57.872**	**42.534**	**0.8384**	**0.2328**
									315.534		
0,15 Amper Calculations							**Table Air**				
T_Reference	**R_Reference**	**Alpha (α)**	**Diameter**	**Emissivity (ε)**	**Boltzman**	**Area**	**k_Air**	**Beta**	**g**	**k_Viscosity**	**Pr**
22.51700	0.87200	0.0004	0.00041	**0.720**	**0.000000057**	**0.0001288**	0.0283	0.00317	9.81	0.0000159	0.706

Table 3. The calculated values of 0.6 A for the free convection

R_Average		T_Air	T_Surface	Q_Total_Average	Q_Radyan	Q_Net	Q"	h	T_Film_Temperate	Nu	Ra
0.894		**23.063**	**86.323**	**0.5686**	**0.0475**	**0.5211**	**4045.541**	**63.951**	**54.693**	**0.9265**	**0.3651**
									327.693		

0,15 Amper Calculations							Table Air				
T_Refe rence	R_Refe rence	Alp ha (α)	Diam eter	Emissivity (ε)	Boltzm an	Area	k_Air	Beta	g	k_Visc osity	Pr
22.517 00	0.8720 0	0.0 004	0.000 41	**0.720**	**0.0000 00057**	**0.000 1288**	0.02 83	0.00 305	9.81	0.000 0159	0.7 06

Table 4. The calculated values of 0.8 A for the free convection

Referential data obtained were used in the free convection computations. The eight specified steps were followed in order to complete these computations. The values of emissivity and area were computed using the formula in the box, while the Boltzmann constant was taken to be fixed. Based on the film temperature, data were extracted from the air table shown in Figure 3 and entered in the section titled Table Air. As a result, for every value of free convection, the Nusselt (Nu) and Rayleigh (Ra) numbers were determined.

5.3 Forced Convection Calculations

T_Air	T_Surface	Q_Total_Average	Q_Radyan	Q_Net	Q"	h
22.84258065	68.13219165	1.735199251	0.031093267	1.704105984	13230.09	292.1220109

T_Film_Temperate	Nu	121(Adc)_Average	deltaP	Re	**R_Average**
45.48738615	4.606539403	0.004741614	4.553834657	74.06595326	**0.887**

0,15 Amper Calculations						
T_Referance	R_Referance	Alpha	Diameter	Emissivity	Boltzman	Area
22.517	0.872	0.0004	0.00041	**0.720**	**0.000000057**	**0.0001288**

Table Air	Constants needed to calculate the Re value			
k_Air	ρ (Air Density)	μ	U∞	I (no air)
0.026	1.225	0.0000185	2.727	0.004013

Table 5. The calculated values of 1.4 A for the forced convection

T_Air	T_Surface	Q_Total_Average	Q_Radyan	Q_Net	Q"	h
22.88390323	68.10703665	2.55889173	0.031049526	2.527842205	19625.3	433.9658756

T_Film_Temperate	Nu	121(Adc)_Average	deltaP	Re	R_Average
45.49546994	6.843308	0.007185335	19.82709627	154.5466321	0.888

0,15 Amper Calculations						
T_Referance	**R_Referance**	**Alpha**	**Diameter**	**Emissivity**	**Boltzman**	**Area**
22.517	0.872	0.0004	0.00041	**0.720**	**0.000000057**	**0.0001288**

Table Air	**Constants needed to calculate the Re value**			
k_Air	**ρ (Air Density)**	**μ**	**U_∞**	**I (N)**
0.026	1.225	0.0000185	5.690	0.004013

Table 6. The calculated values of 1.7 A for the forced convection

T_Air	T_Surface	Q_Total_Average	Q_Radyan	Q_Net	Q"	h
22.7449	75.95771031	3.924772943	0.037944968	3.886828	30175.99	567.0814

T_Film_Temperate	Nu	121(Adc)_Average	deltaP	Re	R_Average
49.35131	8.942438	0.01331	58.10564355	264.5691156	0.89

0,15 Amper Calculations						
T_Referance	**R_Referance**	**Alpha**	**Diameter**	**Emissivity**	**Boltzman**	**Area**
22.517	0.872	0.0004	0.00041	**0.720**	**0.000000057**	**0.0001288**

Table Air	**Constants needed to calculate the Re value**			
k_Air	**ρ (Air Density)**	**μ**	**U_∞**	**I (no air)**
0.026	1.225	0.0000185	9.740	0.004013

Table 7. The calculated values of 2.1 A for the forced convection

The same computations were made for forced convection using the reference values determined for free convection. In contrast to free convection, the Reynolds (Re) numbers and the ΔP value were found in forced convection. Consequently, for each value (1.4, 1.7, 2.1) for forced convection, the Nusselt (Nu) and Reynolds (Re) values were computed. For every data set obtained, an average of 63 scans were carried out during the computations for both forced and free convection. Nevertheless, only the top 31 scan results were published because the rest of the data would take up too much room in the final report.

Forced Conv.				Free Conv.			
	Q_Total_Average	**Q_Radyan**	Percentage		**Q_Total_Average**	**Q_Radyan**	**Percentage**
1.4A	**1.735**	**0.311**	17.9251	0.5A	0.2175	0.0184	8.4598
1.7A	**2.559**	**0.031**	1.2114	0.6A	0.3154	0.0259	8.2118
2.1A	**3.925**	**0.038**	0.9656	0.8A	0.5686	0.0475	8.3539

	Calculated		**Literature**			
	Nu	**Ra**	**Ra**	**Nu**	**C**	**n**
0.5 A	0.1768	0.7707	0.16	0.77770	1.02	0.148
0.6 A	0.2328	0.8384	0.18	0.79137		
0.8 A	0.3651	0.9265	0.20	0.80381		
			0.22	0.81523		
			0.24	0.82579		
			0.26	0.83563		
			0.28	0.84485		
			0.30	0.85352		
			0.32	0.86171		
			0.34	0.86948		
			0.36	0.87687		
			0.38	0.88391		
			0.40	0.89065		

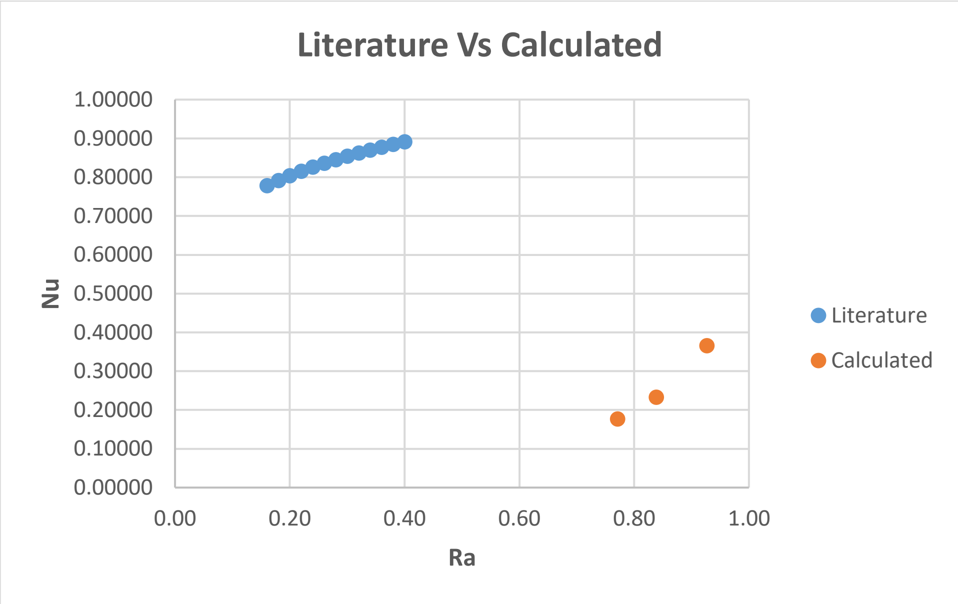
Table 8. The data found in the literature has been used to derive the free convection data values (0.5 A, 0.6 A, and 0.8 A).

	Calculated		**Literature**				
	Re	Nu	Re	Nu	**C**	**m**	**Pr**
1.4 A	71.335	4.443	50	3.765	0.683	0.466	0.7062
1.7 A	153.359	6.348	75	4.548			
2.1 A	263.840	8.173	100	5.201			
			125	5.771			
			150	6.282			
			175	6.750			
			200	7.184			
			225	7.589			
			250	7.971			
			275	8.333			
			300	8.678			

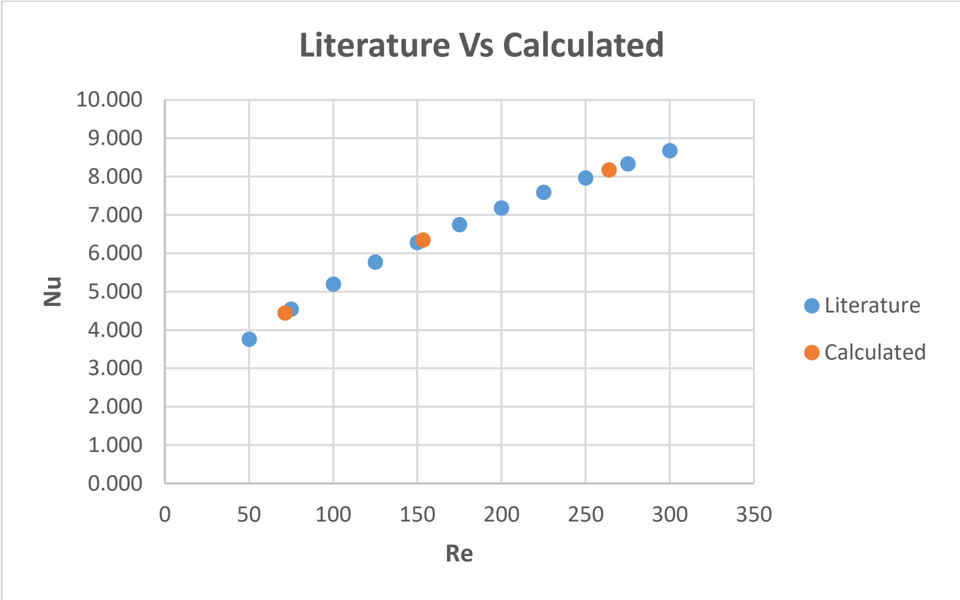
Table 9. . The data found in the literature has been used to derive the forced convection data values (1.4 A, 1.7 A, 2.1 A).

5.4 Graphs

We compared the calculated Re, Ra, and Nu values with those from the literature. Separate graphs were created for Figures 8 and 9 below to analyze and compare error rates. The resulting graphs are as follows:



Graph 1. A comparison graph has been made between the values derived from the data in the literature and the values estimated from the free convection data values (0.5 A, 0.6 A, and 0.8 A).



Graph 2. A comparison graph has been made between the values derived from the data in the literature and the values estimated from the free convection data values (1.4 A, 1.7 A, and 2.1 A).

6. Conclusion

This experiment explored the principles of heat transfer via convection in a nichrome wire under varying air conditions. By conducting a series of measurements and calculations, we were able to observe the impact of both natural (free) and forced convection on the heat transfer characteristics of the wire.

Our findings indicated that for free convection, the Nusselt number (Nu) increased with higher current values, which aligns with theoretical expectations and literature values. This increase can be attributed to the enhanced thermal gradient and buoyancy-driven flow, which facilitates heat dissipation from the wire surface to the surrounding air. However, some deviations from the theoretical values were observed, which could be attributed to experimental errors such as inaccuracies in temperature measurements, fluctuations in ambient conditions, or limitations in the precision of the measuring instruments.

In the case of forced convection, the Nu number also showed an increasing trend with higher airflow speeds. This behavior is consistent with the theoretical predictions that suggest forced convection enhances heat transfer due to the increased mixing and reduced thermal boundary layer thickness around the wire. Similar to free convection, the observed deviations in the results could be linked to experimental inaccuracies, including potential errors in airflow speed measurements and variations in the wire's temperature distribution.

The comparison of our calculated Reynolds (Re), Rayleigh (Ra), and Nusselt (Nu) numbers with literature values demonstrated a general consistency, reinforcing the validity of our experimental approach. The graphical representations in Figures 8 and 9 provided a visual confirmation of the trends and facilitated the identification of discrepancies.

This experiment underscored the critical importance of accurate measurements and controlled experimental conditions. Achieving reliable data requires meticulous attention to detail in the setup and execution of experiments, as well as thorough calibration of the instruments used. Despite the challenges encountered, the experiment successfully demonstrated the fundamental concepts of convective heat transfer and provided valuable insights into the behavior of heated surfaces in different convective regimes.

Future improvements could include enhancing the precision of temperature and airflow measurements, reducing external influences on the experimental setup, and employing more sophisticated data acquisition systems. These enhancements would likely result in even closer alignment with theoretical predictions and further our understanding of convective heat transfer mechanisms.

7. References

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