

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
MCEG 3102- Thermal Science Lab
FALL 2021**

- I. COURSE DESCRIPTION IN ABET FORMAT**
- II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS**
Program Outcomes Assessed in Course
Assessment Summary of Class Semester Averages for Outcomes
End of Semester Course Outcomes Assessment Reports
- II. TESTS**
Summary of Topics covered by Test
Original Test Questions & Master Solution/grading scheme used
(Summary of topics can be a separate page or include on the assignment itself)
Above Average (Graded original work)
Average (Graded original work)
Below Average (Graded original work)
- III. LABORATORY REPORTS**
Summary of Topics covered by lab
Laboratory Handout/Instructions and Grading Scheme
Above Average (Graded original work)
Average (Graded original work)
Below Average (Graded original work)
- IV. PROJECT**
Summary of Topics Covered by Project
Project Problem Statement and Grading Scheme
Above Average (Graded original work)
Average (Graded original work)
Below Average (Graded original work)

[Include any other evaluation used and omit any method above method (Test, Quizzes, Homework, Laboratory and Project reports) that was not used]

(Note: All Pages shown in Yellow should be printed on YELLOW PAPER)

Course Description in ABET Format

MECHANICAL ENGINEERING DEPARTMENT

MCEG 3021 THERMAL SCIENCE LAB

Please use the following format for the course syllabi (2 pages maximum in Times New Roman 12 point font)

1.	Course number and name:	Thermal Science Laboratory – 16926 - MCEG 3102 – P01
2.	Credits and contact hours:	1 credit hours; 3 contact hours
3.	Instructor's or course coordinator's name:	Dr. Shahin Shafiee
4.	Text book: Title:	Thermal Science Laboratory Manual provided by instructor and posted on Canvas
	Author:	
	Publisher, Year & Edition:	
	a. Other Supplemental material	Experimental Methods for Engineers by J. P. Holman, 7 th Edition, McGraw Hill, 2001. ISBN-13: 9780073660554
5.	Specific course information	
	a. Brief description of the content of the course (catalog description)	MCEG 3102. Thermal Science Laboratory. (0-3) Credit 1 semester hour. This course includes experimental investigation of the performance of various thermal systems, such as engines, combustion unit, heat exchangers, nozzles, boilers and turbo machinery.
	b. Prerequisites or Co-requisites	MCEG 3101 Measurement and Instrumentation Laboratory MCEG 3301 Heat transfer ELEG 1304 Computer Applications in Engineering
	c. *Indicate whether a required, elective, or selected elective (as per definition provided) course in the program	Required
6.	Specific goals for the course	Students will be able to :
	a. specific outcomes of instruction (e.g. The student will be able to explain the significance of current research about a particular topic.)	(1)Introduce procedures and instrumentation for verifying theoretical predictions with experimental measurements in thermal science; (2)Relate the differences between theoretical prediction and experimental measurements with underlying assumptions and the physical conditions of experiments; and (3)Introduce students to the analysis of experimental data and preparation of scientific reports.
	b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course.	This course addresses: Outcome 6 An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7	Brief list of topics to be covered	Introduction to the course, EES coding and its applications in

	thermal science and analysis of thermodynamic systems (6 hours) Theory of radiation heat transfer as a heat source and as a light source (3 hours) Experimentation on radiation heat transfer (3 hours) Theory of refrigeration cycles (3 hours) Experimentation on refrigeration cycles (3 hours) Theory of forced convection heat transfer (3 hours) Experimentation on forced convection heat transfer (3 hours) Developing and designing experiment on assessing performance of Heat exchangers (12 hours) Experimentation on heat exchangers (3 hours)
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***Required** courses are required of all students in the program, **elective** courses (often referred to as open or free electives) are optional for students, and **selected elective** courses are those for which students must take one or more courses from a specified group

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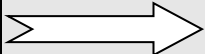
II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

Program Outcomes Assessed in this course

Outcome 6:

An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

Assessment Summary of Class Semester Averages for Outcomes (Should be provided for Fall 2019 through Spring 2022 Assessment Period)

Semester	Analysis Type	Number of Students	Outcome 6 An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions			
			Expected Class Average/	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average
Fall 21	Direct	27	70	70	72	82
Spring 21	Direct	12	70	70	84	100
Fall 20	Direct	14	70	70	73	79
Spring 20	Direct		70	70	72	83
Fall 2019	Direct		70	70	80	65
Fall 2018	Direct		70	70	81	100
Fall 2017	Direct		70	70		
Fall 2016	Direct		75	70		
Fall 2015	Direct		75	70		
Fall 2014	Direct		75	70		
Implementation Summary	Items implemented from previous report or after meeting previous instructor		- A comprehensive handout for each experiment was provided to students - Detailed instructions on how to use EES to process experimental results were given - Sample solutions for results of the experiments were provided as a reference - Review and feedback to students' work was provided promptly - Students were to perform experiments so they get hand-on learning			
Perceived Problems			Students were kept informed of their standing after each report that they submitted. The major problems were: - Students need more practice in utilizing engineering tools such as EES - Students need help to be able to figure out the mathematical and physical relation of the concept that they are running the experiment on - Lack of desire to study to improve even when counseled to do so repeatedly.			
Recommendations for Addressing Problems			The following is recommended for implementation: - Wider variety of experiments to be presented - More engagement of students in performing experiments - Students need to be motivated to study - College/Department should set admission requirements at a level to allow quality students into the College of Engineering/ME department because a large percentage of the students do not have the necessary background and motivation to succeed in engineering.			
Were Expectations Met?			Yes			

*Expected Semester Class Average = 70% (or as defined by the program)
Ideal Semester Class Average = 75% (or as defined by the program)

End of Semester Course Assessment Reports FALL 2021 and Last Three Assessment Periods.

Each summary contains the following Information

1. Performance Statistics

- Total number of students in class
- The class average performance (**stated as %**) in each course outcome assessed in this class and the **two previous times course was assessed**.
- The acceptable class average for the class in each outcome area as set by your Department.
- Percentage of students who scored below the expected average in each outcome.

2. Implementation Summary

- Brief summary of plans implemented during the semester based on last assessment report

3. Perceived Problems

- Instructor's **critical evaluation** of perceived problems that affected students' performance. **Realistic problems should be identified throughout the semester and summarized in this section of the report.**

4. New Plans for Addressing Problems

- Instructor's plans for addressing the perceived problems the next time the class is taught. **These should be specific enough for another instructor to implement. Most of these should be things that, you, the instructor can implement to help students to improve. Be creative.**

5. Overall Trend over last three assessment periods

- Instructors summary of overall performance trend for each outcome measured over the last three periods.

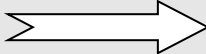
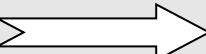
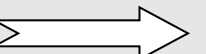
5. Were Expectations Met?

- Answer **YES** if the **class average was above the expected average** and the **stated percentage of students** scored at or above the expected average, else answer **NO**.

Table 2.1 END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT
MCEG3102-P01 Thermal Science Lab
FALL 20201 SEMESTER

Report Prepared by: Dr. Shahin Shafiee

Report Date: December 13, 2021

Semester	Analysis Type	Number of Students	Outcome 6 An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions			
			Expected Class Average/	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average
Fall 21	Direct	27	70	70	72	82
Spring 21	Direct	12	70	70	84	100
Fall 20	Direct	14	70	70	73	79
Spring 20	Direct		70	70	72	83
Fall 2019	Direct		70	70	80	65
Fall 2018	Direct		70	70	81	100
Implementation Summary	Items implemented from previous report or after meeting previous instructor	• A comprehensive handout for each experiment was provided to students • Detailed instructions on how to use EES to process experimental results were given • Sample solutions for results of the experiments were provided as a reference • Review and feedback to students' work was provided promptly • Students were to perform experiments so they get hand-on learning				
Perceived Problems		Students were kept informed of their standing after each report that they submitted. The major problems were: 4. Students need more practice in utilizing engineering tools such as EES 5. Students need help to be able to figure out the mathematical and physical relation of the concept that they are running the experiment on 6. Lack of desire to study to improve even when counseled to do so repeatedly.				
Recommendations for Addressing Problems		The following is recommended for implementation: 5. Wider variety of experiments to be presented 6. More engagement of students in performing experiments 7. Students need to be motivated to study 8. College/Department should set admission requirements at a level to allow quality students into the College of Engineering/ME department because a large percentage of the students do not have the necessary background and motivation to succeed in engineering.				
Were Expectations Met?		Yes				

**Thermal Science Lab
Fall 2021**

Title of Assignment: Report 3

TOPICS COVERED IN Report 3

1. To measure the heat transfer coefficient for forced convection around a sphere using the lumped capacity method.
2. Determine the effects of velocity and Reynolds number on the heat transfer coefficient

Repeated this section for each Quiz and Similarly for all the other assignments in the course binder

**Thermal Science Lab
Fall 2021**

**SAMPLE QUIZ QUESTIONS, SOLUTION,
AND GRADING SCHEME FOR Report 3**

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (your conduct and observations).	3		
Ability to follow the procedure and to properly rephrase the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment functions, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)			
Front End of Report (4 points).	4		
General report format (4 points)	4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters	12		
Correct solutions with consistent units and significant figures.	10		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw /derived) in tabular form to meet the objectives and to aid in plotting the results.	4		
Ability to present the data (raw /derived) in well-labeled graphical form to meet the objectives and to aid in interpretation.	10		
Ability to discuss the raw and derived data/graphs and assess the validity of the results concerning the underlying theory and expected trends. (Interpretation of experimental data & results)			
Effect of independent (X-axis) variable on the dependent (Y-axis variables). 4 Points			
Effect of parametric variable change on the dependent (Y-axis variable). 4 Points	14		
Comparison of experimental results with theoretical results/prediction/trend 4 Points			
Statement on goodness or reasonableness of results. 2 Points			
Ability to use engineering judgement to draw appropriate and reasonable conclusions in relation to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		
Percentage for this Performance Criteria			
TOTAL FOR THIS LAB	100		

Fall 2021 EXPERIMENT 3

MEASUREMENT OF HEAT TRANSFER COEFFICIENT FOR FORCED CONVECTION USING THE LUMPED CAPACITY METHOD

OBJECTIVE:

1. To measure the heat transfer coefficient for forced convection around a sphere using the lumped capacity method.
2. Determine the effects of velocity and Reynolds number on the heat transfer coefficient.
3. Compare the experimental results with the values from theoretical prediction.

THEORY

Consider an object at an initial temperature T_i being cooled by a fluid stream at a temperature T_a . If the object has high thermal conductivity, then its internal resistance to heat flux is small. This means that the temperature profile within the object is uniform and everywhere equal (or almost equal) to the surface temperature. At any instant in time, there is no temperature gradient within the object, only a temperature difference between the surface and the free stream. The heat transfer between the object and the fluid is controlled almost exclusively by the surface resistance i.e., the value of convective heat transfer coefficient h . The heat transfer process, in this case, is known as Newtonian cooling (or heating). Because the temperature does not change (significantly) within the solid, and the heat transfer model can be formulated by performing an energy balance on the object.

The rate at which the internal energy of mass is changing = Rate at which heat energy is transferred from the surface to the free stream

$$\frac{dU}{dt} = -hA(T - T_a) \quad (1)$$

$$mc \frac{dT}{dt} = -hA(T - T_a) \quad (2)$$

Using the initial condition at $t = 0$, $T = T_i$ and integrating equation (2) results in the lumped capacity equation.

$$\frac{T - T_a}{T_i - T_a} = \text{Exp} \left[-\frac{hA}{\rho g C} t \right] \quad (3)$$

$$\text{Or } \frac{T_i - T_a}{T - T_a} = \text{Exp} \left[\frac{hA}{\rho g C} t \right]$$

Taking the log of both sides, we get

$$\ln \left[\frac{T_i - T_a}{T - T_a} \right] = \frac{hA}{\rho g C} t \quad (4)$$

where

T = temperature of the object at any time

T_a = Temperature of the free stream or the ambient air

T_i = the initial temperature of the object

h = the average convective heat transfer coefficient (being determined from the experiment)

A = the surface area of the object ($4\pi R^2$ for sphere)

C = the specific heat of the object

ρ = the density of the object

$\mathcal{V}$ = the volume of the object

The quantity $\tau = \left[\frac{\rho \mathcal{V} C}{hA} \right]$ is called the time constant.

A plot of $\ln \left[\frac{T_i - T_a}{T - T_a} \right]$ vs t will thus be a straight line with a slope of $\left[\frac{hA}{\rho \mathcal{V} C} \right]$.

Thus measuring the slope of the line and equating the slope to $\left[\frac{hA}{\rho \mathcal{V} C} \right]$ will enable h to be computed.

The convective heat transfer coefficient, h , strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent).

In convection, it is a common practice to non-dimensionalize the governing equations and combine the variables which group together into dimensionless numbers.

Nusselt number, the non-dimensional heat transfer coefficient, is defined as $Nu = h\delta/k$,

where δ is the characteristic length, i.e., D for tubes and L for flat plates. Nusselt number represents the enhancement of heat transfer through a fluid as a result of convection relative to conduction across the same fluid layer.

Reynolds number: the ratio of inertia forces to viscous forces in the fluid.

$Re = \text{inertia forces} / \text{Viscous forces} = \rho V \delta / \mu = V \delta / \nu$

At large Re numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces; thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid (turbulent regime).

Prandtl number: is a measure of the relative thickness of the velocity and thermal boundary layer.

$Pr = \text{molecular diffusivity of momentum} / \text{molecular diffusivity of heat} = \nu / \alpha = \mu C_p / k$

Flow over a cylinder:

The characteristic length for a circular tube or sphere is the external diameter, D , and the Reynolds number is defined as $Re = \rho V_{\infty} D / \mu$.

For flow over sphere, Whitaker recommended the following:

$$Nu_{sph} = hD/k = 2 + [0.4 Re^{1/2} + 0.06 Re^{2/3}] Pr^{0.4} (\mu_{\infty}/\mu_s)^{1/4}$$

The above equation is valid for $3.5 < Re < 80000$ and $0.7 < Pr < 380$. The fluid properties are evaluated at the free stream temperature T_{∞} , except for μ_s which is evaluated at the surface temperature.

APPARATUS:

Variable Speed Small Diameter Wind Tunnel, Mantle heater, metal sphere, thermocouple wire, thermocouple read-out, stop watch,

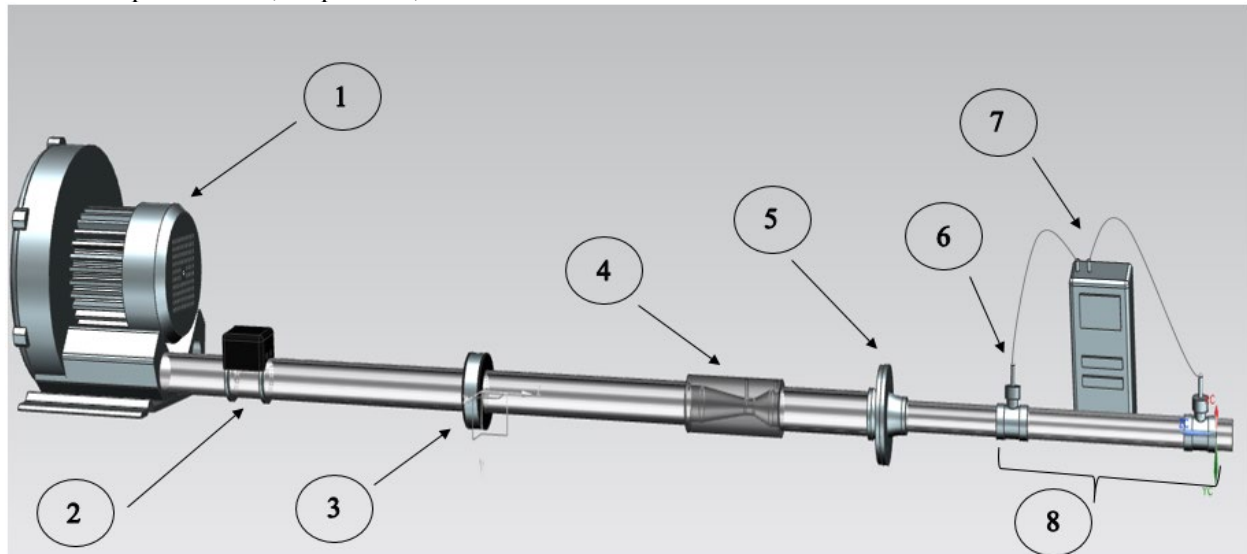


Figure 1. Experimental apparatus for measuring heat transfer coefficient using the lumped capacity method.

Table 1. Uncertainty in Reading Experimental Variables on Instruments.

Name of Instrument	Variable Read Using Instrument and Units	Uncertainty in Reading the Instrument and Units

PROCEDURE:

Forced convection:

1. Measure the room temperature T_a , the diameter of the metal sphere if not provided (either aluminum or brass), the mass, and then calculate the volume and the density of the metal sphere.
2. Heat the metal sphere in an oven (to 200 -220°C).
3. While step 2 is being carried out, start the wind tunnel and adjust the RPM control to obtain an air speed of 2 m/s or at the appropriate speed as indicated in step 7.
4. When the temperature of the metal in the oven reaches the prescribed temperature in step 2, remove the steel sphere from the oven.
5. With the thermocouple connected to the sphere and the thermocouple readout, hang the steel sphere in the air moving in the wind tunnel and measure the initial temperature, T_i (at 180°C) at time 0 sec (start the timer).
6. Record the time at every 4°C or as listed in the table for $V=2$ m/s, every 5°C or as listed in the table for $V=4$ m/s, and every 10°C or as listed in the table for $V=6$ m/s change in temperature of the body until the temperature reaches the last temperature listed in the data table.
7. Repeat steps 2 through 6 for 4 m/s and 6 m/s.

CALCULATIONS:

There are two major parts of your EES main program. The first part is the raw data processing to obtain the slope of the $\ln \left[\frac{T_i - T_a}{T - T_a} \right]$ vs t plot for all velocity conditions in experiments performed. The second part is to obtain experimental and theoretical heat transfer coefficients, as well as other data in Table 2.

Part I Raw data processing

1. Set your energy units in EES to Joules (J).
2. Input the ambient temperature T_a and initial temperature T_i .
3. Convert time to seconds. Using the first-row data, input T and Time. Note that these two inputs will be commented when you "Calculate Table" later.
4. Compute $T_r = \left[\frac{T_i - T_a}{T - T_a} \right]$.

[illegible]

Raw Experimental Data

Diameter of sphere = **2.54 cm**

Sphere Material is **Brass**

$T_{\text{room}} =$ _____

Table 3. Table of Raw Experimental Data.

[illegible]

ABOVE AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3102 THERMAL SCIENCE LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

**“Measurement of Heat Transfer Coefficient for Forced Convection
Using the Lumped Capacity Method”**

**Conducted on
October 27, 2021**

**Submitted by
Andrew Vaughn**



**On
November 10, 2021**

To

**Dr. Shahin Shafiee
*Thermal Science Laboratory Instructor***

**MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY
LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: Measurement of Heat Transfer Coefficient for Forced Convection Using the Lumped Capacity Method

Name: Andrew Vaughn

Date Lab was Performed: 10/27/21 Report Due Date: 11/10/21

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3		
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report) Front End of Report (4 points). General report format (4 points)	4 4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters using consistent units and significant figures.	22		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw /derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14		
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14		
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		
Percentage for this Performance Criteria			
TOTAL FOR THIS LAB			

November 10, 2021

Dr. Shahin Shafiee
Mechanical Engineering
Department Prairie View A&M
University

Dear Dr. Shafiee,

The attached technical laboratory project report contains the detailed results of the laboratory project work on the study of convection heat transfer coefficients using the lumped capacity method that was performed on October 27th, 2021. The report contains the objectives of the experiment, the theories on the convection heat transfer coefficient and the lumped capacity method in regard to the fluid mechanics of the convection fluid, the equations used for analysis of the data, the raw experimental data, graphical presentation of the important results, discussion, and interpretation of results.

Please contact me by e-mail at avaughn12@pvamu.edu, if you have any questions about the report.

Sincerely,

Andrew Vaughn

A handwritten signature in black ink, appearing to read 'Andrew Vaughn', with a stylized flourish at the end.

ABSTRACT

1. The purpose of the experiment

The purpose of this experiment is to study the convection heat transfer coefficient and the effects of fluid velocity and Reynolds number on the values for the coefficient. The experiment also utilizes the lumped capacity method which was studied to provide a simplified method for experimentation in regard to convection heat transfer experimentation.

2. The brief description of the method used

For this experiment the lumped capacity method was used for the properties of a brass sphere in a forced convection apparatus. The brass sphere was treated as a lumped capacity, or a solid thermal state piece with no internal deviation in temperature. The brass sphere equipped with a thermocouple was placed within a small diameter wind tunnel after being heated to a certain temperature. The temperature change was recorded over time via a stopwatch and the thermocouple to establish a rate of heat loss for further analysis of the results.

3. The significant results of the tests

The experimental results showed the correlations between fluid velocity and internal forces with the convection heat transfer correlation. These correlations can be used in practical applications for cooling or heating via forced convection methods or for further experimentation in convection heat transfer.

4. The major conclusions drawn from the results

The experiment concluded that a positive correlation between fluid velocity or internal forces of a fluid and the ability for the fluid to accept heat from an object. The experiment also showed that while the theoretical trends remain constant in the experimental results, there are factors not represented in this experimentation that alter the heat transfer coefficient.

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

The lumped capacity method can be used to simply estimate the variables in the convection heat transfer process, as well as the effects caused by known variables such as fluid speed and stability. In this chapter, the theory and process that was performed for the experiment will be shown as well as the raw experimental data.

1.1 Objectives of the Experiment

The experiment was performed using the knowledge of convection heat transfer with the following objectives.

1. The heat transfer coefficient for forced convection was measured around a sphere using the lumped capacity method.
2. The effects of velocity and Reynold's number on the heat transfer coefficient were determined.
3. The experimental results and the values from theoretical prediction were compared.

1.2 Theory Associated with Experiment

Any object subjected to heat transfer can be represented in an energy balance equation as theoretically, the total heat lost by the object is transferred to the other medium. In convection cooling, this medium is a moving fluid which the heat from the object is taken away. In the energy balance of the object and the fluid, two formulas for heat, Q , will be used. Heat transfer for an object would be represented as:

$$Q_o = mc \frac{dT}{dt} = \rho v c \frac{dT}{dt}$$

Where Q_o is the heat energy lost of time of the object, m is the mass, c is the specific heat of the object, ρ is the density of the object, v is the volume of the object, and dT/dt is the rate of temperature lost over time. For the heat acquired into a fluid, Q_f , Newton's Law of cooling is used and is represented by the following:

$$Q_f = -hA\Delta T = -hA(T - T_a)$$

Where h is the average convection heat transfer coefficient, A is the surface area of the object encountering the fluid, and ΔT is the difference of temperatures between the object, T , and the fluid, T_a . Satisfying the energy balance between the object and the fluid, Q_o and Q_f must be equal. Using this the relation will become the following:

$$\rho v c \frac{dT}{dt} = -hA(T - T_a)$$

Integrating this equation using the initial conditions of time starting at zero, $t = 0$, and temperature beginning at an initial temperature of the object, $T = T_i$, the equation becomes:

$$\frac{T - T_a}{T_i - T_a} = \text{Exp} \left[-\frac{hA}{\rho v c} t \right]$$

Or

$$\frac{T_i - T_a}{T - T_a} = \text{Exp} \left[\frac{hA}{\rho v c} t \right]$$

Taking the log of both sides, to change the right side from being an exponent, yields:

$$\ln \left[\frac{T_i - T_a}{T - T_a} \right] = \frac{hA}{\rho v c} t$$

Therefore, the equation can be changed to:

$$\frac{\ln \left[\frac{T_i - T_a}{T - T_a} \right]}{t} = \frac{hA}{\rho v c}$$

Which equates the slope between $\ln \left[\frac{T_i - T_a}{T - T_a} \right]$ and t to the thermodynamic and material properties, making it possible to calculate the convection heat transfer coefficient.

The convection heat transfer coefficient is a constant between the proportion of heat flux and the difference of temperature. Theoretically, the convection heat transfer coefficient can be determined using the governing equations of heat transfer combined into dimensionless figures. For forced convection, convection that is not due to ambient air movement, these figures include the Nusselt number, Reynolds number, and Prandtl number. The Nusselt number is the ratio of convection heat transfer to pure conduction. The Reynolds number is the ratio of inertia forces of a fluid to viscous forces. This number will show whether a fluid flow is laminar or turbulent, which will change the properties of convection heat transfer. The Prandtl number is the ratio of the fluid velocity boundary layer to the thermal boundary layer. Using the Whitaker correlation, which is the average heat transfer coefficient between a sphere's surface and a fluid stream, the Nusselt number can be found via:

$$Nu = \frac{hD}{k} = 2 + \left[0.4Re^{1/2} + 0.06Re^{2/3} \right] Pr^{0.4} \left(\frac{\mu_\infty}{\mu_s} \right)^{1/4}$$

Where h is the convection heat transfer coefficient, D is the diameter of the sphere, k is the thermal conductivity of the fluid, Re is the Reynolds number, Pr is the Prandtl number, μ_∞ is the viscosity of the fluid at the ambient temperature, and μ_s is the viscosity of the fluid at the temperature of the solid's surface. The Reynolds number is calculated using the following equation:

$$Re = \frac{\rho V_\infty D}{\mu}$$

Where ρ is density of the fluid, V_∞ is the velocity of the fluid, D is the diameter of the sphere, and μ is the viscosity of the fluid. The Prandtl number is calculated using the following equation:

$$Pr = \frac{c_p \mu}{k}$$

Where c_p is the specific heat of the fluid at atmospheric pressure, μ is the viscosity of the fluid, and k is the thermal conductivity of the fluid.

To simplify the study of convection heat transfer, lumped capacity method is used. The lumped capacity method disregards the internal conduction heat transfer of the object being subjected by convection by assuming the object as one lumped entity with no temperature gradient. To determine if this method is accurate, the Biot number is used. The Biot number is the ratio of internal thermal resistance of a solid to the boundary layer thermal resistance. It can be calculated via:

$$Bi = \frac{h}{k} \left(\frac{V}{A} \right)$$

Where h is the convection heat transfer coefficient, k is the thermal conductivity of the fluid, V is the volume of the object, and A is the surface area of the object. This dimensionless figure will determine whether the lumped capacity method is an accurate representation of the heat transfer of inside the object. If the Biot number is less than 1, the assumption creates an accurate representation. If it is larger, there is more temperature gradients inside the object and the assumption provides an inaccurate representation.

1.3 Apparatus and Uncertainty in Reading Instruments

For this experiment, a variable speed small diameter wind tunnel was used as shown in figures 1.1 and 1.2. In addition to this apparatus, a stopwatch application on an iPhone was used to record time. The main components of the apparatus are labeled and noted in table 1.1.

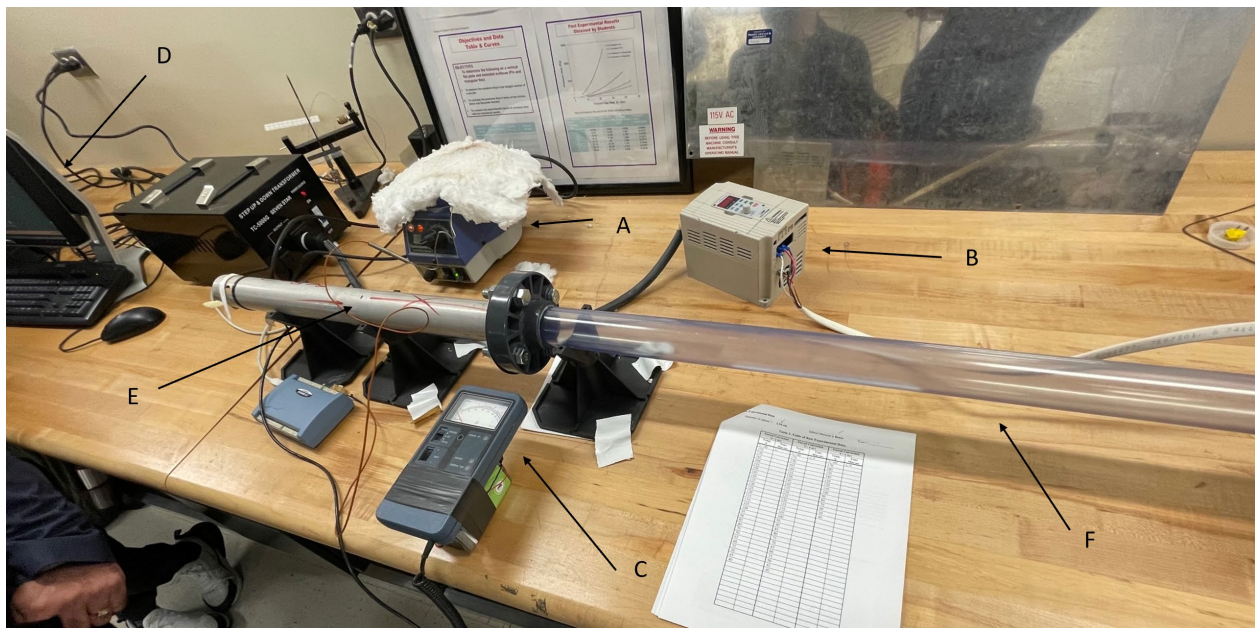


Figure 1.1 Left Side of Variable Speed Small Diameter Wind Tunnel

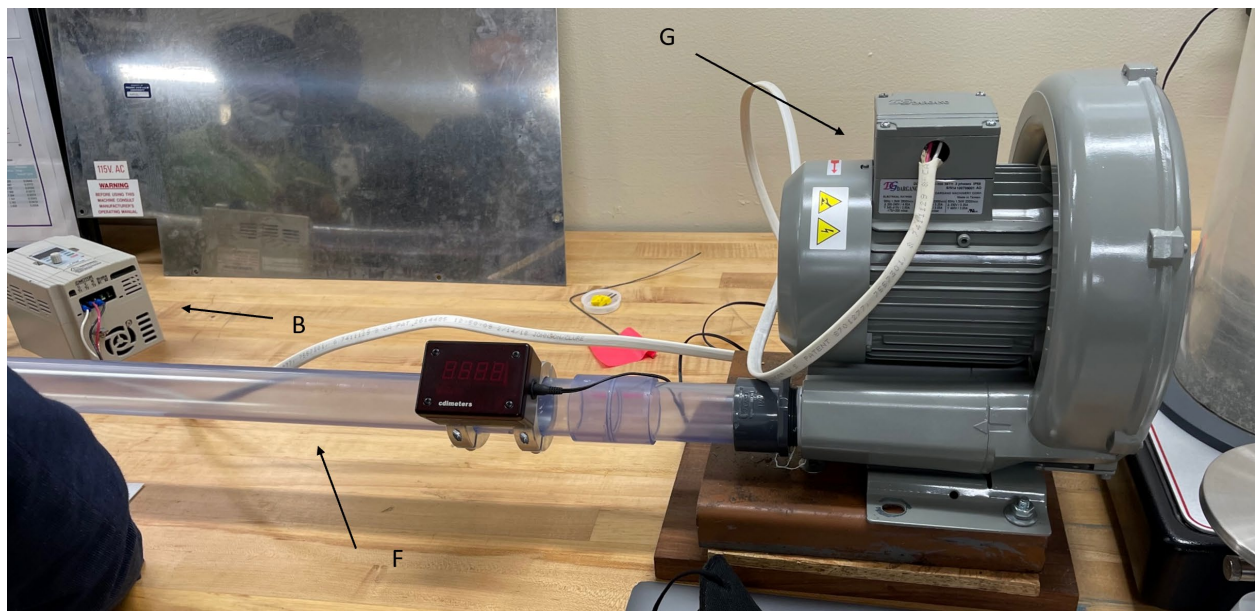


Figure 1.2 Right Side of Variable Speed Small Diameter Wind Tunnel

Table 1.1 Apparatus Legend

Letter	Component Name
A	Mantel Heater
B	RPM Control
C	Anemometer
D	Thermocouple Computer
E	Sphere Insert
F	Wind Tunnel
G	Air Fan

The measurement readings that were taken for this experiment were done using an anemometer and a k-type

thermocouple which added to the uncertainty of the derived results. These uncertainties are shown in table 1.2. Additional uncertainties existed while using the iPhone stopwatch app including human error in the recordings.

Table 1.2 Measurement Uncertainty

Device	Uncertainty
K-Type Thermocouple	$\pm 1.5\text{ }^{\circ}\text{C}$
Anemometer	$\pm 0.1\text{ m/s}$

1.4 Experimental Safety

When using any electrical equipment, check to see if all connections are secure and not made using faulty or frayed wiring that could electrocute or cause a fire. In addition, the use of a heater to heat the metal sphere should be done carefully. The heater itself, as well as the heated sphere may cause burns and should be handled with proper protection and care. The heated metal would not be visibly hot, so it is best to handle it with proper protection at all times.

1.5 Experimental Procedure

After the instructor determined the apparatus was in working order, the procedure of the experiment went as follows.

1. The room temperature of the laboratory, T_a , was measured.
2. The heating device was turned on and set to a high heat.
3. The metal sphere with a thermocouple preinstalled within it was placed within the heating device to above a read temperature of 220°C .
4. During step 2, the wind tunnel was started. The RPM control was adjusted to obtain an air speed of 2 m/s , or the other appropriate speed used.
5. Once the sphere was heated above its desired temperature, the sphere was removed from the heater and placed within the wind tunnel.
6. The temperature of the sphere was read until its initial temperature, T_i , was shown to be 180°C .
7. The time was started on the stopwatch app at this moment.
8. As the temperature fell at an amount of 5°C , the time was recorded on the stopwatch app for each difference in temperature.
9. Step 8 was repeated until the sphere temperature reached 40°C .
10. Steps 2-9 were repeated for a wind tunnel speed of 4 m/s .
11. The devices were turned off and placed in a safe and correct position.

The data for the 6 m/s speed was given from a previous run and was not performed during this experiment.

1.6 Presentation of Raw Experimental Data

The data was recorded for the 2 m/s and 4 m/s settings as indicated in the procedure. These values were used to create a $\ln \left[\frac{T_i - T_a}{T - T_a} \right]$ value for each recording of time to determine the slope of the relation as shown in the relation in the experimental theory. The data for 6 m/s setting was given from a previous experimentation with the relation set as the previous two to determine the slope. Each graph and slope for the air flow velocities are shown in figures 1.3, 1.4, and 1.5.

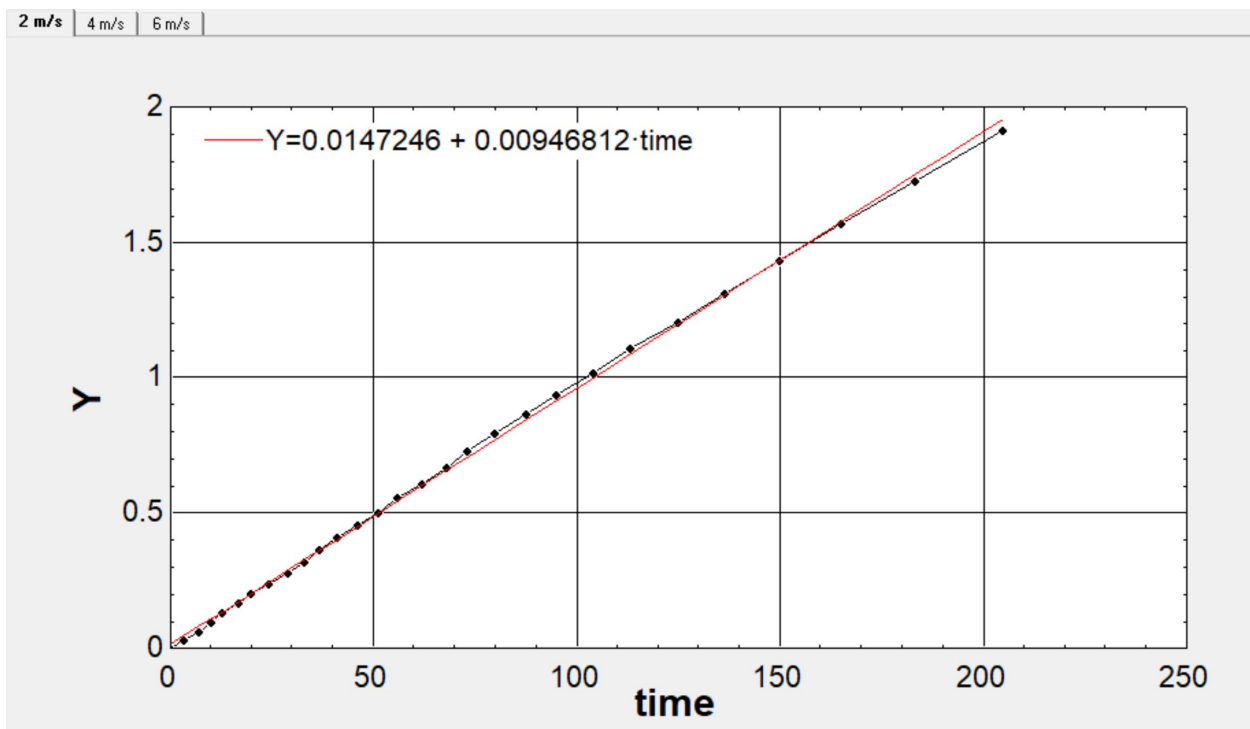


Figure 1.3 Data Set for 2 m/s Velocity

The slope of this data set, $0.00946812 \text{ s}^{-1}$ is used for the analysis of this experiment.

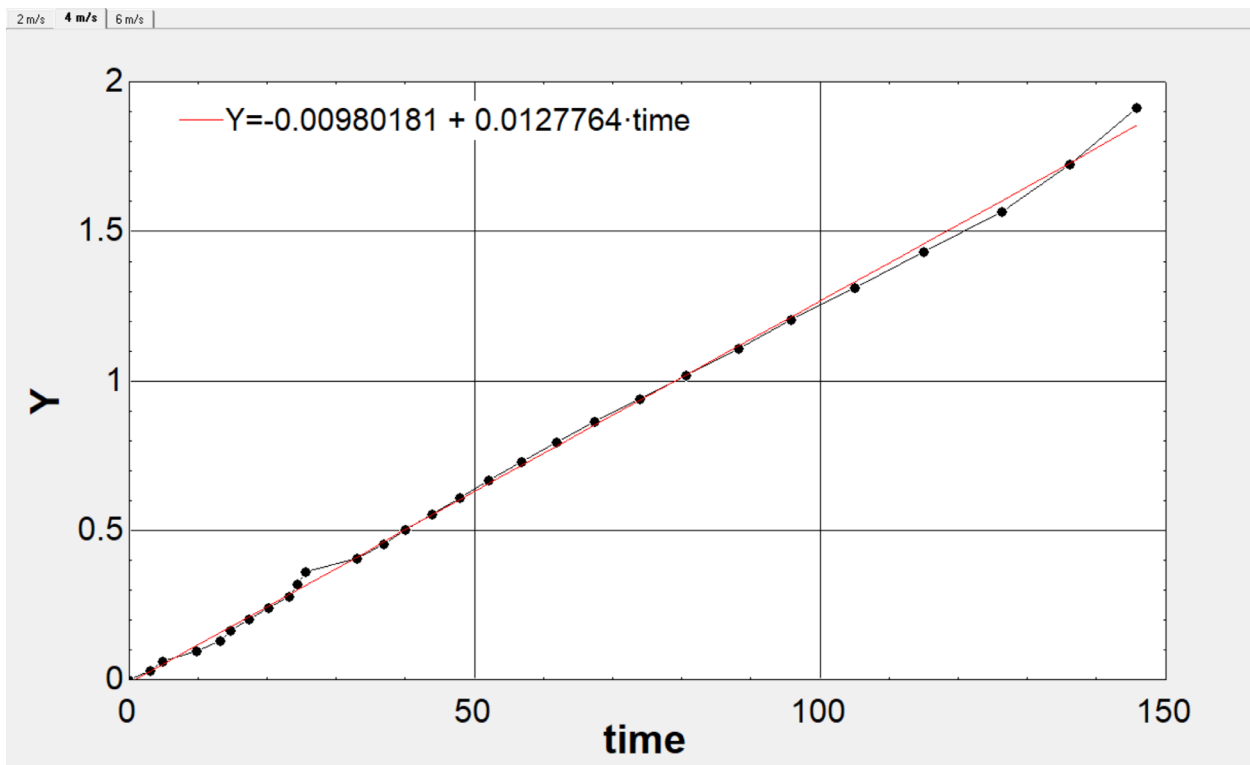


Figure 1.4 Data Set for 4 m/s Velocity

The slope of this data set, 0.0127764 s^{-1} is used for the analysis of this experiment.

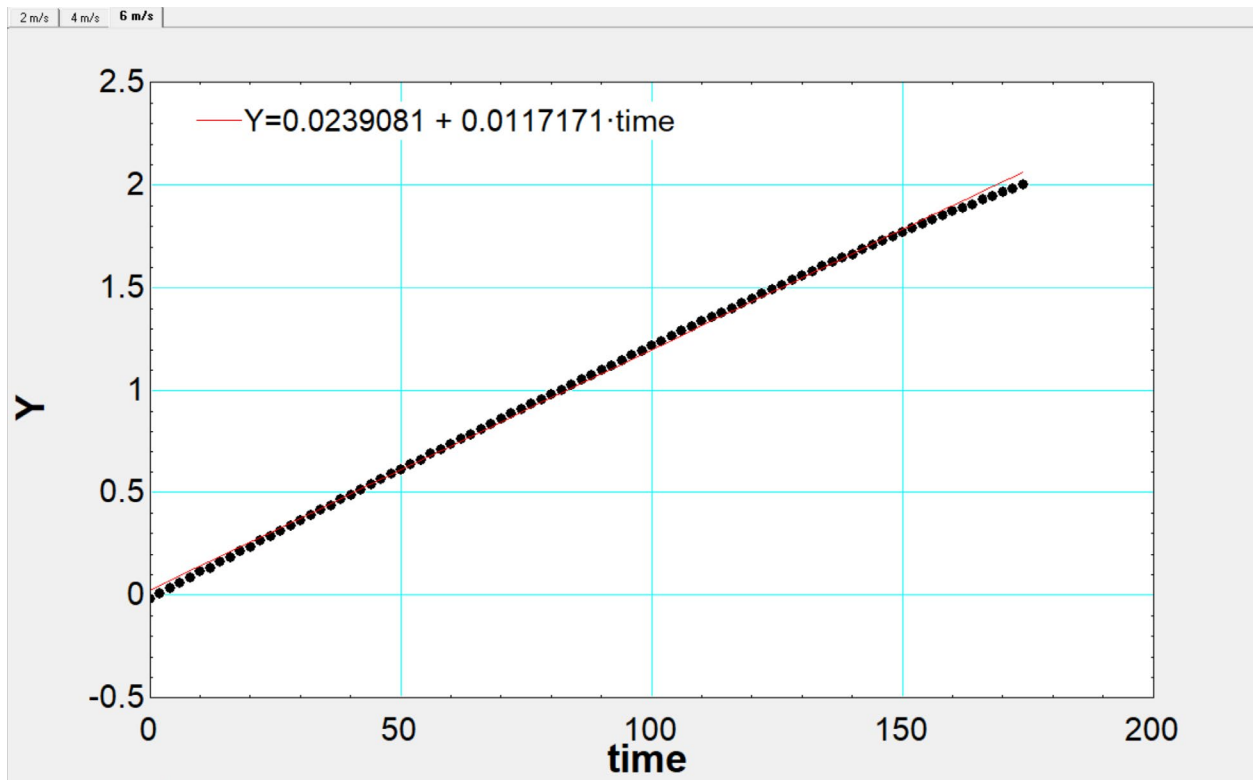


Figure 1.5 Data Set for 6 m/s Velocity

The slope of this data set, 0.0117171 s^{-1} is used for the analysis of this experiment.

In addition to these sets of data, certain values were recorded or given and these values are shown in table 1.3.

Table 1.3 Additional Recorded Values

Ambient Temperature	$15.76 \pm 1.5 \text{ }^{\circ}\text{C}$
Diameter of the Sphere	0.0254 m
Atmospheric Pressure	101.325 kPa

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

This chapter contains the total analysis of the data using the Engineering Equation Solver (EES) program, the results of the total analysis, uncertainty in the computed results, and the analysis results of the data computed through EES.

2.1 Detailed Sample Analysis

The sample analysis was done with the first velocity setting of 2 m/s. The slope recorded from the recorded data was 0.009468 s^{-1} . Using this slope, the time constant was calculated as:

$$\tau = \frac{1}{\text{slope}} = \frac{1}{0.009468 \text{ s}^{-1}} = 105.6 \text{ s}$$

The experimental convection heat transfer coefficient, h_{exp} was calculated as follows:

$$h_{\text{exp}} = \frac{\text{slope} * \rho_{\text{sphere}} * V * c_{\text{sphere}}}{A} = \frac{0.009468 \text{ s}^{-1} * 8490 \frac{\text{kg}}{\text{m}^3} * 8.58 \cdot 10^{-6} \text{ m}^3 * 387.6 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}}{2.027 \cdot 10^{-3} \text{ m}^2}$$

$$= 131.9 \frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$$

Where ρ_{sphere} is the density of the brass sphere, V is the volume of the sphere, c_{sphere} is the specific heat of the brass sphere, and A is the surface area of the sphere.

The Reynolds number was calculated as follows:

$$Re = \frac{\rho_{\text{air}} v D}{\mu_{\infty}} = \frac{1.222 \frac{\text{kg}}{\text{m}^3} * 2 \frac{\text{m}}{\text{s}} * 0.0254 \text{ m}}{1.8 \cdot 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{s}}} = 3449$$

Where ρ_{air} is the density of the air at ambient temperature, v is the velocity of the air, D is the diameter of the sphere, and μ_{∞} is the viscosity of the air at ambient temperature.

The Prandtl number was calculated as follows:

$$Pr = \frac{\mu_{\infty} c_{p,\text{air}}}{k_{\text{air}}} = \frac{1.8 \cdot 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{s}} * 1006 \frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}}{0.02556 \frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}} = 0.7088$$

Where μ_{∞} is the viscosity of the air at ambient temperature, $c_{p,\text{air}}$ is the specific heat of air at ambient pressure, and k_{air} is the thermal conductivity of air.

The Nusselt number was calculated as follows:

$$Nu = 2 + [0.4Re^{1/2} + 0.06Re^{2/3}] Pr^{0.4} \left(\frac{\mu_{\infty}}{\mu_s} \right)^{0.25}$$

$$= 2 + [0.4(3449)^{1/2} + 0.06(3449)^{2/3}] 0.7088^{0.4} \left(\frac{1.8 \cdot 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{s}}}{2.233 \cdot 10^{-5} \frac{\text{kg}}{\text{m} \cdot \text{s}}} \right)^{0.25} = 61.55$$

Where Re is the Reynolds number, Pr is the Prandtl number, μ_{∞} is the viscosity of the air at ambient temperature, and μ_s is the viscosity of the air at the surface temperature of the sphere.

The theoretical heat transfer coefficient was calculated as follows:

$$h_{theo} = \frac{Nu \cdot k_{air}}{D} = \frac{61.55 \cdot 0.02556 \frac{W}{m \cdot ^\circ C}}{0.0254 m} = 61.93 \frac{W}{m^2 \cdot ^\circ C}$$

Where Nu is the Nusselt number, k_{air} is the thermal conductivity of air, and D is the diameter of the sphere.

Lastly, the Biot number was calculated as follows:

$$Bi = \frac{h_{theo} V}{k_{air} A} = \frac{61.93 \frac{W}{m^2 \cdot ^\circ C}}{0.02556 \frac{W}{m \cdot ^\circ C}} \cdot \frac{8.58 \cdot 10^{-6} m^3}{2.027 \cdot 10^{-3} m^2} = 10.26$$

Where h_{theo} is the theoretical convection heat transfer constant, k_{air} is the thermal conductivity of air, V is the volume of the sphere, and A is the surface area of the sphere.

2.2 Sample Analysis Results with Units

The detailed sample analysis using EES is shown below in figure 2.1.

Unit Settings: SI C kPa J mass deg		
A = 0.002027	Bi = 10.26 [K/m-C]	c = 387.6 [J/kg-K]
cp = 1006 [J/kg-K]	D = 0.0254	$h_{exp} = 131.9 [W/m^2 \cdot ^\circ C]$
$h_{theo} = 61.93 [W/m^2 \cdot ^\circ C]$	$k_{air} = 0.02556 [W/m \cdot K]$	$k_{sphere} = 89.09 [W/m \cdot K]$
$\mu_{ambient} = 0.000018 [kg/m \cdot s]$	$\mu_{surface} = 0.00002233 [kg/m \cdot s]$	Nus _{sph} = 61.55
P = 101.3	Pr = 0.7088	Re = 3449 [1/m]
$\rho_{air} = 1.222 [kg/m^3]$	$\rho_{sphere} = 8490 [kg/m^3]$	slope = 0.009468 [1/s]
$\tau = 105.6 [s/1]$	$T_a = 15.76$	$T_f = 40 [C]$
$T_i = 180 [C]$	$T_{avg} = 110 [C]$	V = 2 [m/s]
Volume = 0.00000858		

Figure 2.1 Solve Table for Sample Data

2.3 Uncertainty Analysis of Major Computed Results

The uncertainty results were calculated using EES and shown in table 2.1.

Table 2.1 Uncertainty Results

Unit Settings: SI C kPa J mass deg		
Variable±Uncertainty	Partial derivative	% of uncertainty
$h_{exp} = 131.9 \pm 0.04711 [W/m^2 \cdot ^\circ C]$		
$T_a = 15.76 \pm 1.5$	$\partial h_{exp} / \partial T_a = 0$	0.00 %
$T_f = 40 \pm 1.5 [C]$	$\partial h_{exp} / \partial T_f = 0.02221$	50.00 %
$T_i = 180 \pm 1.5 [C]$	$\partial h_{exp} / \partial T_i = 0.02221$	50.00 %
V = 2±0.1 [m/s]	$\partial h_{exp} / \partial V = 0$	0.00 %
$h_{theo} = 61.93 \pm 1.741 [W/m^2 \cdot ^\circ C]$		
$T_a = 15.76 \pm 1.5$	$\partial h_{theo} / \partial T_a = 0.00269$	0.00 %
$T_f = 40 \pm 1.5 [C]$	$\partial h_{theo} / \partial T_f = -0.01453$	0.02 %
$T_i = 180 \pm 1.5 [C]$	$\partial h_{theo} / \partial T_i = -0.01453$	0.02 %
V = 2±0.1 [m/s]	$\partial h_{theo} / \partial V = 17.4$	99.97 %

2.4 Detailed Computer Analysis of all Data and Presentation of Tables of Derived Results

The data calculated in EES for all three velocities of air are shown in table 2.2.

Table 2.2 Analysis Results of Experiment

2 m/s	4 m/s	6 m/s	Analysis							
1.3	1 V [m/s]	2 T _i [C]	3 T _f [C]	4 slope [1/s]	5 h _{exp} [W/m ² *C]	6 h _{theo} [W/m ² *C]	7 Nus _{sph}	8 Re [1/m]	9 Bi [K/m-C]	10 τ [s/1]
Run 1	2	180	40	0.009468	131.9	61.93	61.55	3449	10.26	105.6
Run 2	4	180	40	0.01278	178	91.79	91.23	6898	15.2	78.27
Run 3	6	180	40	0.01172	163.2	115.9	115.2	10347	19.2	85.35

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

This chapter contains graphical representation of the experimental data as well as interpretation of the experimental results. Following these, concluding remarks are provided based on each experimental objective. The chapter ends with recommendations and an appendix containing the EES code used for analysis.

3.1 Presentation of Graphs and Figures

The experiment calculated both the experimental and theoretical convection heat transfer coefficients. Using these calculated coefficients, the relationship between the coefficients, both theoretical and experimental, and velocity, Reynolds number, the time constant from the energy balance equation, and the Biot number were studied.

The convection coefficients and velocity had a positive correlation, both increasing simultaneously. In figure 3.1 the positive correlation can be shown more accurately on the theoretical as there may be a discrepancy with the data that was given for 6 m/s. The data shows that with increased velocity of the fluid, heat was transferred faster.

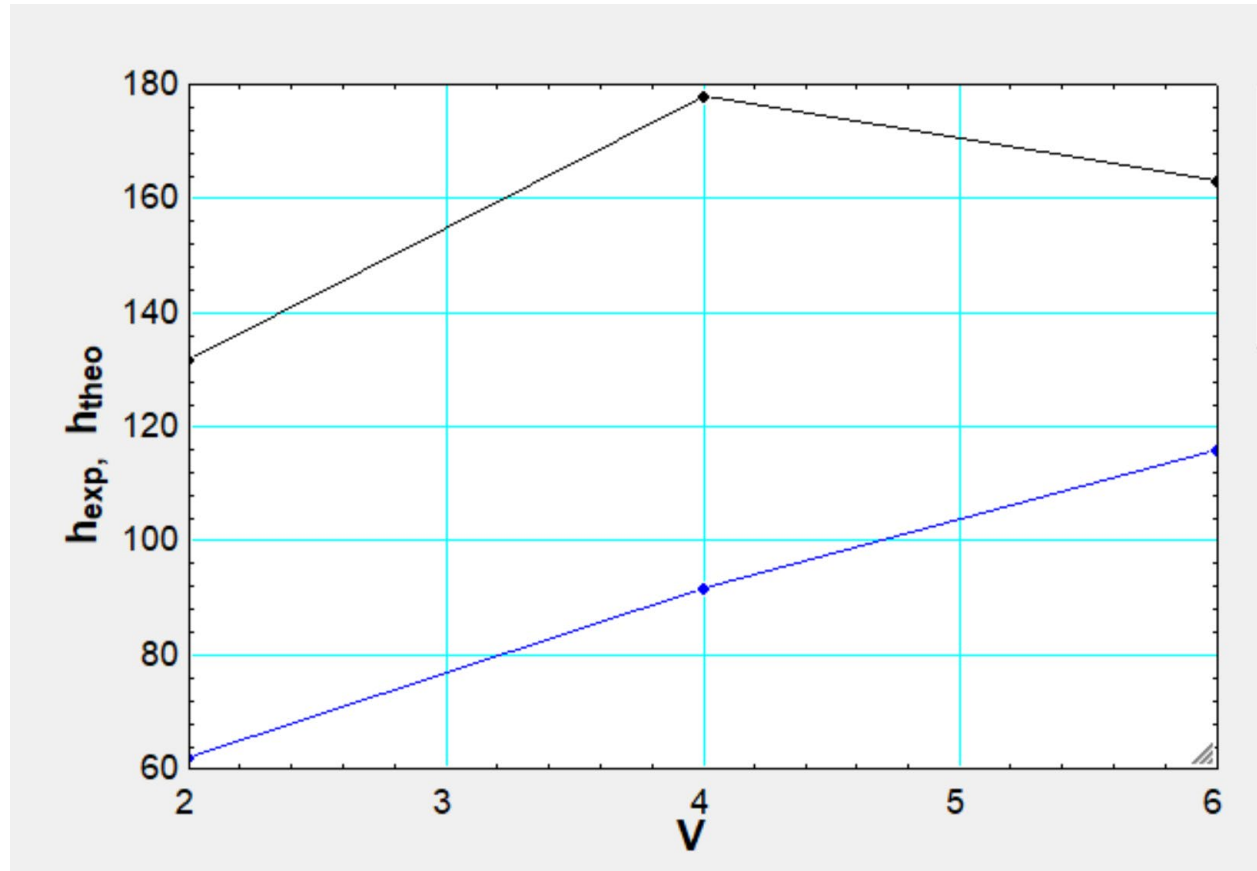


Figure 3.1 Convection Heat Transfer Coefficient vs Velocity

The black, higher values show the theoretical coefficient values, and the blue values represent the experimental coefficient. The units for the heat transfer coefficient, h , are $\frac{W}{m^2 \cdot ^\circ C}$ and the units for velocity, v , are in $\frac{m}{s}$.

The convection coefficients and Reynolds number also had a positive correlation. As with the other figure, the linear relationship shown with the theoretical coefficient is not fully represented in the experimental values due to possible error. Figure 3.2 shows the graphical representation of their correlation, showing that with increased Reynolds number, meaning less laminar flow, there is an increase in heat transfer.

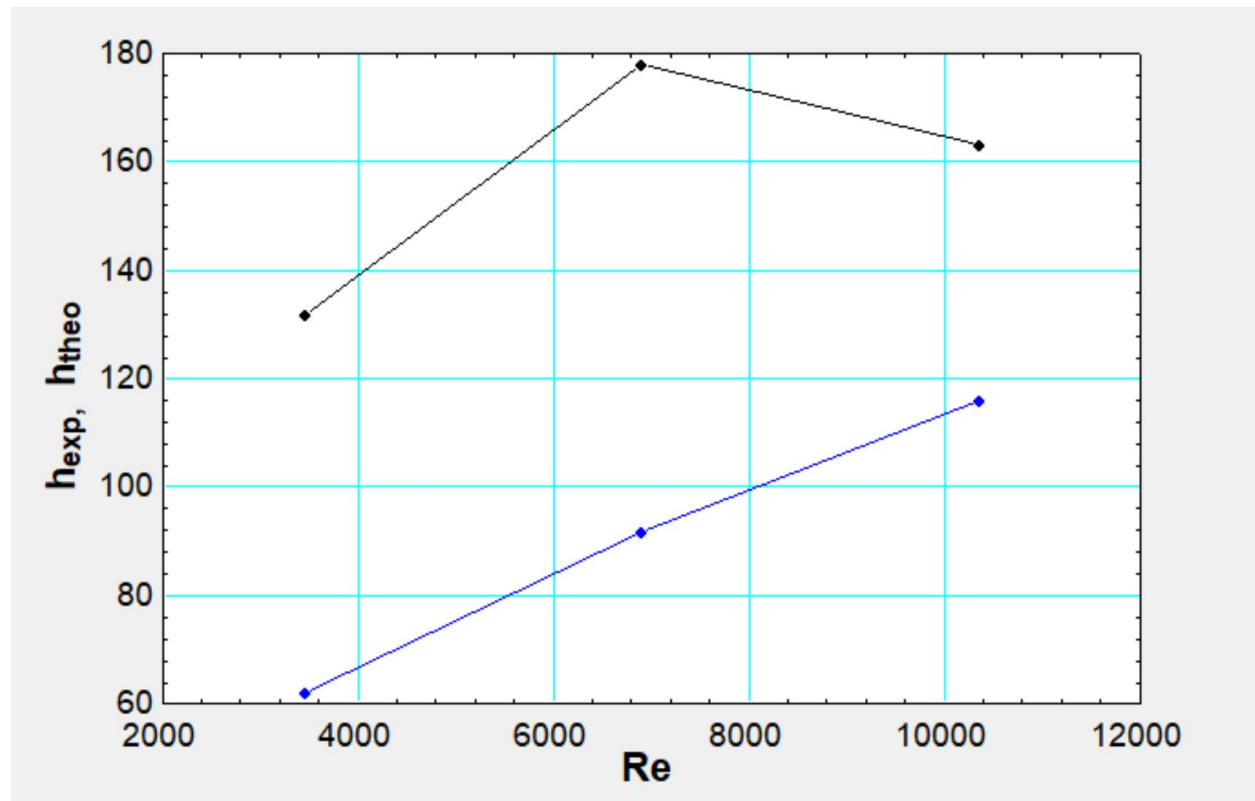


Figure 3.2 Convection Heat Transfer Coefficient vs Reynold Number

The black, higher values show the theoretical coefficient values, and the blue values represent the experimental coefficient. The units for the heat transfer coefficient, h , are $\frac{W}{m^2 \cdot ^\circ C}$ and the Reynolds number, Re , is unitless.

In the experimental theory, the time constant, which is represented as the experimental slope for the recorded data over time, was the value against the thermodynamic properties representing the heat transfer coefficient in the energy balance between the sphere and the moving air. Figure 3.3 shows the graphical representation of negative correlation between the time constant versus velocity meaning that with increased velocity, the temperature relationship between the initial temperature and the ambient vs the current temperature and the ambient is decreased.

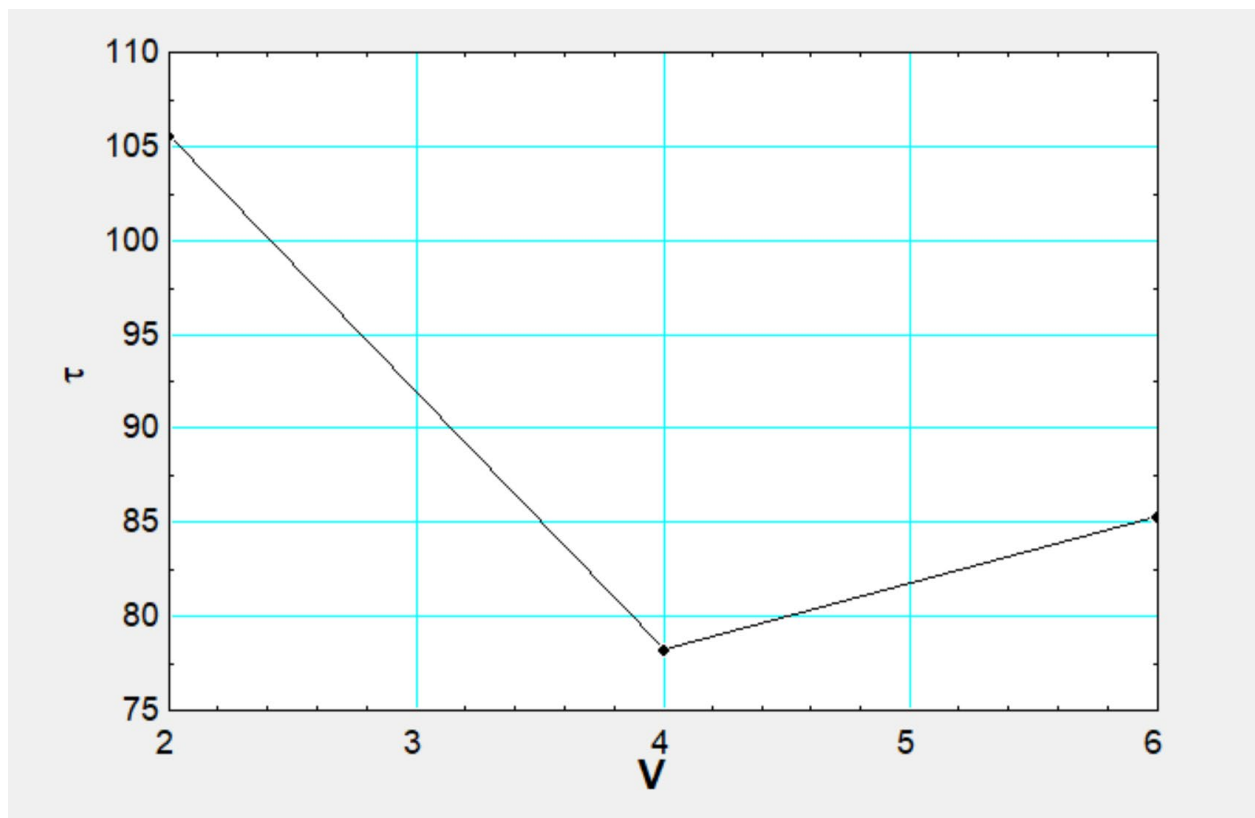


Figure 3.3 Time Constant vs Velocity

The figure shows the negative correlation between the two values, with an obvious deviation for the 4 m/s values the trend. The time constant, τ , has a unit of s^{-2} and velocity, V , has a unit of m/s.

The relationship between the Biot number and convection heat transfer coefficient was a positive correlation as well. Again, the experimental values spike at 4 m/s while the theoretical remain a positive linear correlation. This relationship shows that with an increased Biot number, or ratio of internal thermal resistance of a solid to the boundary layer thermal resistance, the heat transfer on an object can be larger. The experimental and theoretical values are plotted against the Biot number in figure 3.4.

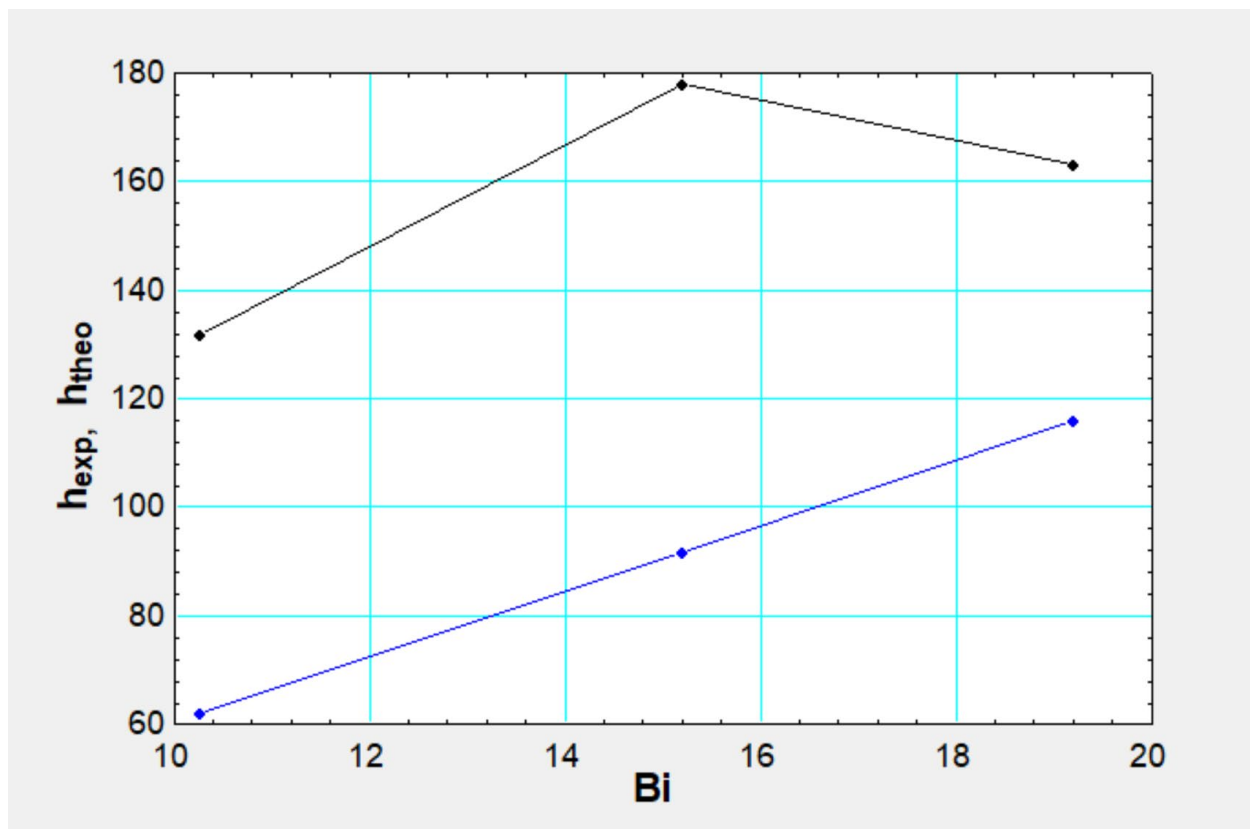


Figure 3.4 Convection Heat Transfer Coefficient vs Biot Number

The black, higher values show the theoretical coefficient values, and the lower, blue values represent the experimental coefficient. The units for the heat transfer coefficient, h , are $\frac{W}{m^2 \cdot ^\circ C}$ and the Biot number, Bi , is unitless. The theoretical values represent a purely linear trend while the experimental values spike at 4 m/s.

3.2 Conclusions Based on each Objective and the Result

As per the objectives of the experiment the following conclusions were derived. The ability to measure the heat transfer coefficient was successful with a possible error in the 4 m/s values or the given 6 m/s values. While the coefficients were successfully recorded and derived, there was also an increase for the experimental values as opposed to the experimental.

The velocity and Reynolds number showed a positive correlation to the heat transfer coefficient as with more fluid movement and a larger ratio of inertia forces of a fluid to viscous forces of a fluid, the ability for heat to be transferred is increased for an object in a fluid.

The experimental results for the heat transfer coefficient were larger than the theoretical values while still showing the same correlation. The possible reasons for this may have been recording error for the time using the stopwatch app, the internal conduction heat transfer of the brass sphere, and other unaccounted errors in the experimentation. The theoretical calculations do not account for the size and conduction of the sphere, as shown in the Biot number, and the placement of the thermocouple.

3.3 Recommendations

As there was an error in the trend for the experimental results for the heat transfer coefficients, more iterations of the experimental procedure should be done to account for possible error. In addition, a program for the recording computer should be written to record the temperature and time values without the addition of human interaction to eliminate error. The lab procedure should also be fully read and understood before performing the experiment as well as making sure that the apparatus is in full working order in order to obtain all data sets.

REFERENCES

Bergman, T., Lavine, A., Incropera, F. and Dewitt, D., 2011. *Fundamentals of Heat and Mass Transfer, Seventh Edition Binder Ready Version*. Chichester: John Wiley and Sons.

Thermal Science Laboratory Manual, Fall 2021 Version. Mechanical Engineering Department Prairie View A&M University. Prairie View, Texas 77446

APPENDIX A EES Formatted Equations

This appendix contains the formatted EES program used to analyze the remaining data using the EES Solve Table feature.

$$T_a = 15.76 \text{ Ambient Temperature}$$

$$T_i = 180 \text{ Initial Temperature}$$

$$\text{time} = \text{Time in seconds}$$

$$T = \text{Actual Temperature of sphere}$$

$$T_r = ((T_i - T_a)/(T - T_a))$$

$$Y = \ln(T_r)$$

$$D = 0.0254 \text{ Sphere diameter in meters}$$

$$A = 4 \cdot \pi \cdot \left[\frac{D}{2} \right]^2 \text{ Surface area of sphere in m}^2$$

$$P = 101.325 \text{ Atmospheric Pressure}$$

$$\text{Volume} = 4 / 3 \cdot \pi \cdot \left[\frac{D}{2} \right]^3 \text{ Volume of sphere}$$

$$V = 2 \text{ velocity}$$

$$T_i = 180 \text{ initial temperature}$$

$$T_f = 40 \text{ final temperature}$$

$$\text{slope} = 0.00946812 \text{ slope of Y vs Time graph}$$

$$T_a = 15.76 \text{ Ambient Temperature}$$

$$T_{\text{avg}} = \frac{T_i + T_f}{2}$$

$$\rho_{\text{sphere}} = \rho(\text{Brass}, T=T_{\text{avg}}) \text{ Density of brass sphere}$$

$$\rho_{\text{air}} = \rho(\text{Air}_{\text{ha}}, T=T_a, P=P)$$

$$c = C_p(\text{Brass}, T=T_{\text{avg}}) \text{ Specific Heat of Brass Sphere}$$

$$cp = C_p(\text{Air}_{\text{ha}}, T=T_a, P=P)$$

$$k_{\text{sphere}} = k(\text{Brass}, T=T_{\text{avg}}) \quad \text{Thermal conductivity of brass sphere}$$

$$k_{\text{air}} = k(\text{Air}_{\text{ha}}, T=T_{\text{a}}, P=P)$$

$$\mu_{\text{ambient}} = \text{Visc}(\text{Air}_{\text{ha}}, T=T_{\text{a}}, P=P)$$

$$\mu_{\text{surface}} = \text{Visc}(\text{Air}_{\text{ha}}, T=T_{\text{avg}}, P=P)$$

$$\tau = \frac{1}{\text{slope}} \quad \text{Time constant}$$

$$h_{\text{exp}} = \frac{\text{slope} \cdot \rho_{\text{sphere}} \cdot \text{Volume} \cdot c}{A} \quad \text{Experimental Heat transfer coefficient}$$

$$\text{Re} = \frac{\rho_{\text{air}} \cdot V \cdot D}{\mu_{\text{ambient}}} \quad \text{Reynolds Number}$$

$$\text{Pr} = \mu_{\text{ambient}} \cdot \frac{c_p}{k_{\text{air}}} \quad \text{Prandtl number of air}$$

$$\text{Nus}_{\text{sph}} = 2 + ((0.4 \cdot \text{Re})^{0.5} + (0.06 \cdot \text{Re})^{(2/3)}) \cdot \text{Pr}^{0.4} \cdot \left[\frac{\mu_{\text{ambient}}}{\mu_{\text{surface}}} \right]^{0.25} \quad \text{Nusselt number of flow over sphere}$$

$$h_{\text{theo}} = \frac{\text{Nus}_{\text{sph}} \cdot k_{\text{air}}}{D}$$

$$\text{Bi} = \frac{h_{\text{theo}}}{k_{\text{air}}} \cdot \frac{\text{Volume}}{A}$$

APPENDIX B EES Unformatted Equations

This appendix contains the unformatted EES program used to analyze the remaining data using the EES Solve Table feature.

"T_a = 15.76 Ambient Temperature "

"T_i = 180 Initial Temperature"

"time = Time in seconds"

"T = Actual Temperature of sphere"

"T_r = ((T_i - T_a)/(T - T_a)) "

"Y = ln(T_r)"

D = 0.0254 "Sphere diameter in meters"

A = 4*pi*((D/2)^2) "Surface area of sphere in m^2"

P = 101.325 "Atmospheric Pressure"

Volume = (4/3)*pi*(D/2)^3 "Volume of sphere"

"V = 2 velocity"

T_i = 180 "initial temperature"

T_f = 40 "final temperature"

"slope = 0.00946812 slope of Y vs Time graph"

T_a = 15.76 "Ambient Temperature"

T_avg = (T_i + T_f)/2

rho_sphere=Density(Brass, T=T_avg) "Density of brass sphere"

rho_air=Density(Air_ha, T=T_a, P=P)

c=SpecHeat(Brass, T=T_avg) "Specific Heat of Brass Sphere"

cp=Cp(Air_ha, T=T_a, P=P)

k_sphere=Conductivity(Brass, T=T_avg) "Thermal conductivity of brass sphere"

k_air=Conductivity(Air_ha, T=T_a, P=P)

mu_ambient=Viscosity(Air_ha, T=T_a, P=P)

mu_surface=Viscosity(Air_ha, T=T_avg, P=P)

tau = 1/slope "Time constant"

h_exp = (slope*rho_sphere*Volume*c)/A "Experimental Heat transfer coefficient"

Re = (rho_air*V*D)/mu_ambient "Reynolds Number"

Pr=mu_ambient*cp/k_air "Prandtl number of air"

Nus_sph = 2 + (((0.4*Re)^.5) + ((0.06*Re)^(2/3)))*(Pr^0.4)*(mu_ambient/mu_surface)^.25) "Nusselt number of flow over sphere"

h_theo = (Nus_sph*k_air)/D

Bi = (h_theo/k_air)*(Volume/A)

AVERAGE

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PRAIRIE VIEW A&M UNIVERSITY



MCEG 3102-P01
THERMAL SCIENCE LABORATORY
LAB REPORT COVER PAGE
Fall 2021

LABORATORY REPORT ON

**Measurement of Heat Transfer Coefficient
for Forced Convection
Using the Lumped Capacity Method**

**Conducted on
October 9, 2021**

**Submitted by
Ihab Ayoubi**

**On
November 12, 2021**

**To
Dr. Shahin Shafiee
*Thermal Science Laboratory Instructor***



MECHANICAL ENGINEERING DEPARTMENT
THERMAL SCIENCE LABORATORY
LABORATORY GRADING SHEET
Fall 2021 SECTION P01

Title of Experiment: Measurement of Heat Transfer Coefficient for Forced Convection Using the Lumped Capacity Method

Name: Ihab Ayoubi

Date Lab was performed: November 3, 2021 Report Due Date: November 13, 2021

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (your conduct and observations).	3		
Ability to follow the procedure and to properly rephrase the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment functions, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report) Front End of Report (4 points). General report format (4 points)	4 4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters	12		
Correct solutions with consistent units and significant figures.	10		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw /derived) in tabular form to meet the objectives and to aid in plotting the results.	4		
Ability to present the data (raw /derived) in well-labeled graphical form to meet the objectives and to aid in interpretation.	10		
Ability to discuss the raw and derived data/graphs and assess the validity of the results concerning the underlying theory and expected trends. (Interpretation of experimental data & results)			
Effect of independent (X-axis) variable on the dependent (Y-axis variables). Points	4		
Effect of parametric variable change on the dependent (Y-axis variable). Points	4		
Comparison of experimental results with theoretical results/prediction/trend Points	4		
Statement on goodness or reasonableness of results. Points	2		
Ability to use engineering judgement to draw appropriate and reasonable conclusions in relation to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		
Percentage for this Performance Criteria			
TOTAL FOR THIS LAB	100		

Letter of Transmittal

November 9, 2021

Dr. Shahin Shafiee

Mechanical Engineering Department
Prairie View A&M University

Dear Dr. Shahin Shafiee,

The attached technical laboratory report contains the detailed results of the experiment on Performance of Refrigeration System with AEV conducted on October 20, 2021. This report contains the objectives of the experiment, a description of the system, the equations used for analysis of the data, the raw experimental data, graphical presentation of the important results, discussion and interpretation of the results and recommendations.

If you have any questions regarding the report, please contact me at 512-987-0999

Best regards,

Ihab Ayoubi

Ihab Ayoubi

ABSTRACT

PURPOSE

The main purpose of this experiment was to determine the heat transfer coefficient in forced convection situation using lumped capacity method. The influence of fluid speed and Reynold number on forced convection heat transfer coefficient was also investigated. Theoretical and experimental data were also compared.

METHOD

The room temperature T_a , the diameter of the metal sphere if not provided (either aluminum or brass), and the mass were measured. The metal sphere was then heated in an oven. Meanwhile start the wind tunnel and adjust the RPM control to obtain an air speed. When the temperature of the metal in the oven reaches the prescribed temperature remove the steel sphere from the oven. With the thermocouple connected to the sphere and the thermocouple readout, hang the steel sphere in the air moving in the wind tunnel and measure the initial temperature. Record the time at every interval until the temperature reaches the last temperature listed in the data table.

RESULTS

Using the data values measured from the experiment, slope units, experimental and theoretical heat transfer co-efficient, Reynold number, Nusselt number, Biot number and time constant were calculated.

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CHAPTER 1

1 ABILITY TO CONDUCT EXPERIMENTS

1.1 Objectives of the Experiment

The objectives of this experiment were to:

1. To measure the heat transfer coefficient for forced convection
2. To have a complete understanding of the lumped capacity method.
3. To determine the effects Reynolds number on the heat transfer coefficient.
4. To compare the experimental results with the values from theoretical prediction.
5. The effect of speed of fluid on the heat transfer coefficient of forced convection will also be studied

1.2 Theory Associated with Experiment

Convection is the transfer of heat by the movement of a fluid (liquid or gas) between areas of different temperature. Warm air is less dense than cold air, and so convection currents can form in the presence of a temperature gradient. When currents are produced only by temperature-derived density differences in the fluid, it is known as natural convection. When the convection currents are due to an external factor such as a pump or fan, this is forced convection. The faster the fluid is moved, the faster the rate of convection.

The exchange of heat by convection between a body and its environment depends on:

- The temperature gradient between the two (this determines the amount of heat absorbed or donated by a given mass of air that meets the surface).
- Relative movement of the fluid with which the body is in contact.
- Convection occurs in liquids and gases. For any solid to lose or gain heat by convection it must be in contact with the fluid. Convection cannot occur in a vacuum.
- Heat transfer by simultaneous conduction and convection, whether free or forced, forms the basis of most industrial heat exchangers and related equipment.

Consider an object at an initial temperature T_i being cooled by a fluid stream at a temperature T_a . If the object has high thermal conductivity, then its internal resistance to heat flux is small. This means that the temperature profile within the object is uniform and everywhere equal (or almost equal) to the surface temperature. At any instant in time, there is no temperature gradient within the object, only a temperature difference between the surface and the free stream. The heat transfer between the object and the fluid is controlled almost exclusively by the surface resistance i.e., the value of convective heat transfer coefficient h . The heat transfer process, in this case, is known as Newtonian cooling (or heating). Because the temperature does not change (significantly) within the solid, and the heat transfer model can be formulated by performing an energy balance on the object.

The rate at which the internal energy of mass is changing = Rate at which heat energy is transferred from the surface to the free stream

$$\frac{dU}{dt} = -hA(T - T_a) \quad (1)$$

$$mc \frac{dT}{dt} = -hA(T - T_a) \quad (2)$$

Using the initial condition at $t = 0$, $T = T_i$ and integrating equation (2) results in the lumped capacity equation.

$$\frac{T - T_a}{T_i - T_a} = \text{Exp} \left[-\frac{hA}{\rho g C} t \right] \quad (3)$$

$$\text{Or } \frac{T_i - T_a}{T - T_a} = \text{Exp} \left[\frac{hA}{\rho g C} t \right]$$

Taking the log of both sides, we get

$$\ln \left[\frac{T_i - T_a}{T - T_a} \right] = \frac{hA}{\rho g C} t \quad (4)$$

where

T = temperature of the object at any time

T_a = Temperature of the free stream or the ambient air

T_i = the initial temperature of the object

h = the average convective heat transfer coefficient (being determined from the experiment)

A = the surface area of the object ($4\pi R^2$ for sphere)

C = the specific heat of the object

ρ = the density of the object

g = the volume of the object

The quantity $\tau = \left[\frac{\rho g C}{hA} \right]$ is called the time constant.

A plot of $\ln \left[\frac{T_i - T_a}{T - T_a} \right]$ vs t will thus be a straight line with a slope of $\left[\frac{hA}{\rho g C} \right]$.

Thus, measuring the slope of the line and equating the slope to $\left[\frac{hA}{\rho g C} \right]$ will enable h to be computed.

The convective heat transfer coefficient, h , strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent).

In convection, it is a common practice to non-dimensionalize the governing equations and combine the variables which group together into dimensionless numbers.

Nusselt number, the non-dimensional heat transfer coefficient, is defined as $Nu = h\delta/k$,

where δ is the characteristic length, i.e., D for tubes and L for flat plates. Nusselt number represents the enhancement of heat transfer through a fluid as a result of convection relative to conduction across the same fluid layer.

Reynolds number: the ratio of inertia forces to viscous forces in the fluid.

$Re = \text{inertia forces} / \text{Viscous forces} = \rho V \delta / \mu = V \delta / \nu$

At large Re numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces; thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid (turbulent regime).

Prandtl number: is a measure of the relative thickness of the velocity and thermal boundary layer.

$Pr = \text{molecular diffusivity of momentum} / \text{molecular diffusivity of heat} = \nu / \alpha = \mu C_p / k$

Flow over a cylinder:

The characteristic length for a circular tube or sphere is the external diameter, D , and the Reynolds number is defined as $Re = \rho V_\infty D / \mu$.

For flow over sphere, Whitaker recommended the following:

$$Nu_{\text{sph}} = hD/k = 2 + [0.4 Re^{1/2} + 0.06 Re^{2/3}] Pr^{0.4} (\mu_\infty / \mu_s)^{1/4}$$

The above equation is valid for $3.5 < Re < 80000$ and $0.7 < Pr < 380$. The fluid properties are evaluated at the free stream temperature T_∞ , except for μ_s which is evaluated at the surface temperature.

1.2.1 Free Convection

A heated surface dissipates heat primarily through a process called convection. Heat is also dissipated by conduction and radiation; however, these effects are not considered in this experiment. Air in contact with the hot surface is heated by the surface and rises

due to a reduction in density. The heated air is replaced by cooler air which is in turn heated by the surface and rises. This process is called free convection.

The hotter the temperature of the surface, the greater the convective currents and more heat (power) will be dissipated. If more power is supplied to a surface, the temperature of the surface must rise to dissipate this power.

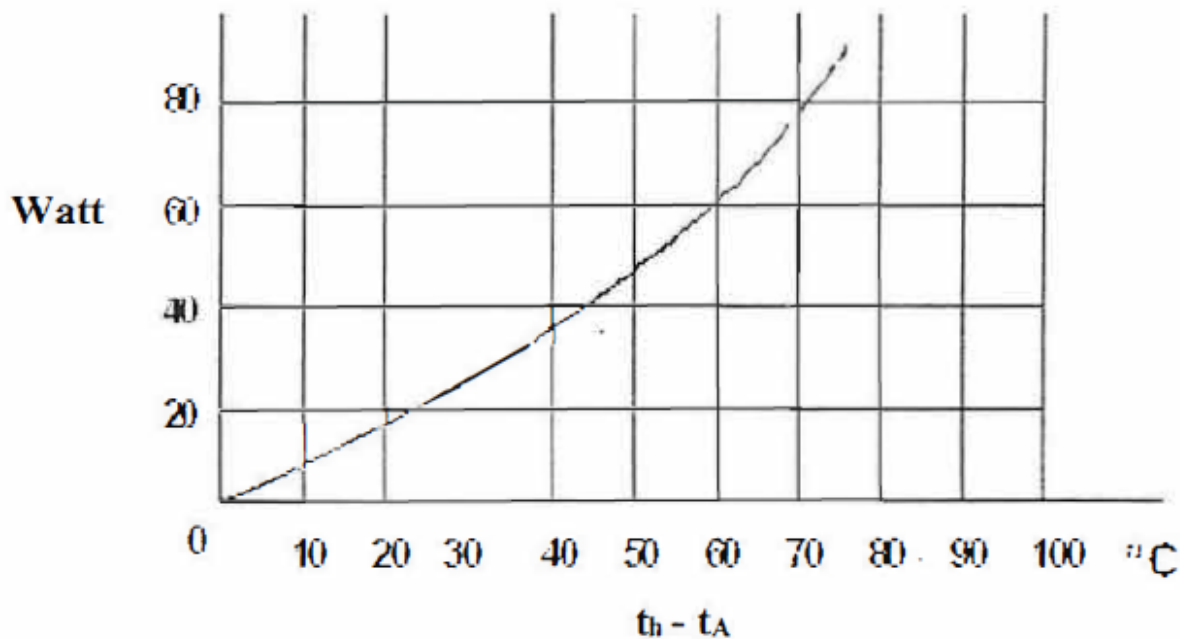


Figure 1-0-1: Typical graph of power against surface temperature

1.2.2 Forced Convection

In free convection the heat transfer rate from the surface is limited by the small movements of air generated by this heat. More heat is transferred if the air velocity is increased over the heated surface. This process of assisting the movement of air over the heated surface is called Forced Convection. Therefore a heated surface experiencing forced convection will have a lower surface temperature than that of the same surface in free convection, for the same power input.

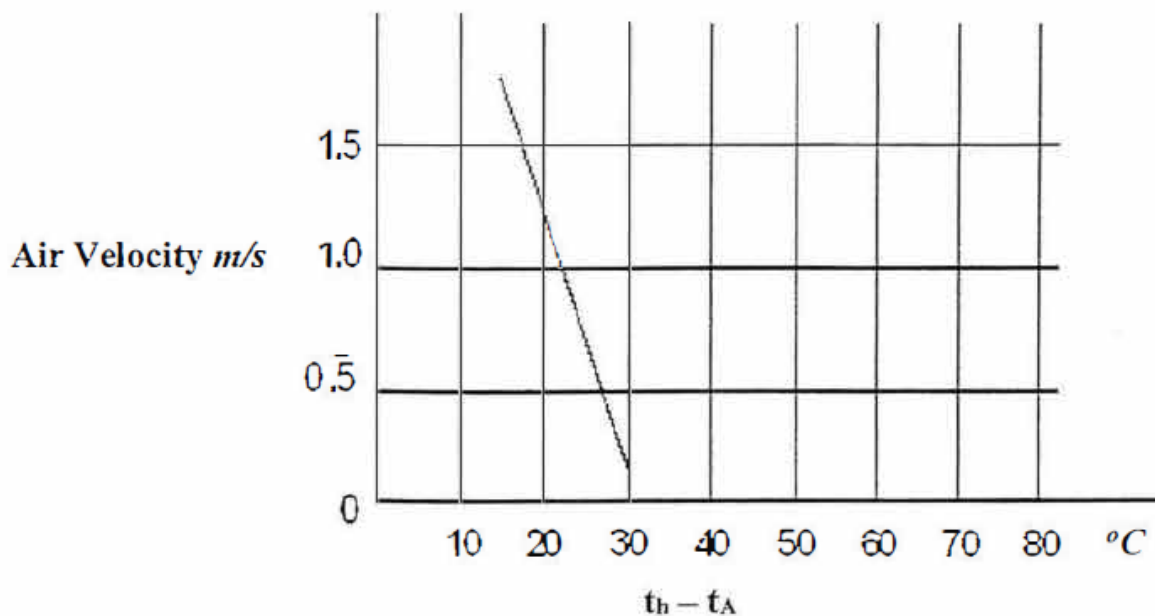


Figure 1-1-2: Typical graph of air velocity against surface temperature

1.3 Experimental Apparatus:

The apparatus of this Experiment Comprises of.

- Variable Speed Small Diameter Wind Tunnel
- Mantle Heater
- Metal Sphere
- Thermocouple Wire
- Thermocouple Read-Out
- Stopwatch,

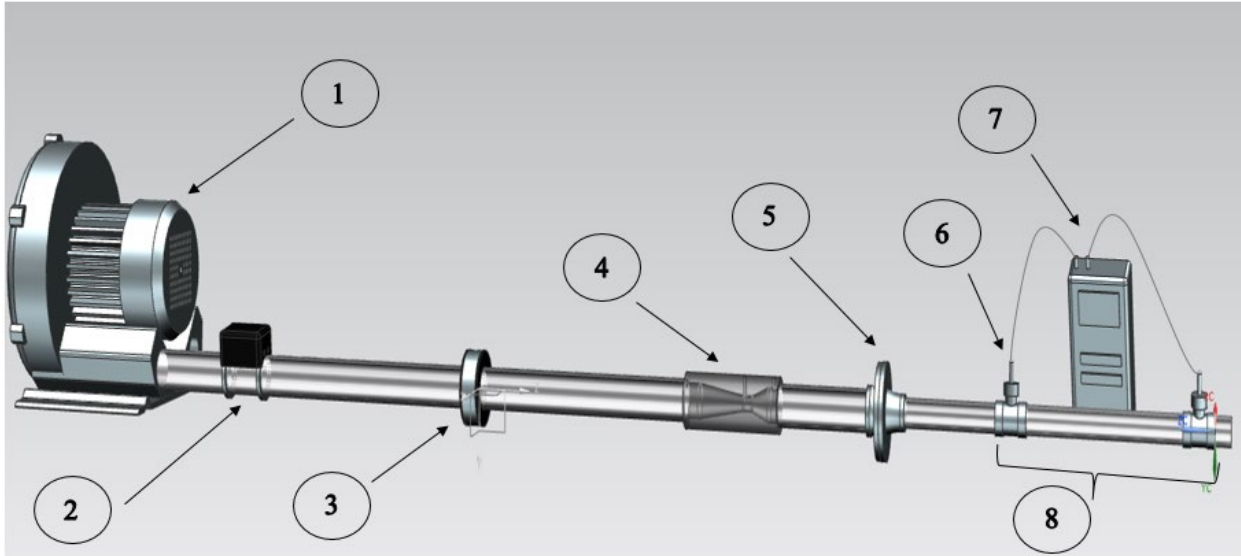


Figure 1-3. Experimental apparatus for measuring heat transfer coefficient using the lumped capacity method.

1.3.1 Apparatus description

Wind tunnel was used for changing the velocities of air to understand the behavior of different properties with velocity. Mantle heater was the oven in which the metal sphere was heated, and metal sphere was our test specimen. Thermocouple wire was used to connect the system to the sensor and thermocouple read-out was helpful in reading the result values of temperature. Stopwatch was used to note the time intervals based on which the temperature values were taken.

1.4 Experimental Procedure:

Forced convection:

1. The system was familiarized with that of the description in Figure 1.
2. A brief discussion was done with the instructor before starting the experiment.
3. The room temperature T_a , the diameter of the metal sphere for both metals, and their masses were measured.
4. The volume and the density of the metal sphere were calculated.
5. After that, heat the metal sphere in an oven to 200 -220oC.
6. While the metal sphere is being heated, wind tunnel was started and RPM control to obtain an air speed of 2 m/s or at the appropriate speed were adjusted.
7. When the temperature of the metal in the oven reached the prescribed temperature, the steel sphere was removed from the oven.
8. With the thermocouple connected to the sphere and the thermocouple readout, the steel sphere in the air moving in the wind tunnel was hanged and the initial temperature, T_i (at 180oC) at time 0 sec was measured.
9. The timer was started.
10. Time was recorded at every 4°C or as listed in the table for $V = 2$ m/s, every 5°C or as listed in the table for $V = 4$ m/s, and every 10°C or as listed in the table for $V = 6$ m/s change in temperature of the body until the temperature reached the last temperature listed in the data table.
11. Same procedure was done for 4 m/s and 6 m/s and readings were taken.

1.5 Presentation of Raw Experimental Data:

In the raw data the temperature values w.r.t time were taken. The independent variables in this experiment were time, temperature,

and velocity while the dependent variables were Biot number, Reynold number, heat transfer coefficient and time constant.

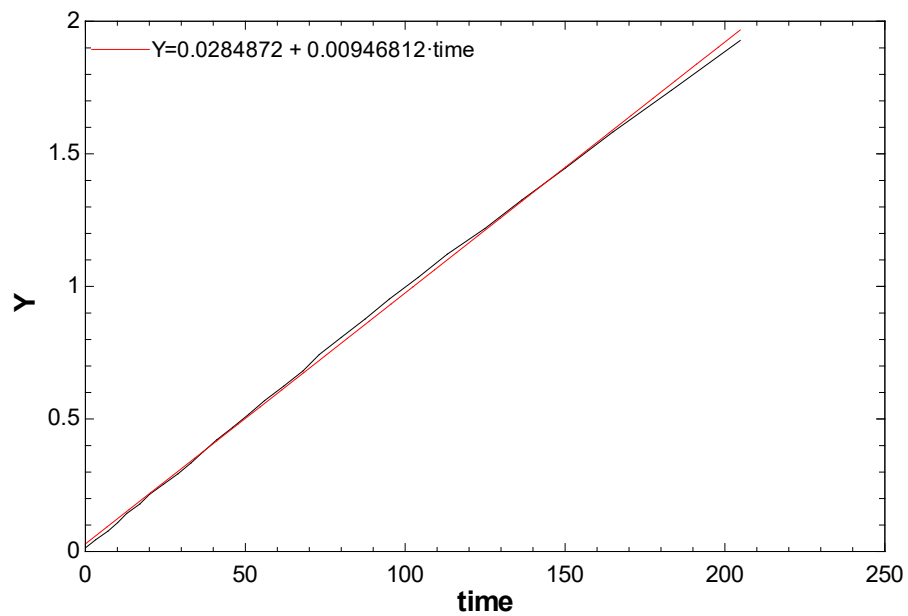
Table 1.1. Lumped Capacity Raw Data

Forced Convection V= 2 m/s		Forced Convection V= 4 m/s		Forced Convection V= 6 m/s	
Temp. °C	Time Min:sec	Temp. °C	Time Min:sec	Temp. °C	Time Min:sec
T _i =180	0	T _i =180	0	182.2767	0
175	3.23	175	3.12	178.2904	2
170	7.06	170	4.98	173.8726	4
165	10.12	165	9.82	170.1535	6
160	12.9	160	13.2	165.9127	8
155	17.01	155	14.78	161.8061	10
150	20.04	150	17.35	158.9491	12
145	24.41	145	20.25	155.0179	14
140	28.97	140	23.15	151.776	16
135	33.01	135	25.65	148.054	18
130	36.87	130	24.38	144.9709	20
125	41.11	125	32.98	141.3974	22
120	46.05	120	36.9	138.4794	24
115	51.05	115	39.98	135.5842	26
110	56	110	43.9	132.2955	28
105	61.97	105	47.93	129.5536	30
100	68.11	100	52.06	126.4276	32
95	73.11	95	56.85	123.8345	34
90	80	90	61.85	121.2963	36
85	87.47	85	67.45	118.3943	38
80	95.06	80	74.01	116.381	40
75	104.04	75	80.65	113.6161	42
70	113.17	70	88.24	110.9371	44
65	124.96	65	95.86	108.7433	46
60	136.43	60	105.1	106.5683	48
55	150	55	115.01	104.4365	50
50	164.94	50	126.35	102.4008	52
45	183.23	45	136.12	100.387	54
40	204.77	40	145.88	98.1223	56
				96.2094	58
				94.071	60
				92.2529	62
				90.5086	64
				88.5718	66
				86.8905	68
				85.0344	70
				83.4065	72
				81.8623	74
				80.1655	76
				78.936	78

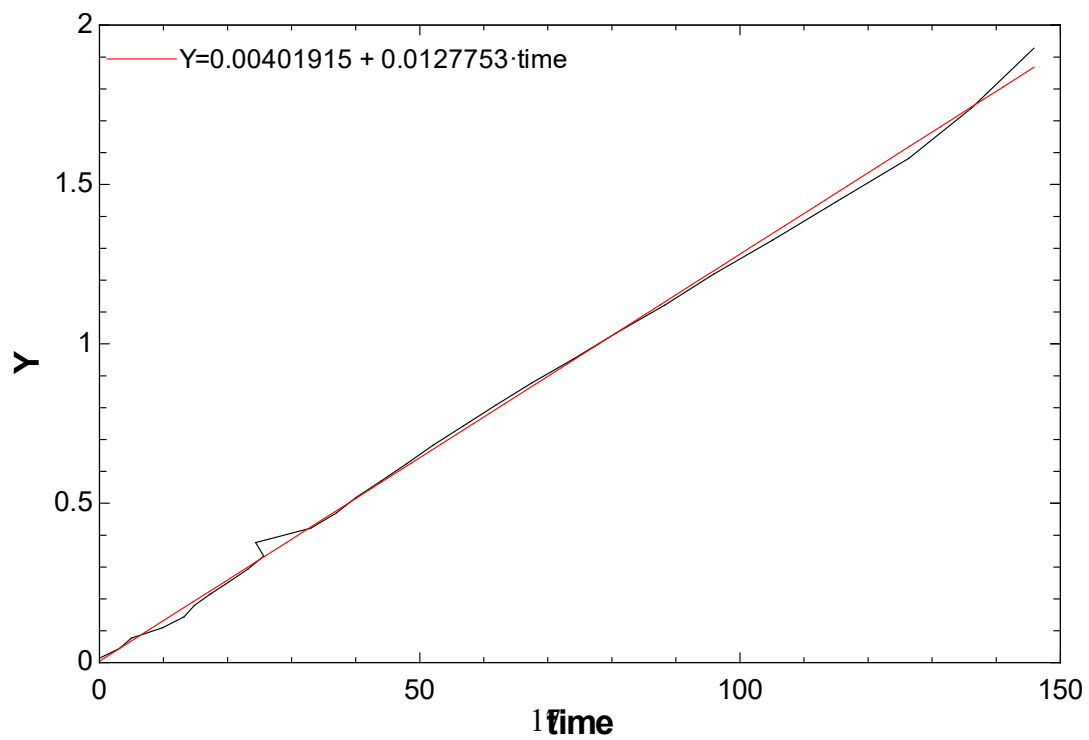
	77.2917	80
	75.905	82
	74.3538	84
	73.0656	86
	71.8059	88
	70.3635	90
	69.1491	92
	67.7938	94
	66.6299	96
	65.4987	98
	64.231	100
	63.1726	102
	61.9812	104
	60.9865	106
	59.8865	108
	58.9216	110
	58.0398	112
	57.1522	114
	56.2381	116
	55.2544	118
	54.4546	120
	53.4987	122
	52.6855	124
	51.8232	126
	51.0614	128
	50.2497	130
	49.5304	132
	48.7585	134
	48.0656	136
	47.4248	138
	46.8145	140
	46.1026	142
	45.4862	144
	44.8921	146
	44.2417	148
	43.6942	150
	43.1619	152
	42.5259	154
	42.0658	156
	41.4801	158
	40.994	160
	40.5541	162
	40.1259	164
	39.582	166
	39.188	168
	38.7001	170

1.5.1 Plots of Y vs Time

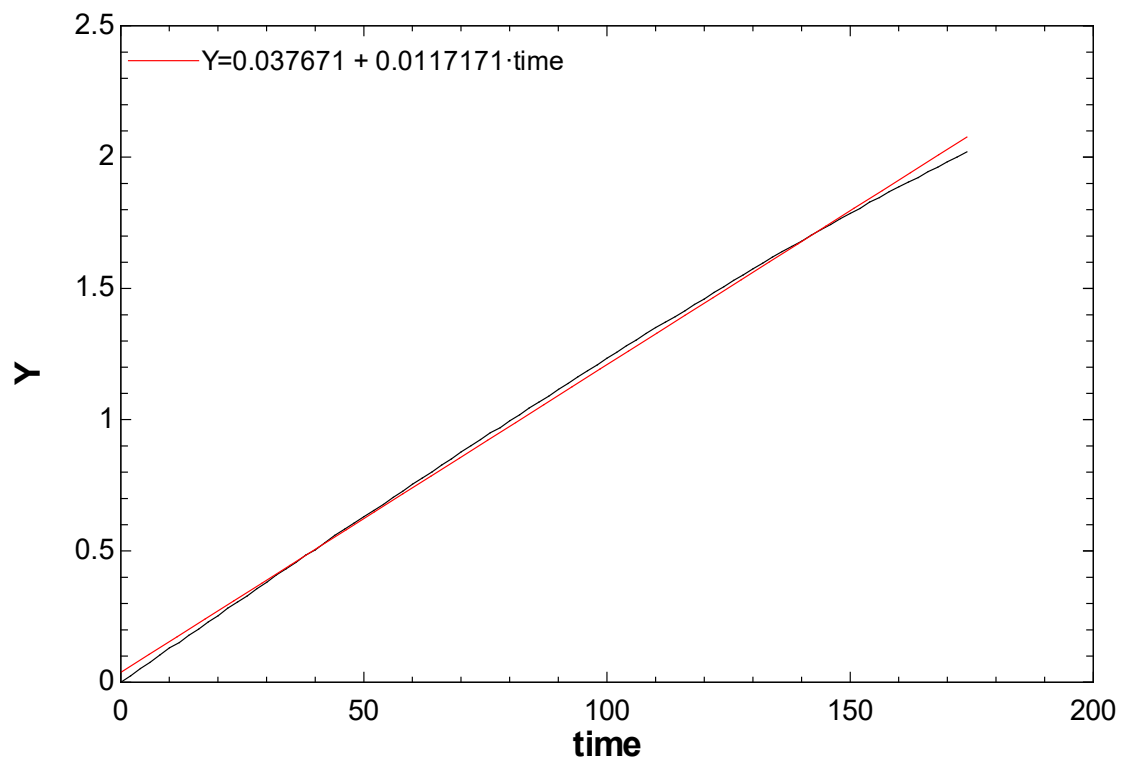
- Y vs time for $v=2$ m/s



- Y vs time for $v=4$ m/s



- Y vs time for $v=6\text{m/s}$



CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

This chapter contains a detailed sample analysis using the Engineering Equation Solver (EES) program, the results of the sample analysis, uncertainty in selected computed results, and the analysis results of the other data computed using solve table feature of EES.

2.1 Detailed Sample Analysis

The detailed sample analysis was done using the collected data from the experiment. Below is the detailed step by step analysis done using the EES program.

Density, specific heat and conductivity of brass is calculated using EES functions. Experimental heat transfer coefficient is calculated using formula given above in first section. Detailed calculation of Nusselt number and biot number according to standard equations can also be seen in the image below.

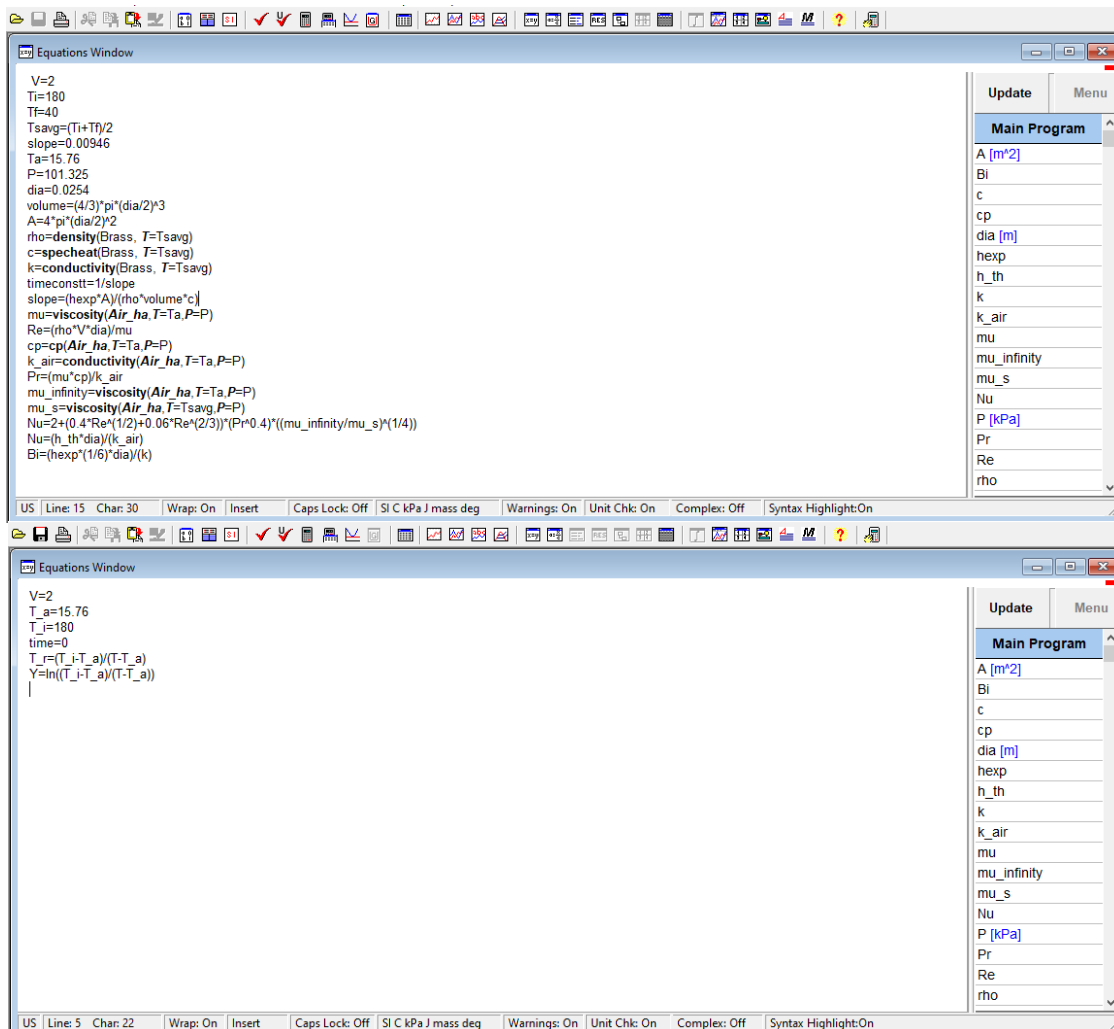


Figure 2.1 Formatted EES Program Equation

2.2 Sample Solution Results with Units

Table 2.1 presents the EES sample analysis solution for all the raw and computed variables in alphabetical order. The units are also shown on each variable.

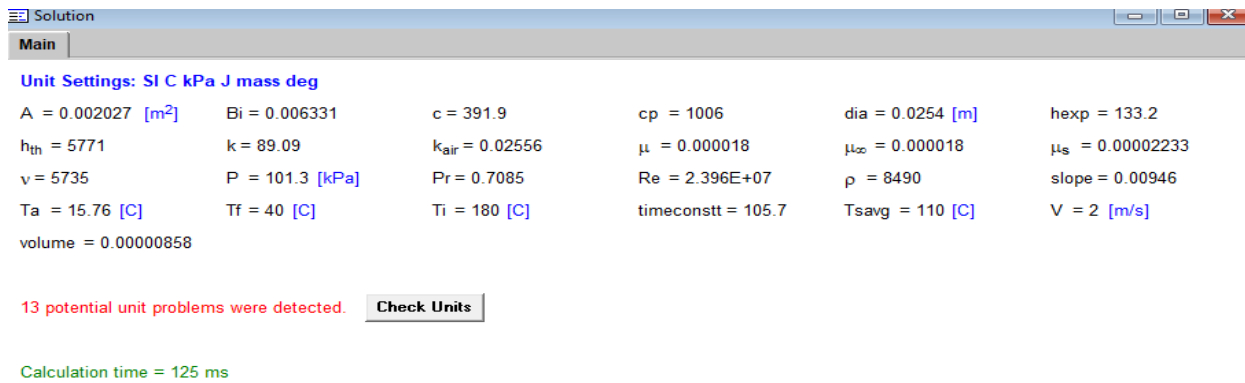


Figure 2.2

Resulting Solution Answers of Sample Analysis

2.3 Uncertainty Analysis of Major Computed Variables

The uncertainty in this experiment is provided in this section considering different instrument used to measure the raw data.

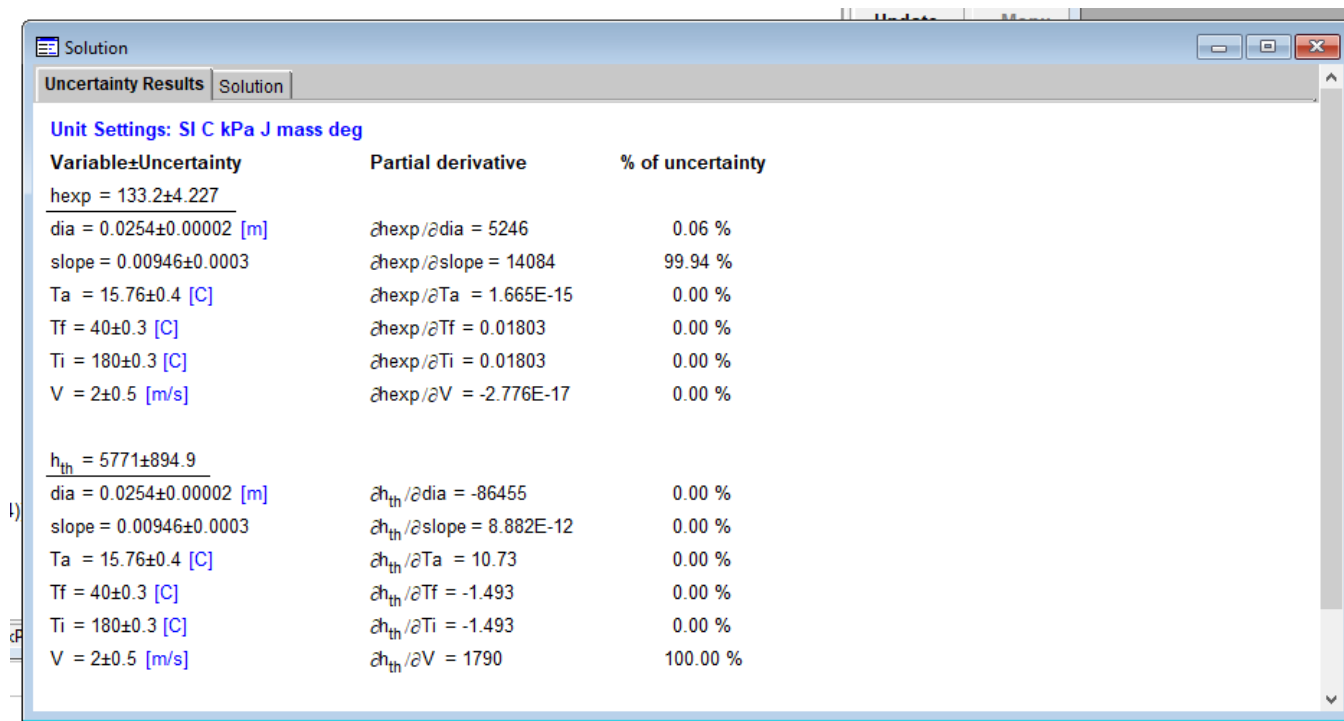


Figure 2.3 Uncertainty Results

2.4 Presentation of Tables of Derived Results

Table 2.2 summarize the results of enthalpies (h_{exp} , h_{theory} , Nu, Bi, Re and time constt) solved using EES. At different velocities these values were calculated. The calculations of each and every quantity were done and the summary of all the results are as follows.

Table 2.2 Summary Results

Velocity (m/s)	T_i Units: C	T_f Units: C	Slope	h_{exp}	h_{theory}	Nu	Re	Bi	τ
2	180	40	0.00946	133.2	5771	5735	2.4E+07	0.006331	105.7
4	180	40	0.01277	179.9	8877	8822	4.79E+07	0.008546	78.31
6	182.3	37.86	0.0117	164.8	11435	11364	7.19E+07	0.00783	85.47

CHAPTER 3

3. ABILITY TO INTERPRET EXPERIMENTAL DATA

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by

Each Graph/Figure:

Provided below is the relationship between P vs v for the refrigeration system experiment. The graph below is shown as follows: pressure is represented in the y-axis plotted against the specific volume in the x-axis.

Heat Transfer Coefficient vs Air Speed

The experimental and theoretical heat transfer coefficients ($\text{W/m}^2\text{-oC}$) versus the air speed in m/s on the same graph

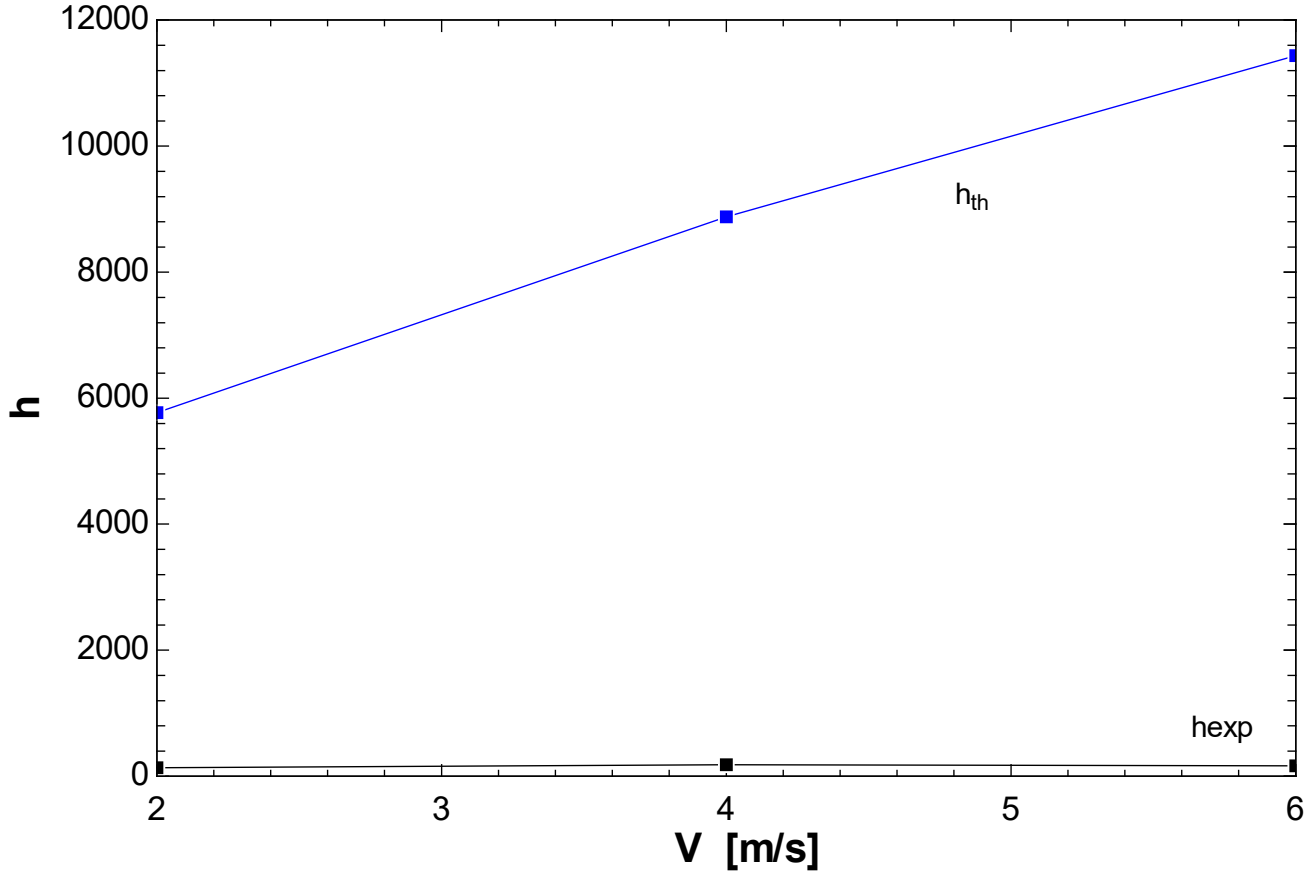
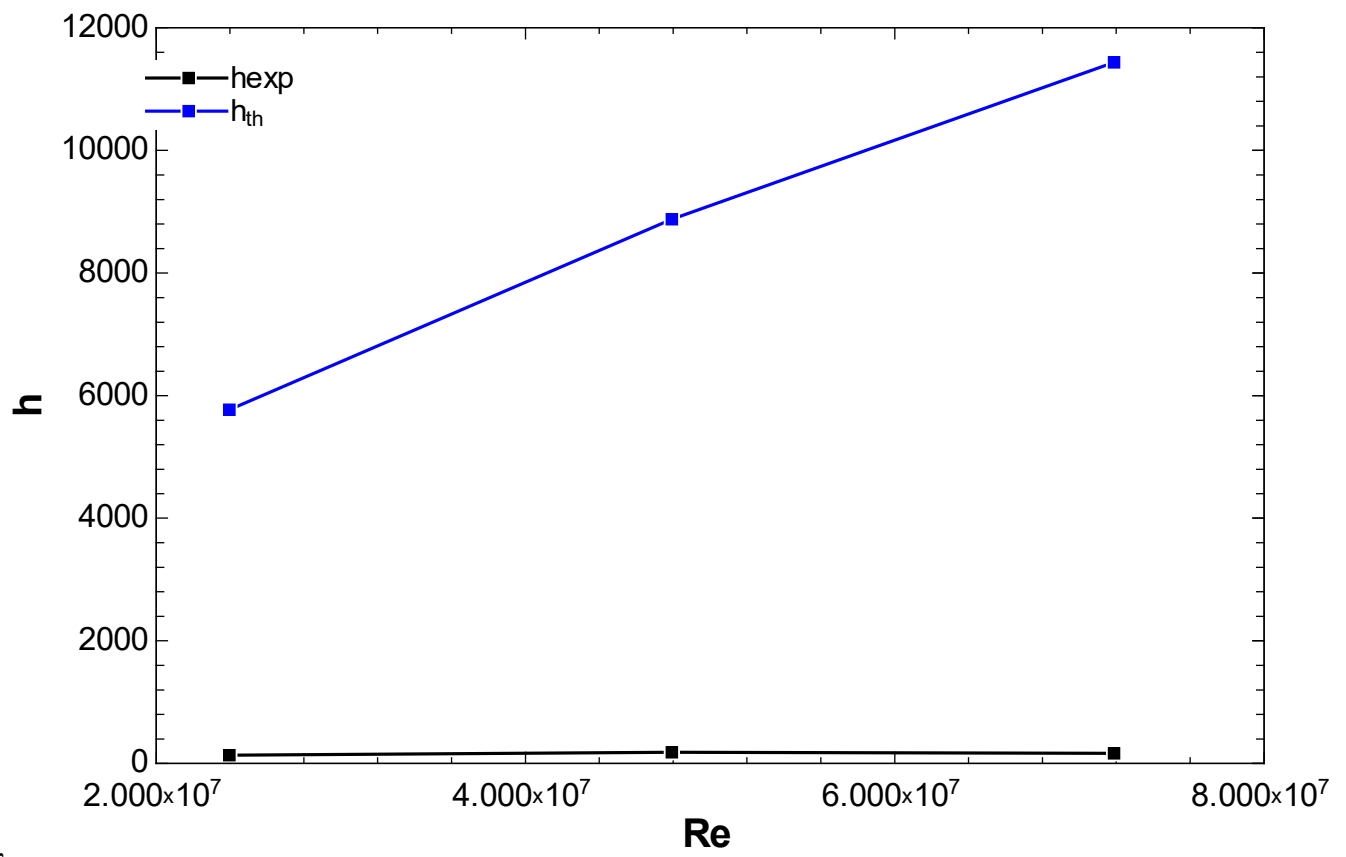


Figure 3.1 theoretical heat transfer coefficients versus the air speed

From the above graph it can be observed that as velocity of air increases heat transfer coefficient also increases. The trend is same for both experimental and theoretical results. It is because with increase in velocity more molecules of air come into contact with the surface and Reynold number increases. As a result, Nusselt number and heat transfer increases.

Heat Transfer Coefficient vs Reynolds Number

The experimental and theoretical heat transfer coefficients versus the Reynolds number on the same



graph,

Figure 3.2 theoretical heat transfer coefficients versus the Reynolds number

Theoretically, heat transfer coefficient and nusselt number have direct relationship which in turn have direct relationship with reynolds number. Same trend can be observed from above graph for both experimental and theoretical results.

Time Constant vs Air Speed

The time constant versus the air speed

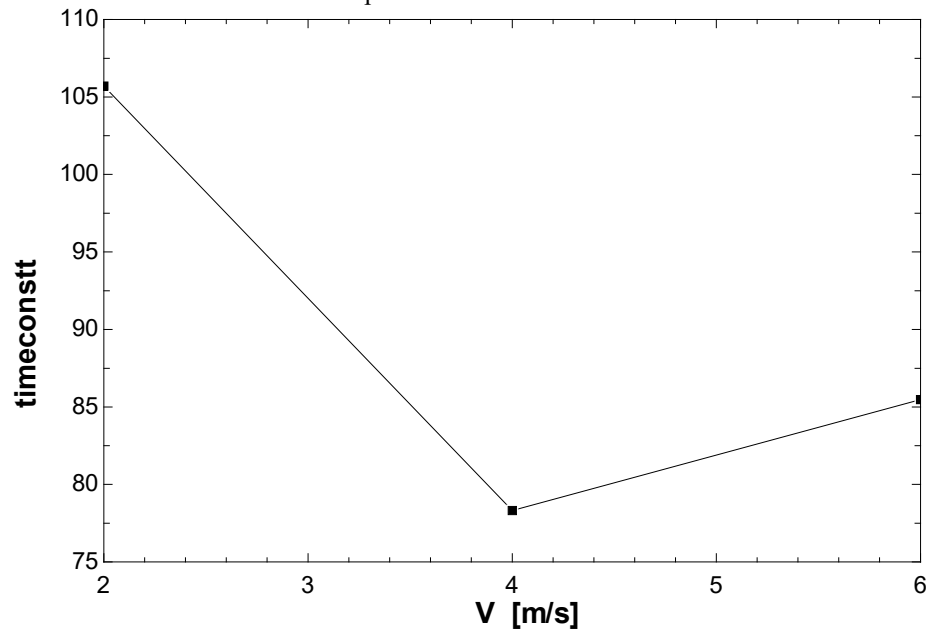


Figure 3.3 time constant versus the air speed

The formula for time constant is $\tau = \left[\frac{\rho \theta C}{hA} \right]$. So time constant have inverse relationship with heat transfer coefficient.

Heat transfer coefficient increases with increase in velocity so time constant should decrease with increase in velocity of fluid. Same trend can be observed from the graph above.

Heat Transfer Coefficient vs Biot Number

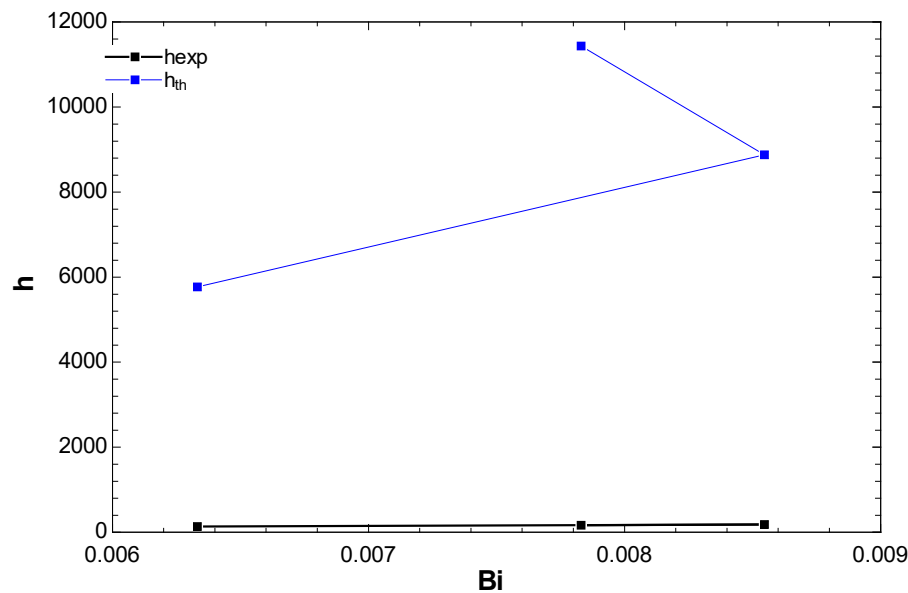


Figure 3.4 theoretical heat transfer coefficients versus the Biot number

Biot number increases with increase in heat transfer coefficient. Because theoretically biot number is directly related to

heat transfer coefficient.

3.2 Conclusions Based on each Objective and Results:

In this experiment, slope units, experimental and theoretical heat transfer co-efficient, Reynold number, Nusselt number, Biot number and time constant were calculated. The graphs between h -Re, h -v, h -Bi, Time constant - velocity were also plotted which indicated the state points and their corresponding path. Trend for Theoretical enthalpy was observed which showed highly deviated from that of experimental. This may be due to any experimental errors or probably due to not properly achieving the steady states.

3.3 Recommendations:

The first recommendation is to produce more stable conditions and temperature within the laboratory. This is crucial for the results of the experiment to be as accurate as possible, as inconsistency in measurements will cause for the graph readings to be incorrect. The second recommendation would be to make sure the wind tunnel velocity is properly set and ensure sphere is properly set in it. The heat transfer coefficient of the system is directed by several sub-steps before the system is operated, so it is important that all settings are verified to record the correct measurements.



REFERENCES:

- [1] Chapman, Allan; Heat Transfer, Fourth Edition, McMillan Publishing Company, New York
- [2] Experimental Methods for Engineers by J. P. Holman, 7th Edition, McGraw Hill
- [3] Engineering Equation Solver (EES) for Microsoft Windows

BELOW AVERAGE

MECHANICAL ENGINEERING DEPARTMENT PRAIRIE



VIEW A&M UNIVERSITY

**MCEG 3021 THERMAL SCIENCE
LABORATORY**

Fall 2021

LABORATORY REPORT ON

**“MEASUREMENT OF HEAT TRANSFER COEFFICIENT
FOR FORCED CONVECTION USING THE LUMPED CAPACITY
METHOD”**

**Conducted on
October 27, 2021**

**Submitted by
Devonte Mitchell**

**On
November 10, 2021**

To

Dr. Shahin Shafiee
Thermal Science Laboratory Instructor

**MECHANICAL ENGINEERING DEPARTMENT
THERMAL SCIENCE LABORATORY
LABORATORY GRADING SHEET
FALL 2021 SECTION P01**

Title of Experiment: Measurement of Heat Transfer Coefficient For Forced Convection using the Lumped Capacity Method

Name: Devonte Mitchell

Date Lab was Performed: October 27, 2021 Report Due Date: November 10, 2021

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (your conduct and observations).	3		
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
<u>Percentage for this Performance Criteria</u>			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report) Front End of Report (4 points). General report format (4 points)	4 4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters Correct solutions with consistent units and significant figures.	12 10		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw /derived) in tabular form to meet the objectives and to aid in plotting the results interpretation.	4		

Ability to present the data (raw /derived) in well labeled graphical form to meet the objectives and to aid in interpretation.	10		
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends. (Interpretation of experimental data & results) Effect of independent (X-axis) variable on the dependent (Y-axis variable). 4 Points Effect of parametric variable change on the dependent (Y-axis variable). 4 Points Comparison of experimental results with theoretical results/prediction/trend. 4 Points Statement on goodness or reasonableness of results. 2 Points	14		
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		
Percentage for this Performance Criteria			
TOTAL FOR THIS LAB			

Letter of Transmittal

November 10, 2021

Dr. Shahin Shafiee
Mechanical Engineering Department
Prairie View A&M University

Dear Dr. Shafiee:

The attached technical laboratory report contains the detailed results of the Measurement of Heat Transfer Coefficient For Forced Convection using the Lumped Capacity Method laboratory work done on October 27, 2021. The report contains the objectives of the experiment, the theory on the Measurement of Heat Transfer Coefficient For Forced Convection, the equations used for analysis of the data, the raw experimental data, graphical presentation of the important results, discussion and interpretation of the results and recommendations.

Please contact me at 832-332-1811 or by e-mail at dmitchell60@pvamu.edu if you have any questions on the report.

Sincerely,

Devonte Mitchell

Abstract

1. The purpose of the experiment

The purpose of the experiment was to measure the heat transfer coefficient for forced convection around a sphere using the lumped capacity method, and determine the effects of velocity and Reynolds number on the heat transfer coefficient. Also to compare the experimental results with the values from theoretical prediction.

2. The brief description of method used

The experiment was conducted using a metal sphere and a wind tunnel. First, the metal sphere was heated to a certain temperature then placed into the wind tunnel, all while it's temperature was being calculated, as the sphere's temperature dropped down to the next desired temperature.

3. The significant results of the tests

The significant results of the experiment were that the sphere's temperature took some time to heat up, but once placed in the wind tunnel, the temperature dropped very fast. As the velocities increased the temperature dropped at faster rates.

4. The major conclusions drawn from the results

In conclusion, as you increase the velocity flow, the time that the temperature takes to decrease, increases. The sphere took longer to heat up than it took to cool off after being placed into the wind tunnel.

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

The experimental objectives and the theory associated with boiling heat transfer are discussed in this chapter in addition to the detailed experimental procedure and the data collected during the experiment. Other topics discussed in this section include the uncertainties in the measured variables and safety issues observed during the lab.

1.1 Objectives of the Experiment

The objectives of this experiment are to:

1. Provide a visual demonstration of the three modes of boiling.
2. Measure the physical variables needed and to determine the heat flux and surface heat transfer coefficient at constant pressure during pool boiling
3. Determine the effects of temperature difference on the experimental and theoretical boiling heat transfer coefficients and the heat flux.
4. Determine the effect of pressure on the experimental and theoretical boiling heat transfer coefficients and the heat flux.
5. Investigate the effects of pressure on the critical heat flux.

1.2 Theory Associated with Experiment

Consider an object at an initial temperature T_i being cooled by a fluid stream at a temperature T_a . If the object has high thermal conductivity, then its internal resistance to heat flux is small. This means that the temperature profile within the object is uniform and everywhere equal (or almost equal) to the surface temperature. At any instant in time, there is no temperature gradient within the object, only a temperature difference between the surface and the free stream. The heat transfer between the object and the fluid is controlled almost exclusively by the surface resistance i.e., the value of convective heat transfer coefficient h . The heat transfer process, in this case, is known as Newtonian cooling (or heating). Because the temperature does not change (significantly) within the solid, and the heat transfer model can be formulated by performing an energy balance on the object.

The rate at which the internal energy of mass is changing = Rate at which heat energy is transferred from the surface to the free stream

$$\frac{dU}{dt} = -hA(T - T_a) \quad (1)$$

$$mc \frac{dT}{dt} = -hA(T - T_a) \quad (2)$$

Using the initial condition at $t = 0$, $T = T_i$ and integrating equation (2) results in the lumped capacity equation.

$$\frac{T - T_a}{T_i - T_a} = \text{Exp} \left[-\frac{hA}{\rho \mathcal{V} C} t \right] \quad (3)$$

$$\text{Or } \frac{T_i - T_a}{T - T_a} = \text{Exp} \left[\frac{hA}{\rho \mathcal{V} C} t \right]$$

Taking the log of both sides, we get

$$\ln \left[\frac{T_i - T_a}{T - T_a} \right] = \frac{hA}{\rho \vartheta C} t \quad (4)$$

where

T = temperature of the object at any time

T_a = Temperature of the free stream or the ambient air

T_i = the initial temperature of the object

h = the average convective heat transfer coefficient (being determined from the experiment)

A = the surface area of the object ($4\pi R^2$ for sphere)

C = the specific heat of the object

ρ = the density of the object

ϑ = the volume of the object

The quantity $\tau = \left[\frac{\rho \vartheta C}{hA} \right]$ is called the time constant.

A plot of $\ln \left[\frac{T_i - T_a}{T - T_a} \right]$ vs t will thus be a straight line with a slope of $\left[\frac{hA}{\rho \vartheta C} \right]$.

Thus measuring the slope of the line and equating the slope to $\left[\frac{hA}{\rho \vartheta C} \right]$ will enable h to be computed.

The convective heat transfer coefficient, h , strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent).

In convection, it is a common practice to non-dimensionalize the governing equations and combine the variables which group together into dimensionless numbers.

Nusselt number, the non-dimensional heat transfer coefficient, is defined as $Nu = h\delta/k$,

where δ is the characteristic length, i.e., D for tubes and L for flat plates. Nusselt number represents the enhancement of heat transfer through a fluid as a result of convection relative to conduction across the same fluid layer.

Reynolds number: the ratio of inertia forces to viscous forces in the fluid.

$Re = \text{inertia forces} / \text{Viscous forces} = \rho V \delta / \mu = V \delta / \nu$

At large Re numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces; thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid (turbulent regime).

Prandtl number: is a measure of the relative thickness of the velocity and thermal boundary layer.

$Pr = \text{molecular diffusivity of momentum} / \text{molecular diffusivity of heat} = \nu / \alpha = \mu C_p / k$

Flow over a cylinder:

The characteristic length for a circular tube or sphere is the external diameter, D , and the Reynolds number is defined as $Re = \rho V_\infty D / \mu$.

For flow over sphere, Whitaker recommended the following:

$Nu_{\text{sph}} = hD/k = 2 + [0.4 Re^{1/2} + 0.06 Re^{2/3}] Pr^{0.4} (\mu_\infty / \mu_s)^{1/4}$

The above equation is valid for $3.5 < Re < 80000$ and $0.7 < Pr < 380$. The fluid properties are evaluated at the free stream temperature T_∞ , except for μ_s which is evaluated at the surface temperature.

1.3 Apparatus and Uncertainty in Reading Instruments

The experimental setup using the Hilton Boiling Heat Transfer Unit is shown in Figure 1.2. Variable Speed Small Diameter Wind Tunnel, Mantle heater, metal sphere, thermocouple wire, thermocouple read-out, stop watch,

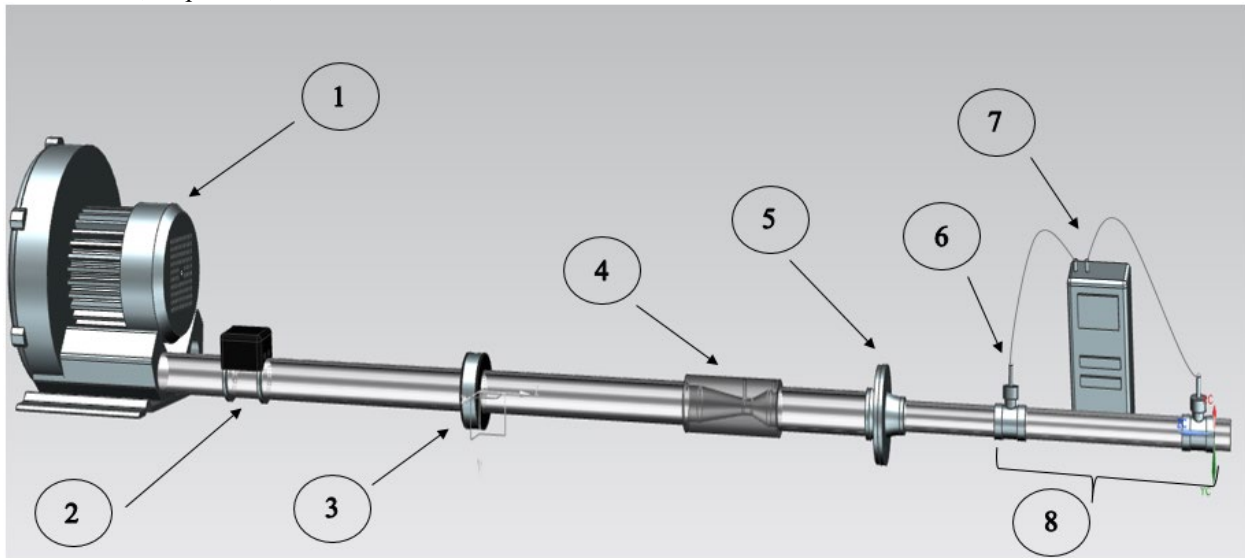


Figure 1. Experimental apparatus for measuring heat transfer coefficient using the lumped capacity method.

Table 1.1 Uncertainty in Reading Experimental Variables on Instruments.

Name of Instrument	Variable Read Using Instrument and Units	Uncertainty in Reading the Instrument and Units

1.4 Experimental Safety

After observing the experimental setup, it became clear that the set-up included a very hot surface, that if touched without any equipment, then serious burns could be caused. The safety precautions that should be taken when running the experiment include ensuring that the students wear appropriate safety equipment and follow safety protocols when handling hot objects. The major safety concerns during the experiment were that there were a lot of chairs in the immediate vicinity of the set-up and since students were not supposed to sit down during the experiment, the chairs could pose a hazard in case of emergency and so should be moved from the vicinity of the experiment.

1.5 Experimental Procedure

Forced convection:

1. Measure the room temperature T_a , the diameter of the metal sphere if not provided (either aluminum or brass), the

mass, and then calculate the volume and the density of the metal sphere.

2. Heat the metal sphere in an oven (to 200 -220°C).

3. While step 2 is being carried out, start the wind tunnel and adjust the RPM control to obtain an air speed of 2 m/s or at the appropriate speed as indicated in step 7.

4. When the temperature of the metal in the oven reaches the prescribed temperature in step 2, remove the steel sphere from the oven.

5. With the thermocouple connected to the sphere and the thermocouple readout, hang the steel sphere in the air moving in the wind tunnel and measure the initial temperature, T_i (at 180°C) at time 0 sec (start the timer).

6. Record the time at every 4°C or as listed in the table for $V = 2$ m/s, every 5°C or as listed in the table for $V = 4$ m/s, and every 10°C or as listed in the table for $V = 6$ m/s change in temperature of the body until the temperature reaches the last temperature listed in the data table.

7. Repeat steps 2 through 6 for 4 m/s and 6 m/s.

CALCULATIONS:

There are two major parts of your EES main program. The first part is the raw data processing to obtain the slope of the

$\ln \left[\frac{T_i - T_a}{T - T_a} \right]$ vs t plot for all velocity conditions in experiments performed. The second part is to obtain experimental and theoretical heat transfer coefficients, as well as other data in Table 2.

Part I Raw data processing

1. Set your energy units in EES to Joules (J).

2. Input the ambient temperature T_a and initial temperature T_i .

3. Convert time to seconds. Using the first-row data, input T and Time. Note that these two inputs will be commented when you "Calculate Table" later.

4. Compute $T_r = \left[\frac{T_i - T_a}{T - T_a} \right]$.

5. Compute $Y = \ln \left[\frac{T_i - T_a}{T - T_a} \right]$.

6. Create a parameter table that includes Time, T , T_r , and Y .

7. Copy your raw data from the Excel Spreadsheet to columns Time and T .

8. Solve for T_r and Y in the table.

9. Plot Y vs. Time.

10. Add a linear curve fit to the plot generated in Step 9 and show the equation in your plot. Record the slope obtained in the curve fit, and this slope will be one of your inputs in Table 2.

11. Repeat Steps 2 to 10 for each of the remaining sets of data at $V = 4$ and 6 m/s.

12. The three plots of Y vs Time with a curve fit equation on each plot should be your raw data. Please include these plots in Section 1.6 of your Lab Report as the raw experimental data.

Part II Compute h_{exp} , h_{theory} , and other results listed in Table 2.

13. After you obtain three slopes in Part I, you can now comment all codes in Part I. (Note that do not delete these codes since you are expected to show them in the formatted equation part in your report.)

14. Input the following raw data: V , T_i , T_f , and slope for $V = 2$ m/s.

15. Input the ambient temperature T_a .

16. From the diameter of the metal sphere, calculate the volume $\mathcal{V}$ and surface area A .

17. Find the following properties for the metal sphere using EES: density ρ , specific heat C , and thermal conductivity k . The metal properties should be evaluated in EES using T_{avg} , which is the average of the initial temperature, T_i and the final temperature T_f of the sphere.

18. Use the slope to compute the time constant: $\tau = 1/\text{slope}$.

19. Equate the slope to $\left[\frac{h_{exp} A}{\rho \mathcal{V} C} \right]$ and calculate the average heat transfer coefficient h_{exp} .

20. Compute Reynolds number, Nusselt number, and theoretical values of the heat transfer coefficients (depending on value of V). Use appropriate temperatures (T_a or T_{avg}) to find properties of the air in the Whitaker correlation and other

relevant equations. Use $P_a = 101.325 \text{ kPa}$ for the atmospheric air pressure. (Hint: The Reynolds number should be based on the diameter of the sphere and the stream velocity of the air.)

21. Calculate the Biot Number.
22. Generate a table similar to that shown in Table 2. Note that T_i , T_f , and Slope should be the inputs in Table 2 and the rest of the parameters are computed results.
23. Plot the experimental and theoretical heat transfer coefficients ($\text{W/m}^2\text{-}^\circ\text{C}$) versus the air speed in m/s on the same graph, and label each curve appropriately.
24. Plot the experimental and theoretical heat transfer coefficients versus the Reynolds number on the same graph, and label each curve appropriately.
25. Plot the time constant versus the air speed.
26. Plot the Biot Number versus the experimental and theoretical heat transfer coefficients on the same graph, and label each curve appropriately.
27. Compute uncertainties for experimental heat transfer coefficient h_{exp} and theoretical heat transfer coefficient h_{theory} .
28. Prepare and submit your report following the standard report format. When you include your EES program in the Lab Report, please make sure your program is written in the following sequence: Part I (Steps 1-12) and Part II (Steps 13-21).



A. Observation of Convective, Nucleate and Film Boiling.

1. After setting up the equipment, the heat input to the metal surface and cooling for the vapor were both set at low levels.
2. The liquid surrounding the metal surface was carefully watched. The convection currents were observed, and at the same time the liquid was watched as it was condensed on the condenser coils, indicating that vaporization was proceeding although at a low rate.
3. A picture of the observation was drawn and this convective boiling phenomenon was described in Row 1 of Table 1.1 of Observed Results
4. The heat input was increased, keeping the vapor pressure at any desired value. Nucleate boiling soon started increased until vigorous boiling was seen. A picture of the bubbles surrounding the metal surface was shown in Row 2 of the Table 1.1 of Observed Results.
5. The heat input power was increased further while keeping the vapor pressure constant, until the nature of boiling changed dramatically which time the metal-liquid temperature difference rose quickly. The heat input cut off automatically by safety device. Reduced the heat input was reduced to a proper value and waited for equilibrium condition.
6. Careful examination of metal surface showed that it was enveloped in an almost unbroken film of vapor. A picture of the bubbles surrounding the metal surface was taken using a digital camera. 7.

Table 1.2. Computed Results for Heat Transfer Coefficients.

Velocity (m/s)	T_i Units:	T_f Units:	Slope Units:	h_{exp}	h_{theory}	Nu	Re	Bi	
2									
4									
6									

1.6 Raw Experimental Data



Table 1.3 Table of Raw Experimental Data.

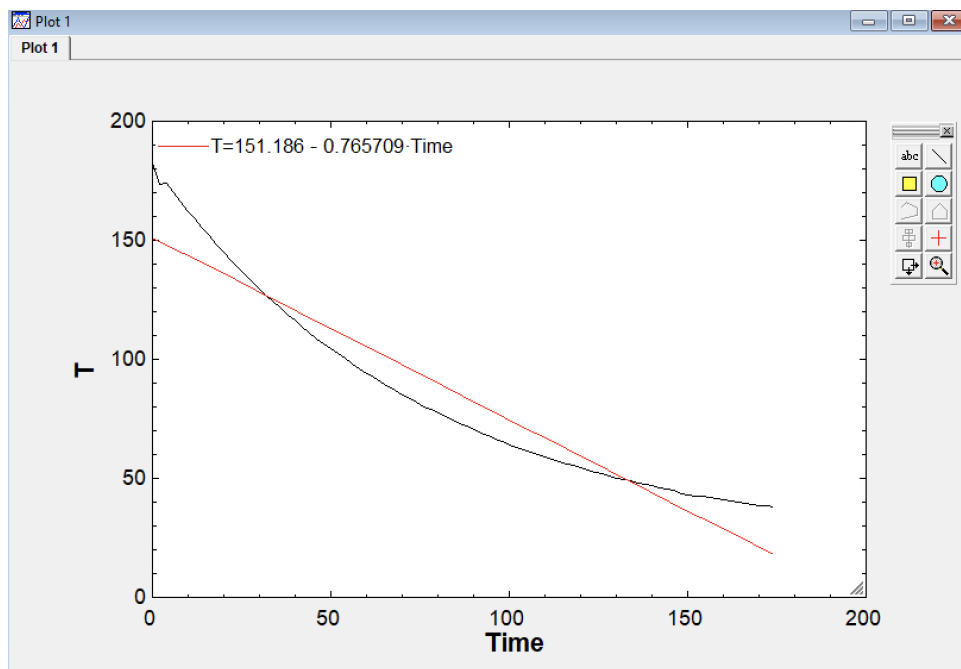


Table 1.4 Table of Raw Experimental Data Continued

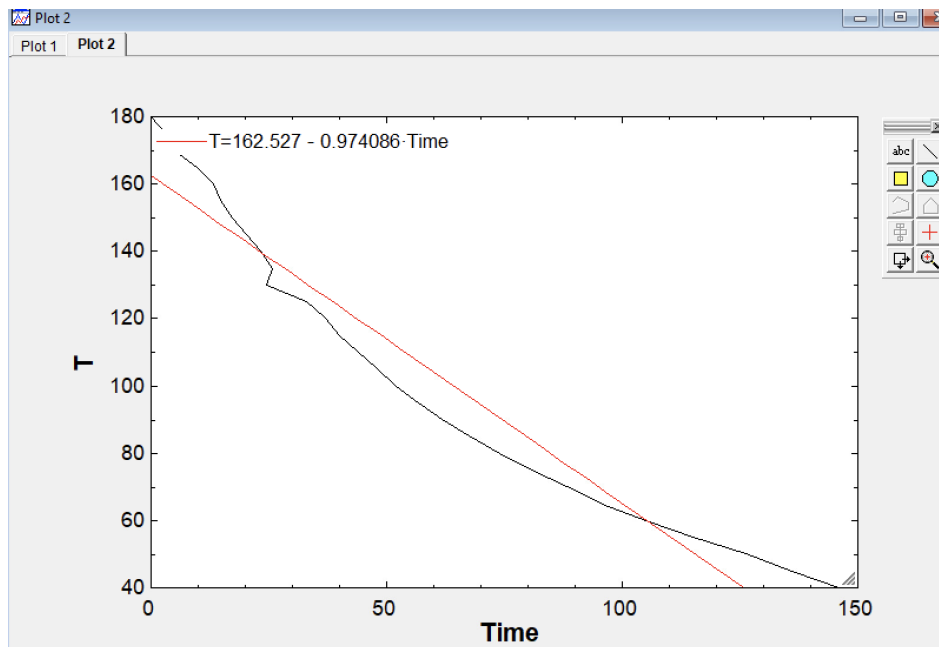
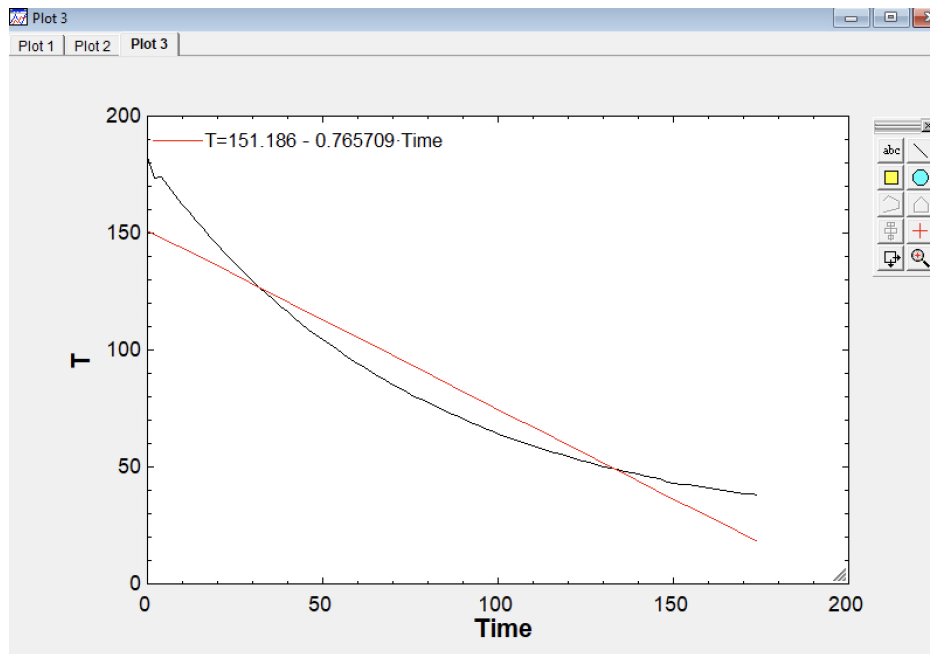


Table 1.5 Table of Raw Experimental Data Continued



CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

This chapter contains a detailed sample analysis using the Engineering Equation Solver (EES) program, the results of the sample analysis, uncertainty in selected computed results, and the analysis results of the remaining data computed using the Solve Table feature of EES.

2.1 Detailed Sample Analysis

The detailed sample analysis was done using the first row data in Table 2.1. The step by step analysis done using the EES program [2] is provided sequentially and in detail below. All the variables have their definitions as provided in the theory section of the report.

Figure 2.1 Formatted EES Program Equation



Formatted Equations

$$T_a = 20$$

$$T_i = 180$$

$$T = 180$$

$$\text{Time} = 1$$

$$Tr = \frac{T_i - T_a}{T - T_a}$$

$$Y = \frac{\ln(T_i - T_a)}{T - T_a}$$

2.2 Sample Solution Results with Units

The EES sample analysis solution is provided Table 2.1 for all the raw and computed variables in alphabetical order. The units are also shown on each variable.

Table 2.1 Results for V=2m/s

1.29	1 Time	2 T	3 Tr	4 Y
Run 1	0	180	1	0.03172
Run 2	3.23	175	1.032	0.03274
Run 3	7.06	170	1.067	0.03383
Run 4	10.12	165	1.103	0.035
Run 5	12.9	160	1.143	0.03625
Run 6	17.01	155	1.185	0.03759
Run 7	20.04	150	1.231	0.03904
Run 8	24.41	145	1.28	0.0406
Run 9	28.97	140	1.333	0.04229
Run 10	33.01	135	1.391	0.04413
Run 11	36.87	130	1.455	0.04614
Run 12	41.11	125	1.524	0.04833
Run 13	46.05	120	1.6	0.05075
Run 14	51.05	115	1.684	0.05342
Run 15	56	110	1.778	0.05639
Run 16	61.97	105	1.882	0.05971
Run 17	68.11	100	2	0.06344
Run 18	73.11	95	2.133	0.06767
Run 19	80	90	2.286	0.0725
Run 20	87.47	85	2.462	0.07808
Run 21	95.06	80	2.667	0.08459
Run 22	104	75	2.909	0.09228

Table 2.2 Results for V=2m/s continued

Table 1	1 Time	2 T	3 Tr	4 Y
1.29				
Run 8	24.41	145	1.28	0.0406
Run 9	28.97	140	1.333	0.04229
Run 10	33.01	135	1.391	0.04413
Run 11	36.87	130	1.455	0.04614
Run 12	41.11	125	1.524	0.04833
Run 13	46.05	120	1.6	0.05075
Run 14	51.05	115	1.684	0.05342
Run 15	56	110	1.778	0.05639
Run 16	61.97	105	1.882	0.05971
Run 17	68.11	100	2	0.06344
Run 18	73.11	95	2.133	0.06767
Run 19	80	90	2.286	0.0725
Run 20	87.47	85	2.462	0.07808
Run 21	95.06	80	2.667	0.08459
Run 22	104	75	2.909	0.09228
Run 23	113.2	70	3.2	0.1015
Run 24	125	65	3.556	0.1128
Run 25	136.4	60	4	0.1269
Run 26	150	55	4.571	0.145
Run 27	164.9	50	5.333	0.1692
Run 28	183.2	45	6.4	0.203
Run 29	204.8	40	8	0.2538

Table 2.3 Results for V=4m/s

Table 1	Table 2			
1.29	1 Time	2 T	3 Tr	4 Y
Run 1	0	180	1	0.03172
Run 2	3.12	175	1.032	0.03274
Run 3	4.98	170	1.067	0.03383
Run 4	9.82	165	1.103	0.035
Run 5	13.2	160	1.143	0.03625
Run 6	14.78	155	1.185	0.03759
Run 7	17.35	150	1.231	0.03904
Run 8	20.25	145	1.28	0.0406
Run 9	23.15	140	1.333	0.04229
Run 10	25.65	135	1.391	0.04413
Run 11	24.38	130	1.455	0.04614
Run 12	32.98	125	1.524	0.04833
Run 13	36.9	120	1.6	0.05075
Run 14	39.98	115	1.684	0.05342
Run 15	43.9	110	1.778	0.05639
Run 16	47.93	105	1.882	0.05971
Run 17	52.06	100	2	0.06344
Run 18	56.85	95	2.133	0.06767
Run 19	61.85	90	2.286	0.0725
Run 20	67.45	85	2.462	0.07808
Run 21	74.01	80	2.667	0.08459
Run 22	80.65	75	2.909	0.09228

Table 2.4 Results for V=4m/s Continued

Table 1	Table 2			
1.29	1 Time	2 T	3 Tr	4 Y
Run 8	20.25	145	1.28	0.0406
Run 9	23.15	140	1.333	0.04229
Run 10	25.65	135	1.391	0.04413
Run 11	24.38	130	1.455	0.04614
Run 12	32.98	125	1.524	0.04833
Run 13	36.9	120	1.6	0.05075
Run 14	39.98	115	1.684	0.05342
Run 15	43.9	110	1.778	0.05639
Run 16	47.93	105	1.882	0.05971
Run 17	52.06	100	2	0.06344
Run 18	56.85	95	2.133	0.06767
Run 19	61.85	90	2.286	0.0725
Run 20	67.45	85	2.462	0.07808
Run 21	74.01	80	2.667	0.08459
Run 22	80.65	75	2.909	0.09228
Run 23	88.24	70	3.2	0.1015
Run 24	95.86	65	3.556	0.1128
Run 25	105.1	60	4	0.1269
Run 26	115	55	4.571	0.145
Run 27	126.4	50	5.333	0.1692
Run 28	136.1	45	6.4	0.203
Run 29	145.9	40	8	0.2538

Table 2.5 Results for V=6m/s

Table 1	Table 2	Table 3		
1..88	Time	T	Tr	Y
Run 64	126	51.8	5.031	0.1596
Run 65	128	51.1	5.145	0.1632
Run 66	130	50.24	5.291	0.1678
Run 67	132	49.53	5.418	0.1719
Run 68	134	48.75	5.565	0.1765
Run 69	136	48.06	5.702	0.1809
Run 70	138	47.42	5.835	0.1851
Run 71	140	46.81	5.968	0.1893
Run 72	142	46.1	6.13	0.1945
Run 73	144	45.48	6.279	0.1992
Run 74	146	44.89	6.428	0.2039
Run 75	148	43.69	6.754	0.2142
Run 76	150	43.16	6.908	0.2191
Run 77	152	42.52	7.105	0.2254
Run 78	154	42.52	7.105	0.2254
Run 79	156	42.06	7.253	0.2301
Run 80	158	41.48	7.449	0.2363
Run 81	160	40.99	7.623	0.2418
Run 82	162	40.55	7.786	0.247
Run 83	164	40.12	7.952	0.2522
Run 84	166	39.58	8.172	0.2592
Run 85	168	39.18	8.342	0.2646

Table 2.6 Results for V=6m/s continued

Table 1	Table 2	Table 3		
1.88	1 Time	2 T	3 Tr	4 Y
Run 43	84	74.4	2.941	0.09329
Run 44	86	73.1	3.013	0.09558
Run 45	88	71.8	3.089	0.09798
Run 46	90	70.4	3.175	0.1007
Run 47	92	69.1	3.259	0.1034
Run 48	94	67.8	3.347	0.1062
Run 49	96	66.6	3.433	0.1089
Run 50	98	65.5	3.516	0.1115
Run 51	100	64.2	3.62	0.1148
Run 52	102	63.17	3.706	0.1176
Run 53	104	61.98	3.811	0.1209
Run 54	106	60.98	3.904	0.1238
Run 55	108	59.88	4.012	0.1273
Run 56	110	58.92	4.111	0.1304
Run 57	112	58.03	4.207	0.1335
Run 58	114	57.15	4.307	0.1366
Run 59	116	56.2	4.42	0.1402
Run 60	118	55.3	4.533	0.1438
Run 61	120	54.5	4.638	0.1471
Run 62	122	53.5	4.776	0.1515
Run 63	124	52.7	4.893	0.1552
Run 64	126	51.8	5.031	0.1596

Table 2.7 Results for V=6m/s continued

Table 1	Table 2	Table 3		
1.88	1 Time	2 T	3 Tr	4 Y
Run 22	42	113.6	1.709	
Run 23	44	110.9	1.76	
Run 24	46	108.7	1.804	
Run 25	48	106.6	1.848	
Run 26	50	104.4	1.896	
Run 27	52	102.4	1.942	
Run 28	54	100.3	1.993	
Run 29	56	98.1	2.049	
Run 30	58	96.2	2.1	
Run 31	60	94.1	2.159	
Run 32	62	92.3	2.213	
Run 33	64	90.5	2.27	
Run 34	66	88.6	2.332	
Run 35	68	86.9	2.392	
Run 36	70	85	2.462	
Run 37	72	83.4	2.524	
Run 38	74	81.9	2.585	
Run 39	76	80.2	2.658	
Run 40	78	78.9	2.716	
Run 41	80	77.3	2.792	
Run 42	82	75.9	2.862	

Table 2.8 Results for V=6m/s continued

Table 1	Table 2	Table 3		
1.88	Time	T	Tr	Y
Run 1	0	182.3	0.986	0.03128
Run 2	2	173.3	1.044	0.03311
Run 3	4	173.9	1.04	0.03298
Run 4	6	170.2	1.065	0.03379
Run 5	8	165.9	1.097	0.03479
Run 6	10	161.8	1.128	0.03579
Run 7	12	158.9	1.152	0.03654
Run 8	14	155	1.185	0.03759
Run 9	16	151.8	1.214	0.03851
Run 10	18	148.1	1.249	0.03962
Run 11	20	144.9	1.281	0.04063
Run 12	22	141.4	1.318	0.04181
Run 13	24	138.5	1.35	0.04283
Run 14	26	135.6	1.384	0.0439
Run 15	28	132.3	1.425	0.04519
Run 16	30	129.6	1.46	0.04631
Run 17	32	126.4	1.504	0.0477
Run 18	34	123.8	1.541	0.04889
Run 19	36	121.3	1.579	0.0501
Run 20	38	118.4	1.626	0.05158
Run 21	40	116.4	1.66	0.05265
Run 22	42	113.6	1.709	0.05422

Table 2.9 Results for V=6m/s continued

Table 1	Table 2	Table 3		
1.88	Time	T	Tr	Y
Run 67	132	49.53	5.418	0.1719
Run 68	134	48.75	5.565	0.1765
Run 69	136	48.06	5.702	0.1809
Run 70	138	47.42	5.835	0.1851
Run 71	140	46.81	5.968	0.1893
Run 72	142	46.1	6.13	0.1945
Run 73	144	45.48	6.279	0.1992
Run 74	146	44.89	6.428	0.2039
Run 75	148	43.69	6.754	0.2142
Run 76	150	43.16	6.908	0.2191
Run 77	152	42.52	7.105	0.2254
Run 78	154	42.52	7.105	0.2254
Run 79	156	42.06	7.253	0.2301
Run 80	158	41.48	7.449	0.2363
Run 81	160	40.99	7.623	0.2418
Run 82	162	40.55	7.786	0.247
Run 83	164	40.12	7.952	0.2522
Run 84	166	39.58	8.172	0.2592
Run 85	168	39.18	8.342	0.2646
Run 86	170	38.7	8.556	0.2714
Run 87	172	38.3	8.743	0.2773
Run 88	174	37.85	8.964	0.2843

2.3 Uncertainty Analysis of Major Computed Variables

The uncertainty in the experimentally calculated heat transfer coefficient computed using the uncertainty analysis in EES for the first row of experimental data is shown in Table 2.2. The uncertainty is about 10.5% of the value of the heat transfer coefficient.

Table 2.2 Results of Uncertainty Analysis for the Experimental Heat Transfer Coefficient

Unit Settings: [J]/[C]/[kPa]/[kg]/[degrees]		
Variable±Uncertainty	Partial derivative % of uncertainty	
h = 851.8±89.83 [W/m ² -C]		
I1 = 0.59±0.01 [Amps]	∂h/∂ I1 = 478.5	0.28 %
I2 = 0.59±0.01 [Amps]	∂h/∂ I2 = 478.5	0.28 %
I3 = 0.6±0.01 [Amps]	∂h/∂ I3 = 478.5	0.28 %
m = 10±1 [kg/s]	∂h/∂ m = 0	0.00 %
Pgauge = 40±5 [kPa]	∂h/∂ Pgauge = 0	0.00 %
T1 = 32±1 [C]	∂h/∂ T1 = 25.81	8.26 %
T2 = 32±1 [C]	∂h/∂ T2 = 25.81	8.26 %
T3 = 32±1 [C]	∂h/∂ T3 = 25.81	8.26 %
Ti = 22.7±1 [C]	∂h/∂ Ti = 0	0.00 %
To = 23.2±1 [C]	∂h/∂ To = 0	0.00 %
Tw = 43±1 [C]	∂h/∂ Tw = -77.44	74.32 %
V = 40±0.1 [Volts]	∂h/∂ V = 21.3	0.06 %

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

This chapter contains graphical representation of the experimental and theoretical results and detailed discussions and interpretation of the experimental results. Following these, concluding remarks are provided based on each experimental objective. The chapter ends with recommendations and an Appendix containing additional information related to the experiment.

3.1 Presentation of Graphs/Figures, Discussion and Interpretation of Results Presented by each Graph/Figure

Figure 3.1 Temperature vs Time Graph

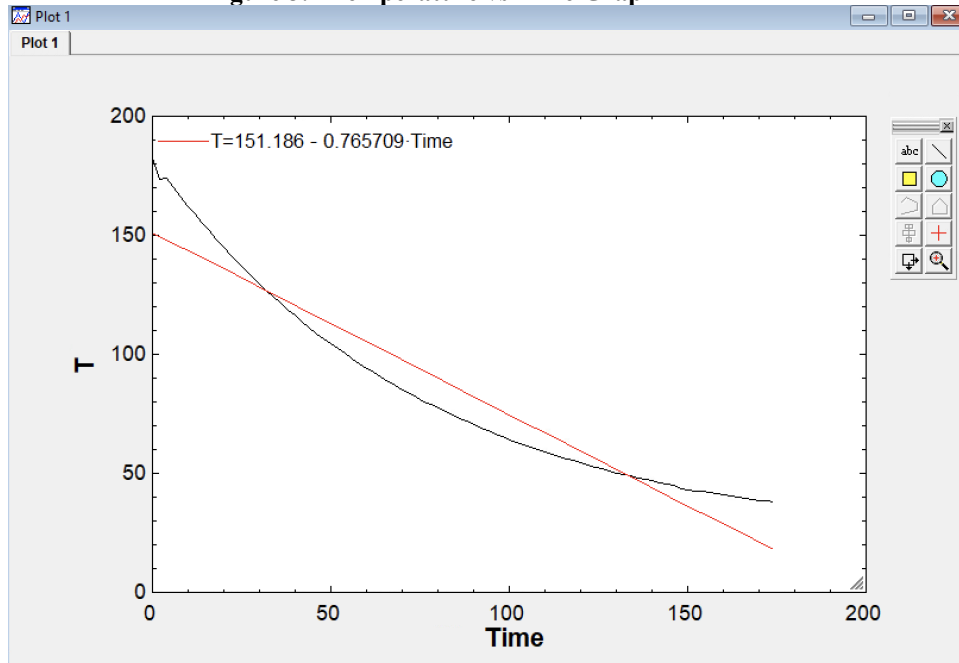


Figure 3.1 shows the effects of the temperature difference vs the time difference from the experiment.

3.2 Conclusions Based on each Objective and the Results

In conclusion, the sphere's temperature, after being heated, cooled off faster with the change in velocity. From velocities two, four, and six, the rate in which the temperature dropped increased as the velocities increased.

3.3 Recommendations

The sphere that was heated could have a more secure handle that could be used to hold the sphere instead of having to use a very small piece of insulated material to pick the sphere up and move it from the heating device to the wind tunnel. There also could be a better spot to place the sphere inside of the wind tunnel, so that there are no gaps in the tunnels for a more accurate reading of the temperature.

REFERENCES

[1] Chapman, Allan; Heat Transfer, Fourth Edition, McMillan Publishing Company, New York [2]
Engineering Equation Solver (EES) for Microsoft Windows, F-Charts Software,



APPENDIX A EES Formatted Equations

This Appendix contains the formatted EES program used to analyze the remaining data using the EES Solve Table feature.

$$T_a = 20$$

$$T_i = 180$$

$$T = 180$$

$$\text{Time} = 1$$

$$Tr = \frac{T_i - T_a}{T - T_a}$$

$$Y = \frac{\ln(T_i - T_a)}{T - T_a}$$

APPENDIX B EES Unformatted Equations

This Appendix contains the unformatted EES program used to analyze the remaining data using the EES .Solve Table feature.

Ta=20

Ti=180

T=180

Time=1

Tr=(Ti-Ta)/(T-Ta)

Y=ln(Ti-Ta)/(T-Ta)

**Thermal Science Lab
Fall 2021**

Title of Assignment: Report 2

TOPICS COVERED IN Report 2

1. Assessing performance of a refrigeration cycle

Repeated this section for each Quiz and Similarly for all the other assignments in the course binder

Ability to Conduct Experiments	MAX	Your Score	Comments
Ability to demonstrate general lab safety (your conduct and observations).	3		
Ability to follow the procedure and to properly rephrase the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment functions, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
Ability to Analyze and Interpret experimental Data in a Formal Report			
Report format (Ability to properly format and present a technical report)			
Front End of Report (4 points).	4		
General report format (4 points)	4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters	12		
Correct solutions with consistent units and significant figures.	10		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw /derived) in tabular form to meet the objectives and to aid in plotting the results.	4		
Ability to present the data (raw /derived) in well-labeled graphical form to meet the objectives and to aid in interpretation.	10		
Ability to discuss the raw and derived data/graphs and assess the validity of the results concerning the underlying theory and expected trends. (Interpretation of experimental data & results)			
Effect of independent (X-axis) variable on the dependent (Y-axis variables). 4 Points			
Effect of parametric variable change on the dependent (Y-axis variable). 4 Points	14		
Comparison of experimental results with theoretical results/prediction/trend 4 Points			
Statement on goodness or reasonableness of results. 2 Points			
Ability to use engineering judgement to draw appropriate and reasonable conclusions in relation to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		
Percentage for this Performance Criteria			
TOTAL FOR THIS LAB	100		

PERFORMANCE OF A REFRIGERATION SYSTEM WITH AEV

INTRODUCTION:

A typical vapor compression refrigeration system has four major components: compressor, condenser, capillary tube or expansion device (automatic expansion valve in this experiment), and evaporator. These are briefly described in the following.

Compressor

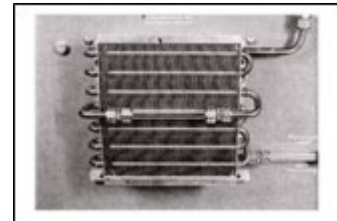
The first process encountered by the refrigerant is an adiabatic compression. refrigerant in the vapor state is compressed to higher pressure in the The compressor is located between states 2 and 1. It is used to increase the temperature of the refrigerant, it should operate with refrigerant vapor only. compression is adiabatic since only work is performed on the vapor and no transferred in or out at this time. However, the compression itself causes a increase in the vapor temperature (based on the Ideal Gas Law).



Here, the compressor. pressure and This heat is dramatic

Condenser

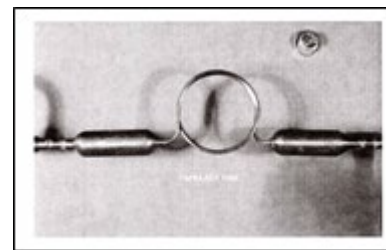
The second process is the transfer of heat out of the refrigerant at pressure (i.e. isobaric process). During this process, the vapor condenses state. This is carried out in the condenser. The condenser is located 1 and 4. It is a heat exchanger to remove heat from the refrigerant vapor condense it into liquid. The heat removed is used to achieve the space required.



constant to the liquid between states in order to heating

Capillary tube

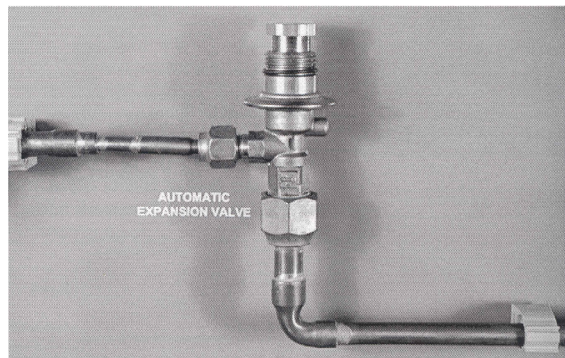
The next process involves what is known as an "isenthalpic the refrigerant from state 4 to state 3. The saturated liquid refrigerant pressure passes through an expansion valve where the pressure is lowered. Because the pressure changes so quickly, a portion of the instantly boils off into vapor (this is also known as "flashing"). This liquid at high pressure contains too much heat to remain completely the lower pressure. This is located between states 4 and 3. The throttle valve is a constant enthalpy process. This expansion is called because the enthalpy of the refrigerant is the same before and after the expansion valve. Recall that enthalpy represents the total energy contained in the refrigerant. When the refrigerant passes through the expansion valve, the energy must remain the same since no heat or work is added to the system. During the expansion, both the pressure and temperature of the refrigerant are dramatically decreased. This new temperature is now *below* that of the storage space being cooled. The refrigerant begins as a saturated liquid at high pressure at state 4. During the expansion, the refrigerant decreases in pressure at constant enthalpy.



expansion" of at high immediately liquid is because the as a liquid at process in the "isenthalpic"

Automatic Expansion Valve

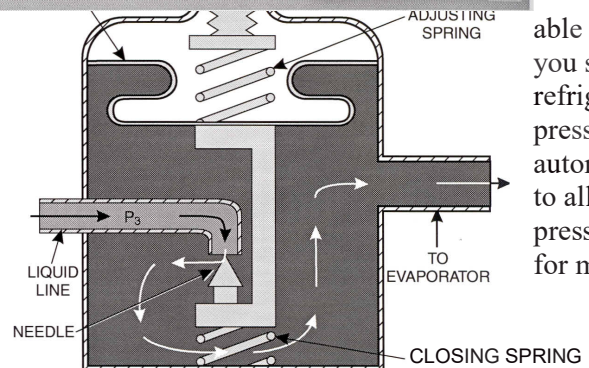
An *automatic expansion valve* (AEV) is another control used to meter out a specific amount of the evaporator. The closing spring supplies a fixed force against the needle valve. The adjusting spring modified by using an adjusting screw. As the screw is out, the position of the needle valve changes allowing lesser amount of refrigerant to flow toward the evaporator. The amount of flow is determined by the low side



refrigerant to amount of force is adjusted in or a greater or pressure.

High and Low Pressure Liquids

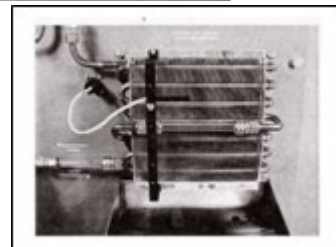
Automatic expansion valves are useful because they are heat loads. This is a big advantage over the capillary tube earlier. As the heat load is increased in the evaporator, the evaporated at a higher rate. This tends to lower the evaporator. To compensate for this condition, the expansion valve will shift the position of the needle valve refrigerant to enter the evaporator and thus maintain the constant level. This is all done automatically with no need



able to adjust to you studied refrigerant is pressure in the automatic to allow more pressure at a for monitoring.

Evaporator

The final process is the transfer of heat into the refrigerant at constant another isobaric process). During this process, the liquid evaporates state. This change of phase is carried out at constant pressure. This present in the thermal storage area to be absorbed at constant fixed temperature. The vapor begins as a two-phase mixture at state 3. As the refrigerant, the remaining liquid is vaporized to a saturated vapor absorption will superheat the vapor until state 2 is reached.



pressure (i.e. into the vapor allows the heat pressure and heat is added to Further heat

OBJECTIVE:

The objectives of this experiment are to:

1. show how the system operates with an automatic expansion valve.
2. plot the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h and p-v diagrams and compare these with those from thermodynamics predictions.
3. determine the power requirement for the compressor.
4. calculate the heat rejected by the condenser.
5. calculate the heat absorbed by the evaporator.
6. calculate the maximum theoretical and actual coefficients of performance for the cycle.
7. calculate the compressor efficiency.

EQUIPMENT:

The Amatrol T7082 Thermal System Trainer. There are many refrigerants that can be used in a vapor compression refrigeration system. Refrigerant 134a is currently one of the most widely used refrigerants today. It is safe, stable, non-toxic, non-flammable, non-explosive, and economical to use. It does not harm the ozone layer as the previous CFC refrigerants did. The refrigeration system and the corresponding thermodynamic cycle are shown in Figure. 1. This lab uses the Thermostatic Expansion Valve instead of the capillary tube for expansion of the refrigerant.

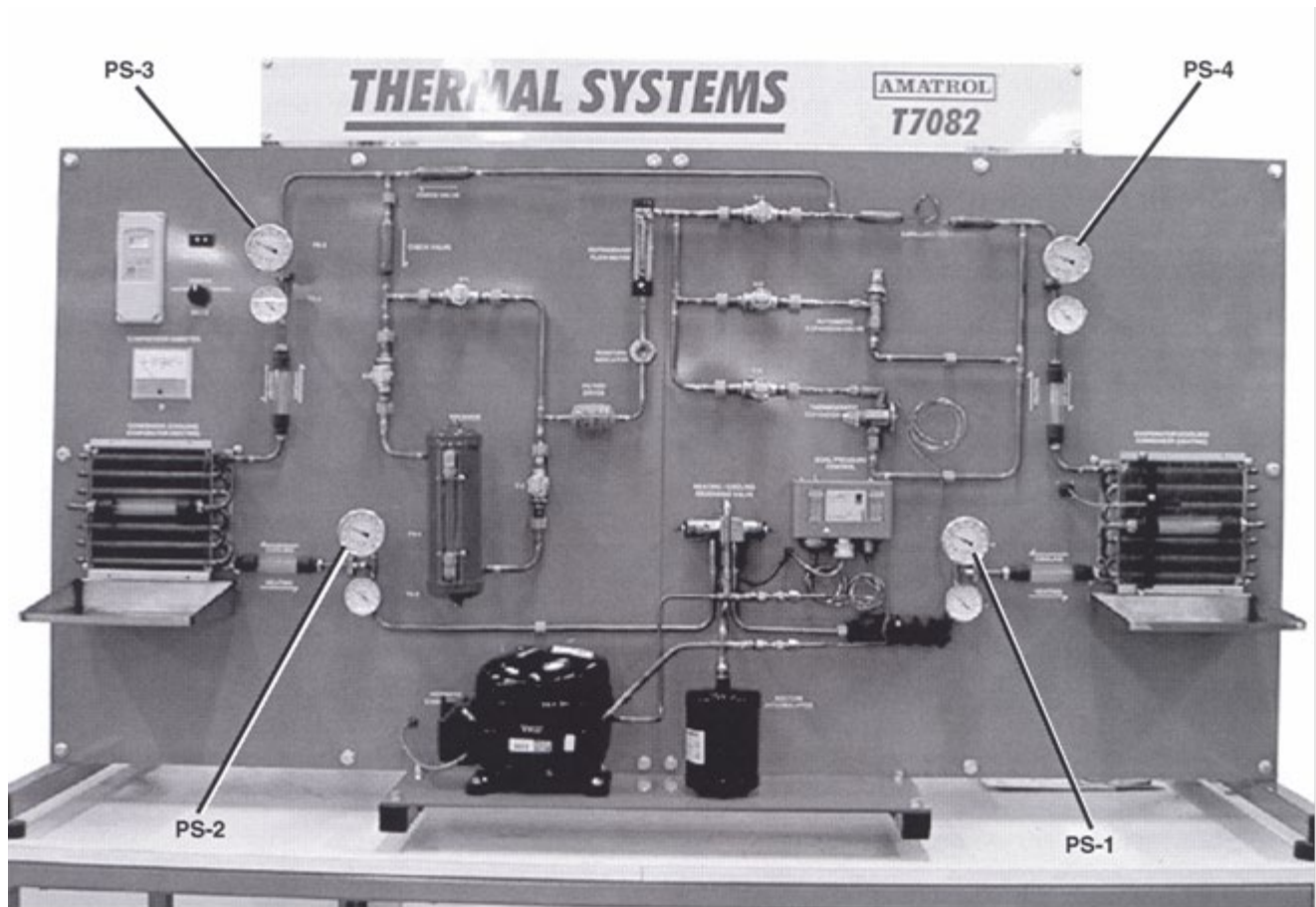


Figure 1: the AMATROL T7082 Thermal Systems Unit

Table 1 Uncertainty in Reading Experimental Variables on Instruments

Name of Instrument	Variable Read Using Instrument and Units	Uncertainty in Reading the Instrument and Units
Electronic temperature controller display	Room temperature (°C)	
Evaporator Outlet Pressure Gauge	Evaporator Outlet Pressure PS1 (kPa)	
Evaporator Outlet Temperature Gauge	Evaporator Outlet Temperature TS1 (°C)	
Condenser Inlet Pressure Gauge	Condenser Inlet Pressure, PS2 (kPa)	
Condenser Inlet Temperature Gauge	Condenser Inlet Temperature TS2 (°C)	
Condenser Outlet Pressure Gauge	Condenser Outlet Pressure PS3 (kPa)	
Condenser Outlet temperature Gauge	Condenser Outlet temperature TS3 (°C)	
Evaporator Inlet Temperature Gauge	Evaporator Inlet Temperature PS4 (kPa)	
Evaporator Inlet Temperature Gauge	Evaporator Inlet Temperature TS4 (°C)	
Compressor Current	Compressor Current Reading (Amps)	

It is usually important to avoid the admission of a liquid phase fluid to the compressor, Several degrees of superheating will ensure against local entrainment of liquid. The schematic diagram for the refrigeration cycle is shown in Figure 2.

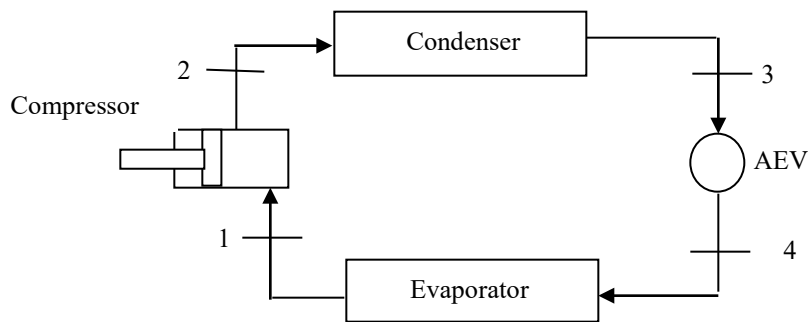


Figure 2 the Refrigeration Cycle

The absolute value of the power requirement by the compressor can be computed by

$$w = h_2 - h_1$$

The heat rejected by the condenser can be computed by

$$q_{cond} = h_2 - h_3$$

The heat absorbed by the evaporator can be obtained by

$$q_{evap} = h_1 - h_4$$

The coefficient of performance, COP, of the refrigeration system is given by

$$COP_R = \frac{q_{evap}}{w_c}$$

PROCEDURE:

1. Familiarize the refrigeration system with the description in Figure 1
2. Have your instructor make sure the trainer is properly prepared for operation.
3. Locate the power switch and make sure that it is in the OFF position.
4. Locate the mode switch and make sure that it is set on STAND-BY.
5. Perform the following sub-steps to make sure the dual pressure controller is properly set. Note that that dual pressure controller has only an English gauge for the pressure in psi even though this lab is in SI units:
 - A. Locate the cut-out scale and make sure it is set to 5 psi. If it is not, use a standard screwdriver to turn its adjusting screw.
 - B. Locate the cut-in scale and make sure it is set to 45 psi. Adjust if necessary.
 - C. Locate the high pressure cut-out setting on the right side of the pressure controller and make sure it is set to 200 psi. Adjust if necessary.
6. Reset the refrigerant valves to the following positions (if necessary):
 - VI - open
 - V2 - closed
 - V3 - closed
 - V4 - closed
 - V5 - open
 - V6 - closed
7. Locate the electric cord and plug it into a standard wall outlet.
8. Turn the power switch to the ON position. You should see the LCD on the electronic temperature controller display the room temperature.
9. **Record the room temperature being displayed** by the electronic temperature controller. You will use this

- temperature to determine the theoretical coefficient of performance in the next skill. $T_{\text{room}} =$
10. Perform the following sub-steps to ensure that the electronic temperature controller is set properly.
 - A. Press the button marked SET on the controller.
 - B. Use the up and down arrow keys to select °C on the LCD.
 - C. Press the SET button once again to enter into the set temperature mode. Use the arrow keys to select 13°C for the set point. The compressor will disengage when this temperature is reached. This is set lower than the room temperature so that the unit will run constantly.
 - D. Press the SET button once more to enter the temperature differential mode. Use the arrows to set this to 6°C. This tells the controller at what temperature above set point to engage the compressor (19°C in this case).
 - E. Press the SET button again to enter into the heating/cooling mode selection. Use the arrow keys to select "C1" on the LCD. This sets the controller for cooling mode.
 - F. Finally, press the SET button once more and check the LCD to make sure the ambient temperature is being displayed.
 11. Turn the mode switch to the COOLING position. The blowers should come on and the compressor should engage as well. Notice the direction of the fluid flow. You should observe that it now flows in the opposite direction from the heating mode.
 12. Allow the trainer to operate until it comes to steady state conditions (10 – 15 minutes). There should be no bubbles flowing through the flow meter.
 13. The AEV should have a plastic cover sitting on the adjustment screw. Remove it at this time.
 14. Use a ¾ inch open end wrench to adjust the screw in or out so the vapor pressure settles to 240 kPa (35 psi) as read on PS-4.
 15. Perform the following sub-steps to determine the pressures and temperatures at each of the four locations. These are needed to determine the specific enthalpies at these locations in order to compute the coefficient of performance.
 - A. Locate pressure and temperature gauges PS-I and TS-I. through PS4, TS4. Note the pressure is in bar and needs to be multiplied by 100 to convert it to kPa.
 - B. Record at least six different readings of each pressure, temperature, rotameter ball height, and compressor current using the Table 2. (convert the indicated gauge pressure to absolute pressure before using them to determine the specific enthalpies).

Table 2 Pressure and Temperature Readings

Pressure and Temperature Gauge Readings	1	2	3	4	5	6
Evaporator Outlet Pressure PS1 (kPa)						
Evaporator Outlet Temperature TS1 (°C)						
Condenser Inlet Pressure, PS2 (kPa)						
Condenser Inlet Temperature TS2 (°C)						
Condenser Outlet Pressure PS3 (kPa)						
Condenser Outlet temperature TS3 (°C)						
Evaporator Inlet Temperature TS4 (°C)						
Evaporator Inlet Pressure PS4 (kPa)						
Compressor Current Reading (Amps)						

*Take the average of the last two steady state readings

LAB REPORT:

1. Standard format for lab reports.
2. In your EES program, set units to SI, pressure to kPa, and energy to kJ.

3. Input pressures, temperatures, and the compressor current from the last two columns in Table 1 for each state. Input the atmospheric pressure $P_a = 101$ (kPa).
4. Compute the average of each set of pressure and temperature reading in Table 1 (The average should be taken for the last two steady state readings, and NOT for all the six data points). Compute the average compressor current.
5. Convert the pressures obtained in the previous step to absolute pressure.
6. Compute enthalpy, specific volume, and entropy at each state point. Note that the throttling process in the AEV is isenthalpic and based on that determine the enthalpy of State 4. You would need to calculate the quality of the refrigerant at State 4.
7. Store temperature, pressure, h , s , and v values into array variables for plotting.
8. Compute w_c , q_{cond} , q_{evap} , and COP of the refrigeration cycle.
9. Calculate the maximum possible coefficient of performance for the refrigeration cycle (Note that for this your temperatures should be absolute temperatures). Take a moment to review your results. You should have calculated the theoretical maximum coefficient of performance to be a value much higher than the actual one. This shows how actual systems are much less efficient than "theoretically perfect" systems. However, making actual systems more efficient means that we are getting closer to the maximum value all the time.
10. Calculate the compressor power assuming the voltage is 110 Volts. $P_{comp} = VI/1000$ (kW).
11. Assuming a compressor efficiency of 25%, calculate the mass flow rate of the refrigerant, m_{ref} through the system in kg/s.
12. Compute the uncertainties in COP_R , q_{evap} and w_{comp} .
13. Plot states 1 through 4 on $p-h$, $T-s$, and $p-v$ diagrams using the property plots feature on EES. **Clearly indicate the state points, and the process directions at these points.** Compare these plots to those obtained from your thermodynamics study. In discussing and interpreting the results, discuss the four processes in each cycle and then each cycle as a whole. Compare the experimental processes and the experimental cycles to what it should look like from your thermodynamics analysis of these cycles from your thermodynamics II course.
14. Summarize your results in Table 3 and include this in your report. Just after the sample solution.
15. Include the array table in your report as the table of "Derived Results."

Table 3 Summary of Results

Quantity	Value	Units
h_1		kJ/kg
h_2		kJ/kg
h_3		kJ/kg
h_4		kJ/kg
Specific volume at state 3		kg liq/kg mixture
Quality, x_4 at state 4		
W_{comp}		kJ/kg
q_{cond}		kJ/kg
q_{evap}		kJ/kg
COP		
Maximum possible COP		
Mass flow rate of R-134a		kg/s

ABOVE AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



**MCEG 3021 P01
THERMAL SCIENCE LABORATORY
Fall 2021 Section P01
LABORATORY REPORT ON**

“Refrigeration Cycle”

Conducted on

October 6,2021

Submitted by

Carrington Julian

Drake Cheatum

Alvin Ibeabuchi

Chris Nylander

Liana Bellamy

Leonardo Herrera

On

October 23,2021

To

Dr. Shafiee

Thermal Science Laboratory Instructor

Title of Experiment: Refrigeration Cycle

Names: Carrington Julian, Drake Cheatum, Alvin Ibeabuchi, Chris Nylander, Liana Bellamy, Leonardo Herrera

Date Lab was Performed: October 6, 2021

Report Due Date: October 23, 2021

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (your conduct and observations).	3		
Ability to follow the procedure and to properly rephrase the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment functions, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)			
Front End of Report (4 points).	4		
General report format (4 points)	4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters	12		
Correct solutions with consistent units and significant figures.	10		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw /derived) in tabular form to meet the objectives and to aid in plotting the results.	4		
Ability to present the data (raw /derived) in well-labeled graphical form to meet the objectives and to aid in interpretation.	10		
Ability to discuss the raw and derived data/graphs and assess the validity of the results concerning the underlying theory and expected trends. (Interpretation of experimental data & results)	14		
Effect of independent (X-axis) variable on the dependent (Y-axis variables). 4 Points Effect of parametric variable change on the dependent (Y-axis variable). 4 Points Comparison of experimental results with theoretical results/prediction/trend 4 Points Statement on goodness or reasonableness of results. 2 Points			
Ability to use engineering judgement to draw appropriate and reasonable conclusions in relation to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		
Percentage for this Performance Criteria			
TOTAL FOR THIS LAB	100		

Letter of Transmittal

October 23, 2021

Dr. Shahid Shafiee

Mechanical Engineering Department

Prairie View A& M University

Dear Dr. Shafiee:

The attached technical laboratory project report contains the detailed results of the laboratory project work on the performance of a refrigeration system that was assigned on October 12th, 2021. The report contains the objectives of the experiment, the theories on the performance of a refrigeration system, the equations used for analysis of the data, the raw experimental data, graphical presentation of the important results, discussion, and interpretation of results.

Please contact the name listed below if you have any questions or comments.

Sincerely,

Carrington Julian

Carrington Julian

Cjulian@pvamu.edu

Enclose: Lab Report

ABSTRACT

Purpose of Experiment

The purpose of the experiment is to show how the system operates with an automatic expansion valve. This is achieved by plotting the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h and p-v diagrams and compare these with those from thermodynamics predictions. Students then will determine the power requirement for the compressor, calculate the heat rejected by the condenser, calculate the heat absorbed by the evaporator, calculate the maximum theoretical and actual coefficients of performance for the cycle and calculate the compressor efficiency.

Method

The experiment was conducted using the Amatrol T7082 Thermal System Trainer. Within that system, the widely used refrigerant 134a was used as the liquid coolant in the analysis of a Vapor Compression Refrigeration System. This lab used the Thermostatic Expansion Valve instead of a capillary tube for the expansion of the refrigerant. Once the apparatus was started, it was used to record measurements of pressure, temperature and current at each stage needed to perform the lab analysis.

This process was repeated until the results became steady state.

Significant results

The results shown in Figures indicate that the refrigerant enters with low pressure and temperature before it can be expanded and have the heat absorbed. Pressure has a direct proportional relationship to enthalpy and regarding temperature, there is also a direct proportional relationship to Entropy.

Conclusions

In line with the objectives, the system uses an automatic expansion valve to have a constant pressure. Pressure has different relationships with volume and entropy just as there is a relationship with temperature and entropy. The ideal vapor compression refrigeration cycle uses the four processes to stabilize the system so heat can either be absorbed or released.

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

The experimental objectives and the theories associated with the refrigeration are discussed in addition to the detailed experimental procedure, safety precautions taken, and the raw experimental data collected during the experiment.

1.1 Objectives of the Experiment

The objectives of this experiment are to:

1. Operate the correct instrumentation (automatic expansion valve) in the department lab to accurately study the performance of the refrigeration system.
2. Create a plot of the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h, and p-v diagrams and compare to form thermodynamics predictions.
3. Identify the power requirement for the compressor.
4. Analyze values for condenser heat rejection.
5. Analyze values for evaporator heat absorption.
6. Analyze the maximum theoretical and actual coefficients of cycle performance.
7. Analyze efficiency of the compressor.

1.2 Theory Associated with Experiment

Simple Literature Review

A typical vapor compression refrigeration system has four major components: compressor, condenser, capillary tube or expansion device (automatic expansion valve in this experiment), and evaporator.

These are briefly described in the following.



Figure 1.1 Compressor

Compressor

The first process encountered by the refrigerant is an adiabatic compression. Here, the refrigerant in the vapor state is compressed to higher pressure in the compressor. The compressor is located between states 2 and 1. It is used to increase the pressure and temperature of the refrigerant; it should operate with refrigerant vapor only. This compression is adiabatic since only work is performed on the vapor and no heat is transferred in or out at this time. However, the

compression itself causes a dramatic increase in the vapor temperature (based on the Ideal Gas Law).

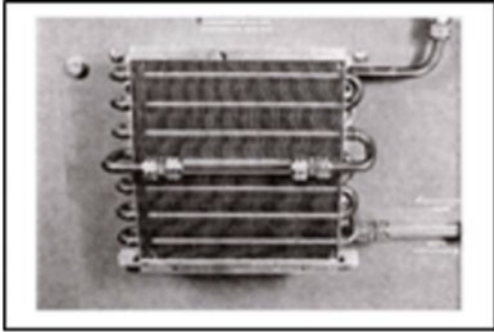


Figure 1.2 Condenser

Condenser

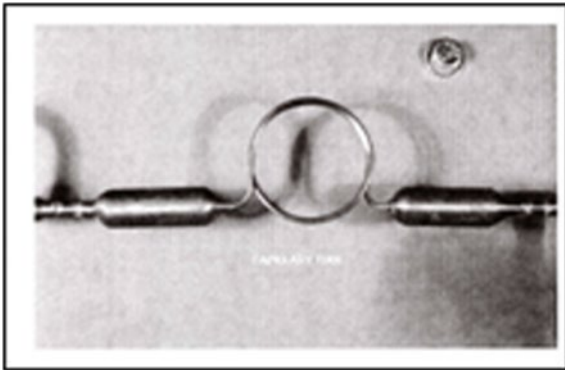


Figure 1.3 Capillary Tube

Capillary tube

refrigerant is the same before and after the expansion valve. Recall that enthalpy represents the total energy contained in the refrigerant. When the refrigerant passes through the expansion valve, the energy must remain the same since no heat or work is added to the system. During the expansion, both the pressure and temperature of the refrigerant are dramatically decreased. This new temperature is now below that of the storage space being cooled. The refrigerant begins as a saturated liquid at high pressure at state 4. During the expansion, the refrigerant decreases in pressure at constant enthalpy.

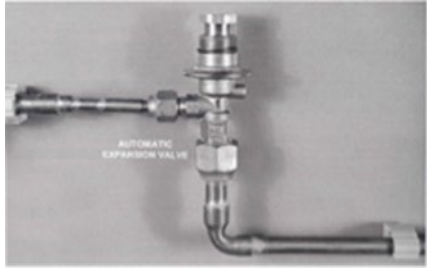


Figure 1.4 Automatic Expansion Valve

An automatic expansion valve (AEV) is another refrigerant control used to meter out a specific amount of refrigerant to the evaporator. The closing spring supplies a fixed amount of force against the needle valve. The adjusting spring force is modified by using an adjusting screw. As the screw is adjusted in or out, the position of the needle valve changes allowing a greater or lesser amount of refrigerant to flow toward the evaporator. The amount of flow is determined by the low side pressure.

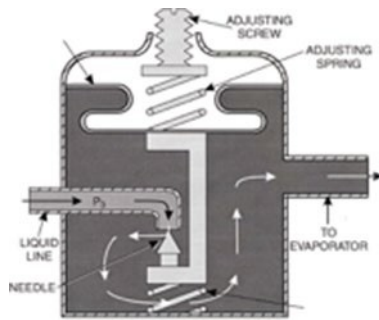
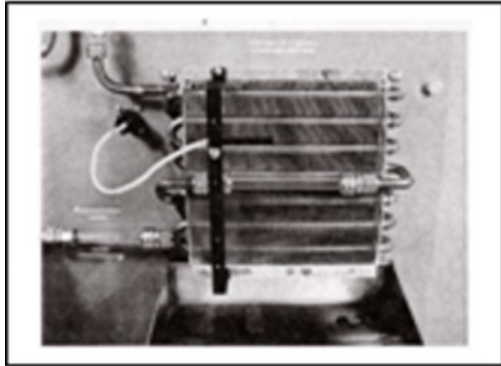


Figure 1.5 High- and Low-Pressure Liquids

Automatic expansion valves are useful because they are able to adjust to heat loads. This is a big advantage over the capillary tube you studied earlier. As the heat load is increased in the evaporator, the refrigerant is evaporated at a higher rate. This tends to lower the pressure in the evaporator. To compensate for this condition, the automatic expansion valve will shift the

position of the needle valve to allow more refrigerant to enter the evaporator and thus maintain the pressure at a constant level. This is all done automatically with no need for monitoring.



Evaporator

The final process is the transfer of heat into the refrigerant at constant pressure (i.e. another isobaric process). During this process, the liquid evaporates into the vapor state. This change of phase is carried out at constant pressure. This allows the heat present in the thermal storage area to be absorbed at constant fixed pressure and temperature. The vapor begins as a two-phase mixture at state 3. As heat is added to the refrigerant, the remaining liquid is vaporized to a saturated vapor. Further heat absorption will superheat the vapor until state 2 is reached.

1.3 Apparatus and Uncertainty in Reading Instruments

EQUIPMENT:

The Amatrol T7082 Thermal System Trainer. There are many refrigerants that can be used in a vapor compression refrigeration system. Refrigerant 134a is currently one of the most widely used refrigerants today. It is safe, stable, non-toxic, non-flammable, non-explosive, and economical to use. It does not harm the ozone layer as the previous CFC refrigerants did. The refrigeration system and the corresponding thermodynamic cycle are shown in Figure. 1. This lab uses the Thermostatic Expansion Valve instead of the capillary tube for expansion of the refrigerant.

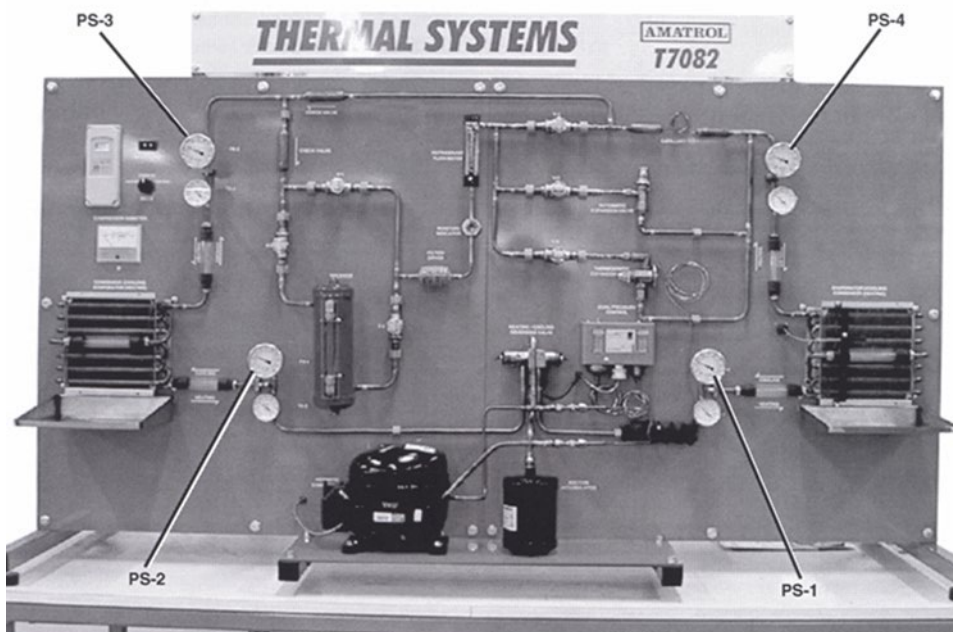


Table 1.1 Uncertainty in Reading Experimental Variables on Instruments

Name of Instrument	Variable Read Using Instrument and Units	Uncertainty in Reading the Instrument and Units
Electronic temperature controller display	Room temperature (°C)	.5 degrees C
Evaporator Outlet Pressure Gauge	Evaporator Outlet Pressure PS1 (kPa)	25 kPa
Evaporator Outlet Temperature Gauge	Evaporator Outlet Temperature TS1 (°C)	.5 degrees C
Condenser Inlet Pressure Gauge	Condenser Inlet Pressure, PS2 (kPa)	25 kPa
Condenser Inlet Temperature Gauge	Condenser Inlet Temperature TS2 (°C)	.5 degrees C
Condenser Outlet Pressure Gauge	Condenser Outlet Pressure PS3 (kPa)	25 kPa
Condenser Outlet temperature Gauge	Condenser Outlet temperature TS3 (°C)	.5 degrees C
Evaporator Inlet Temperature Gauge	Evaporator Inlet Temperature PS4 (kPa)	25 kPa
Evaporator Inlet Temperature Gauge	Evaporator Inlet Temperature TS4 (°C)	.5 degrees C
Compressor Current	Compressor Current Reading (Amps)	.2 A

1.4 Experimental Safety

After observing the experimental setup in the Refrigeration Cycle video, the pressure and temperature gauges are most important for the readings of the experiment.

The safety precautions that should be taken into consideration are a neat area and the pressure gages and temperature ages are clear and not tampered with. Also, it is important that the room temperature is noted for the proper starting temperature for the experiment.

Students should wear protective equipment to protect themselves from the heat from the evaporator and condenser and the heat from the whole project to protect from skin damage and damage to the hands.

1.5 Experimental Procedure

1. Familiarized the refrigeration system with the description in Figure 1
2. Had instructor make sure the trainer is properly prepared for the operation.
3. Located the power switch and made sure that it was in the OFF position.
4. Located the mode switched and made sure that it was set on STAND-BY.
5. Performed the following sub-steps to make sure the dual pressure controller was properly set.

Also, noted that

the dual pressure controller has only an English gauge for the pressure in psi even though this lab is

in SI units:

A. Located the cut-out scale and made sure it was set to 5 psi. If it was not, used a standard screwdriver to

turn the adjusting screw.

B. Located the cut-in scale and made sure it was set to 45 psi.

C. Located the high pressure cut-out setting on the right side of the pressure controller and made sure

It was set to 200 psi. Adjust if necessary.

6. Reset the refrigerant valves to the following positions (if necessary):

- V1 - open
- V2 - closed
- V3 - closed
- V4 - closed
- V5 - open
- V6 - closed

7. Located the electric cord and plugged it into a standard wall outlet.

8. Turned the power switch to the ON position.

9. Recorded the room temperature being displayed by the electronic temperature controller. Used this temperature to determine the theoretical coefficient of performance in the next skill. Room Temperature =

10. Performed the following sub-steps to ensure that the electronic temperature controller was set properly.

- Pressed the button marked SET on the controller.
- Used the up and down arrow keys to select °C on the LCD.
- Pressed the SET button once again to enter the set temperature mode. Used the arrowkeys to select 13°C for the set point. The compressor disengaged when this temperature was reached. This is set lower than the room temperature so that the unit ran constantly.
- Pressed the SET button again to enter the temperature differential mode. Used the arrowsto set to 6°C.
- Pressed the SET button again to enter the heating/cooling mode selection. Used the arrowkeys to select "C1" on the LCD.
- Finally, pressed the SET button again and checked the LCD to make sure the ambient temperature is being displayed.

F. Finally, pressed the SET button again and checked the LCD to make sure the ambient temperature was being displayed.

11. Turned the mode switch to the COOLING position.

12. Allowed the trainer to operate until it became steady state conditions (10 – 15 minutes).

There were
no bubbles flowing through the flow meter.

13. Removed the AEV plastic covering that was sitting on the adjustment screw

14. Used a 3/4 inch open end wrench to adjust the screw in or out so the vapor pressure settled to 240 kPa

(35 psi) as read on PS-4.

15. Performed the following sub-steps to determine the pressures and temperatures at each of the four locations. These are needed to determine the specific enthalpies at these locations to compute the coefficient of performance.

- Located pressure and temperature gauges PS-I and TS-I. through PS4, TS4. Noted the pressure is in
bar and needed to be multiplied by 100 to convert it to kPa.
- Recorded at least six different readings of each pressure, temperature, rotameter ball height, and
compressor using Table 2. (convert the indicated gauge pressure to absolute pressure before using them to determine the specific enthalpies).

1.6 Presentation of Raw Experimental Data

Table 1.2 Raw Experimental Data

Units?

Pressure and Temperature Gauge Readings	1	2	3	4	5	6
PS1	3	3	3	3	3	3
TS1	15.5	15.5	15.5	15	15.7	15
PS2	4.2	4.3	4.3	4.3	4.4	4.4
TS2	15	15.5	15.5	15	15.2	15
PS3	4.4	4.4	4.4	4.2	4.4	4.4
TS3	14.5	14.5	14.5	15	15.2	15
PS4	14.5	14.5	14.5	14.5	14.75	14.75
TS4	3.3	3.4	3.4	3.4	3.3	3
Icompressor (A)	4	4.1	4.15	4.15	4.2	4.18

CHAPTER 2

2.1 Detailed Computer Analysis of All Data

The detailed sample analysis is shown below. The step by step analysis is done in order. Units are provided in the theory section in chapter 1.

Atmospheric Temperature

$$P_a = 101$$

Step 4 Average Values

$$P_{s1avg} = 300$$

$$P_{s2avg} = 440$$

$$P_{s3avg} = 440$$

$$P_{s4avg} = 1475$$

$$T_{s1avg} = 15.35$$

$$T_{s2avg} = 15.1$$

$$T_{s3avg} = 14.5$$

$$T_{s4avg} = 3.15$$

$$I_{compavg} = 4.19$$

Step 5 Absolute Pressure

$$P_{s1abs} = P_{s1avg} + 101$$

$$P_{s2abs} = P_{s2avg} + 101$$

$$P_{s3abs} = P_{s3avg} + 101$$

$$P_{s4abs} = P_{s4avg} + 101$$

Step 6 Enthalpy

$$h_1 = h(R134a, T=T_{s1avg}, P=P_{s1abs})$$

$$h_2 = h(R134a, T=T_{s2avg}, P=P_{s2abs})$$

$$h_3 = h(R134a, T=T_{s3avg}, P=P_{s3abs})$$

$$h_4 = h_3$$

Step 6 Cont. Specific Volume

$$V_1 = v(R134a, T=T_{s1avg}, P=P_{s1abs})$$

$$V_2 = v(R134a, T=T_{s2avg}, P=P_{s2abs})$$

$$V_3 = v(R134a, T=T_{s3avg}, P=P_{s3abs})$$

$$V_4 = v(R134a, T=T_{s4avg}, P=P_{s4abs})$$

Step 6 Cont. Entropy

$$s_1 = s(R134a, T=T_{s1avg}, P=P_{s1abs})$$

$$s_2 = s(R134a, T=T_{s2avg}, P=P_{s2abs})$$

$$s_3 = s(R134a, T=T_{s3avg}, P=P_{s3abs})$$

$$s_4 = s(R134a, T=T_{s4avg}, P=P_{s4abs})$$

Quality at state 4

$$x_4 = x(R134a, T=T_{s4avg}, h=h_4)$$

Step 8

$$w_c = h_2 - h_1$$

$$q_{cond} = h_2 - h_3$$

$$q_{evap} = h_1 - h_4$$

$$COP_R = \frac{q_{evap}}{w_c}$$

Note: The reason COP_R is negative is because $T_{s2} < T_{s1}$, making w_c negative

$$T_H = 17 + 273$$

$$T_C = 3.15 + 273$$

$$COP_{MaxR} = \frac{T_C}{T_H - T_C}$$

Step 10

$$P_{comp} = 110 \cdot \frac{I_{compavg}}{1000}$$

Step 11

$$P_{compActual} = P_{comp} \cdot 0.25$$

$$m_{ref} = \frac{P_{compActual}}{h_2 - h_1}$$

2.2 Presentation of Tables of Derived Results

Table 2.1 shows the sample solution results derived from EES. Table

2.1 Sample Solution Results

Quantity	Value	Units
h1	261.5	kJ/kg
h2	72.48	kJ/kg
h3	71.65	kJ/kg
h4	71.65	kJ/kg
Specific volume at state 3	1	kg liq/kg mixture
Quality, x4 at state 4	0.07926	
wcomp	189.1	kJ/kg
qcond	0.8314	kJ/kg
qevap	189.9	kJ/kg
COP	1.004	
Maximum possible COP	19.94	
Mass flow rate of R-134a	0.0006095	kg/s

2.3 Uncertainty Analysis of Major Computed Variables

The uncertainty analysis is shown below. The uncertainty calculated for COP_R, w_c, and q_{evap} are derived as 0.003684, 1.041 kJ/kg, and 0.7767 kJ/kg respectively.

Unit Settings: SI C kPa kJ mass deg

Variable±Uncertainty	Partial derivative	% of uncertainty
<u>COP_R = -1.004±0.003684</u>		
P _{s1avg} = 300±25 [kPa]	$\partial \text{COP}_R / \partial P_{s1avg} = -5.797\text{E-}07$	0.00 %
P _{s2avg} = 440±25 [kPa]	$\partial \text{COP}_R / \partial P_{s2avg} = -6.695\text{E-}07$	0.00 %
P _{s4avg} = 1475±25 [kPa]	$\partial \text{COP}_R / \partial P_{s4avg} = 0$	0.00 %
T _{s1avg} = 15.35±0.5 [C]	$\partial \text{COP}_R / \partial T_{s1avg} = 0.00002158$	0.00 %
T _{s2avg} = 15.1±0.5 [C]	$\partial \text{COP}_R / \partial T_{s2avg} = -0.007368$	100.00 %
T _{s4avg} = 3.15±0.5 [C]	$\partial \text{COP}_R / \partial T_{s4avg} = 0$	0.00 %
<u>w_c = -189.1±1.041</u>		
P _{s1avg} = 300±25 [kPa]	$\partial w_c / \partial P_{s1avg} = 0.02492$	35.80 %
P _{s2avg} = 440±25 [kPa]	$\partial w_c / \partial P_{s2avg} = 0.000126$	0.00 %
P _{s4avg} = 1475±25 [kPa]	$\partial w_c / \partial P_{s4avg} = 0$	0.00 %
T _{s1avg} = 15.35±0.5 [C]	$\partial w_c / \partial T_{s1avg} = -0.9277$	19.85 %
T _{s2avg} = 15.1±0.5 [C]	$\partial w_c / \partial T_{s2avg} = 1.387$	44.35 %
T _{s4avg} = 3.15±0.5 [C]	$\partial w_c / \partial T_{s4avg} = 0$	0.00 %

Unit Settings: SI C kPa kJ mass deg

Variable±Uncertainty	Partial derivative	% of uncertainty
<u>q_{evap} = 189.9±0.7767</u>		
P _{s1avg} = 300±25 [kPa]	$\partial q_{evap} / \partial P_{s1avg} = -0.02492$	64.34 %
P _{s4avg} = 1475±25 [kPa]	$\partial q_{evap} / \partial P_{s4avg} = 0$	0.00 %
T _{s1avg} = 15.35±0.5 [C]	$\partial q_{evap} / \partial T_{s1avg} = 0.9277$	35.66 %
T _{s4avg} = 3.15±0.5 [C]	$\partial q_{evap} / \partial T_{s4avg} = 0$	0.00 %

4 potential unit problems were detected.

Calculation time = .0 sec.

2.4 Detailed Computer Analysis of all Data and Presentation of Tables of Derived Results

The EES tables were developed leading to the solution of the experiment. Shown below is the detailed computer analysis of all data is a presentation of tables of derived results.

Unit Settings: SI C kPa kJ mass deg

$COP_{MaxR} = 19.94$	$COP_R = -1.004$	$h_1 = 261.5 \text{ [kJ/kg]}$	$h_2 = 72.48 \text{ [kJ/kg]}$
$h_3 = 71.65 \text{ [kJ/kg]}$	$h_4 = 71.65$	$I_{compavg} = 4.19 \text{ [A]}$	$m_{ref} = -0.0006095$
$P_a = 101 \text{ [kPa]}$	$P_{comp} = 0.4609 \text{ [kW]}$	$P_{compActual} = 0.1152 \text{ [kW]}$	$P_{s1abs} = 401 \text{ [kPa]}$
$P_{s1avg} = 300 \text{ [kPa]}$	$P_{s2abs} = 541 \text{ [kPa]}$	$P_{s2avg} = 440 \text{ [kPa]}$	$P_{s3abs} = 541 \text{ [kPa]}$
$P_{s3avg} = 440 \text{ [kPa]}$	$P_{s4abs} = 1576 \text{ [kPa]}$	$P_{s4avg} = 1475 \text{ [kPa]}$	$q_{cond} = 0.8314$
$q_{evap} = 189.9$	$s_1 = 0.9477 \text{ [kJ/kg-K]}$	$s_2 = 0.2772 \text{ [kJ/kg-K]}$	$s_3 = 0.2743 \text{ [kJ/kg-K]}$
$s_4 = 0.2172 \text{ [kJ/kg-K]}$	$T_C = 276.2 \text{ [K]}$	$T_H = 290 \text{ [K]}$	$T_{s1avg} = 15.35 \text{ [C]}$
$T_{s2avg} = 15.1 \text{ [C]}$	$T_{s3avg} = 14.5 \text{ [C]}$	$T_{s4avg} = 3.15 \text{ [C]}$	$V_1 = 0.05282 \text{ [m}^3\text{/kg]}$
$V_2 = 0.0008043 \text{ [m}^3\text{/kg]}$	$V_3 = 0.0008029 \text{ [m}^3\text{/kg]}$	$V_4 = 0.0007756 \text{ [m}^3\text{/kg]}$	$w_c = -189.1$
$x_4 = 0.07926$			

1.1	1	2	3	4	5	6	7	8	9	10	11	12	13
	P _{s1avg} [kPa]	T _{s1avg} [C]	P _{s2avg} [kPa]	T _{s2avg} [C]	P _{s3avg} [kPa]	T _{s3avg} [C]	P _{s4avg} [kPa]	T _{s4avg} [C]	I _{compressoravg} [A]	P _{s1abs} [kPa]	P _{s2abs} [kPa]	P _{s3abs} [kPa]	P _{s4abs} [kPa]
Run 1	300	15.35	440	15.1	440	14.5	1475	3.15	4.19	401	541	541	1576

14	15	16	17	18	19	20	21	22	23	24	25	26
h ₁ [kJ/kg]	h ₂ [kJ/kg]	h ₃ [kJ/kg]	h ₄ [kJ/kg]	V ₁ [m ³ /kg]	V ₂ [m ³ /kg]	V ₃ [m ³ /kg]	V ₄ [m ³ /kg]	s ₁ [kJ/kg-K]	s ₂ [kJ/kg-K]	s ₃ [kJ/kg-K]	s ₄ [kJ/kg-K]	x ₄ [kJ/kg-K]
261.5	72.48	71.65	71.65	0.05282	0.0008043	0.0008029	0.0007756	0.9477	0.2772	0.2743	0.2172	0.07926

Chapter 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

This chapter contains graphical representation of the experimental and theoretical results and detailed discussions and interpretation of the experimental results. Following these, concluding remarks are provided based on experimental objectives. The chapter ends with recommendations and an Appendix containing additional information related to the experiment.

3.1 Presentation of Graphs/Figures and Interpretation of Results Presented by each Graph/Figure

Figure 3.1 shows the plot of pressure vs. enthalpy of the experimental data received. It shows where the different stages of the system take place and at what values it happens.

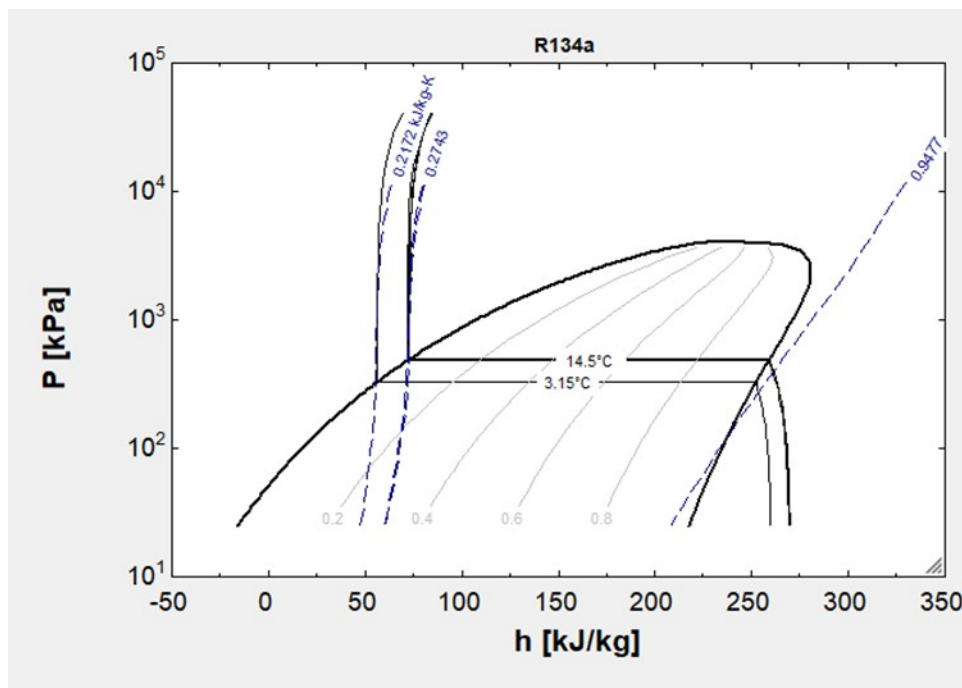


Figure 3.1 P vs H

When the liquid's pressure is reduced, it begins to evaporate. The energy released by the refrigerant's evaporation is used to cool everything down. The refrigerant is a mixture of liquid and vapor as it passes through the evaporator, and the energy it absorbs is in the amount of Q continues to evaporate.

Figure 3.2 shows the temperature vs. entropy plot from the experimental data. It depicts where the various stages of the system occur and at what values they occur.

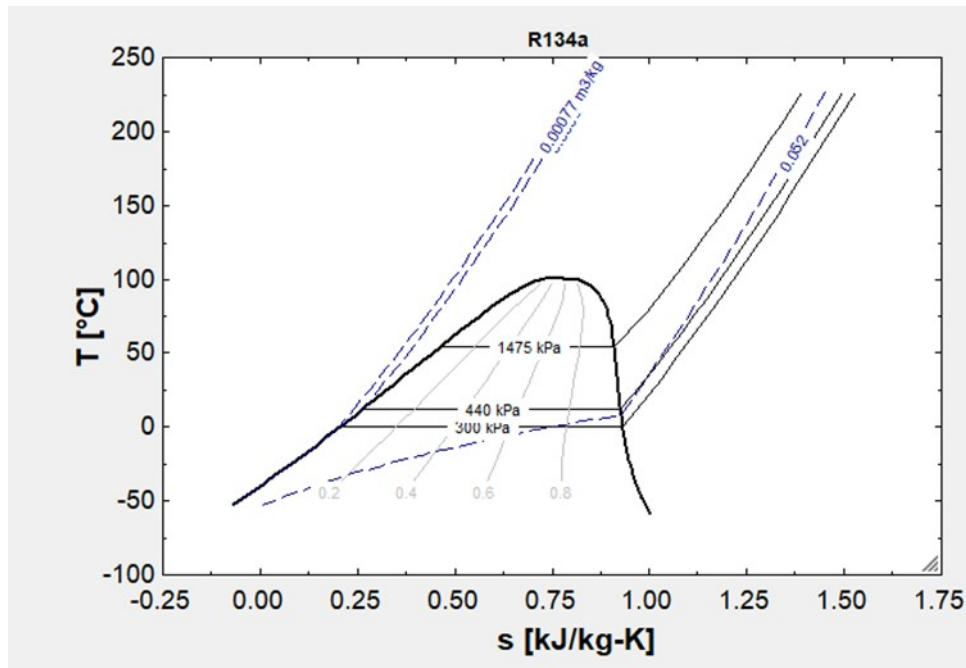


Figure 3.2 T vs S

In Figure 3.2 you can see work is being done on the working fluid at a constant entropy resulting in an increased temperature (isentropic compression) then heat is rejected turning into isentropic expansion where work is done by the working fluid at a constant creating a decrease in temperature.

Figure 3.3 shows the pressure vs. volume plot from the experimental data. It depicts where the various stages of the system occur and at what values they occur.

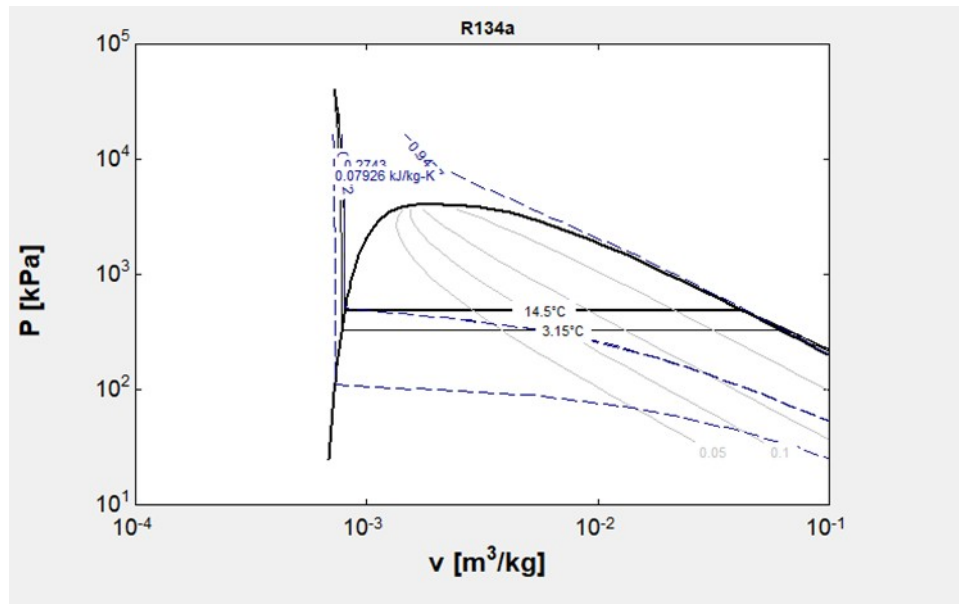


Figure 3.3 P vs V

A float-controlled expansion valve allows the high-pressure liquid to exit the condenser. Because of the pressure drop in the valve, some of the liquid flashes into vapor, resulting in a two-phase flow, as shown in figure 3.3.

Why did you find a negative COP?
What was wrong with the results or the experiment.

-5

3.2 Discussion

We arrived at a conclusion about how a refrigeration system works as a result of this experiment. We learned about the compressor, evaporator, expansion device, and condenser, as well as other components of the system. We also learned what a reversible valve is and how it can be used in a variety of systems, such as the refrigeration cycle, where it allows the system to flow forward for cooling and then backward for heating, making it a more practical and useful system for operations. We had a few major conclusions

for this experiment that we were able to find by running the experimental data. First is that this refrigeration cycle's COP is only 5.04% percent efficient when compared to the system's maximum COP.

Determined how much work the compressor must do to keep the system running. The amount of heat dissipation and absorption of the condenser and evaporator, respectively, were also to be determined. We were able to estimate the correct values of the results using the uncertainty readings. In conclusion, this experiment was informative and helpful in understanding how a refrigeration cycle works and how efficient it is. Also, we found that T_{s2} is less than T_{s1} .

3.3 Conclusions based on each Objective and the Results

3.3.1 Statement of Objective 1: show how the system operates with an automatic expansion valve.

The constant pressure or an automatic expansion valve (AEV) is another refrigerant control used to meter out a specific amount of refrigerant to the evaporator, maintaining a constant evaporator pressure. Refrigerant flows at a rate that exactly matches compressor capacity. The closing spring supplies a fixed amount of force against the needle valve. the position of the needle valve changes allowing a greater or lesser amount of refrigerant to flow toward the evaporator. The amount of flow is determined by the low side pressure. High- and Low-Pressure Liquids Automatic expansion valves are useful because they are able to adjust to heat loads. The automatic expansion valve will shift the position of the needle valve to allow more refrigerant to enter the evaporator and maintain the pressure at a constant level. This is done automatically.

3.3.2 Statement of Objective 2: plot the actual refrigeration cycle of the T7082 Thermal Systemstrainer on T-s, p-h and p-v diagrams and compare these with those from thermodynamics predictions.

The actual refrigeration cycle of the T7082 Thermal Systems trainer was plotted on T-s, p-h, and p-v diagrams. The results on the p-h and p-v diagrams were consistent with the theoretical predictions. The T-s diagram is where a difference between the theoretical predictions and results from the experiment differs with the T_{s1} and T_{s2} values. T_{s2} was supposed to be much greater than T_{s1} , because it was not, errors arose in the results.

3.3.3 Statement of Objective 3: determine the power requirement for the compressor.

In the experiment the compressor power was calculated assuming the voltage was 110 Volts. $I = 4.19$ (A). The equation $P_{comp} = VI/1000$ (kW) was used equating compressor power to 0.46 (kW). The absolute value of the power requirement by the compressor can be computed by w_{comp}

$$= h_2 - h_1 = 72.48 - 261.5 \text{ (kJ/kg)} = 189.1 \text{ (kJ/kg)}.$$

3.3.4 Statement of Objective 4: calculate the heat rejected by the condenser.

The heat rejected by the condenser was computed by the equation, $q_{cond} = h_2 - h_3$. Substituting the values for h_2 and h_3 , the equation becomes $q_{cond} = 72.48 - 71.65 \text{ (kJ/kg)} = 0.8314 \text{ (kJ/kg)}$. Subtracting the enthalpies from state 2 to state 3 gives the heat rejected by the condenser to be 0.8314 (kJ/kg).

3.3.5 Statement of Objective 5: calculate the heat absorbed by the evaporator.

The heat absorbed by the evaporator was obtained by the equation, $q_{evap} = h_1 - h_4$. Substituting the values for h_1 and h_4 , the equation becomes $q_{evap} = 261.5 - 71.65 \text{ (kJ/kg)} = 189.9 \text{ (kJ/kg)}$. Subtracting the enthalpies from state 1 to state 4 gives the heat absorbed the evaporator to be 189.9(kJ/kg).

3.3.6 Statement of Objective 6: calculate the maximum theoretical and actual coefficients of performance for the cycle.

The coefficient of performance, COP, of the refrigeration system is given by the equation, $COP_R = q_{evap} / w_c$ which equals 1.004 when the values are plugged in. The maximum possible COP = 19.94.

3.3.7 Statement of Objective 7: calculate the compressor efficiency.

The compressor efficiency was given as 25%. This meant that the output power used the 25% of the input power. The equation for compressor output power is given as $VI*0.25$, where V is the voltage as 110 Volts and I in amps.

In conclusion, after the experiment was performed, the student was able to show how the system operates with an automatic expansion valve, plot the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h, and p-v diagrams and compare those with thermodynamics predictions, determine the power requirement for the compressor, calculate the heat rejected by the condenser, the heat absorbed by the evaporator, the coefficients of performance for the cycle, and the compressor efficiency. The experiment allowed a better understanding of the performance of a refrigeration system.

3.4 Recommendations

According to the thermodynamic predictions for this experiment, Ts2 is supposed to be much greater than Ts1. The values obtained for Ts2_avg were 15.1 (C) and 15.35 (C) for Ts1_avg. Because Ts2 was lower than Ts1 after running the experiment some of the analysis was off. If Ts2 has to be much higher to get better results. Further evaluation should be held to determine why these values did not match the predictions, they were not only close, but Ts1 was greater than Ts2.

REFERENCES

1. Bergman, T.L., et al., Fundamentals of heat and mass transfer. 2011: John Wiley & Sons.
2. Engineering Equation Solver (EES) for Microsoft Windows, F-Charts Software

Appendix A EES Formatted Equations

Atmospheric Temperature

$$P_a = 101$$

Step 4 Average Values

$$P_{s1avg} = 300$$

$$P_{s2avg} = 440$$

$$P_{s3avg} = 440$$

$$P_{s4avg} = 1475$$

$$T_{s1avg} = 15.35$$

$$T_{s2avg} = 15.1$$

$$T_{s3avg} = 14.5$$

$$T_{s4avg} = 3.15$$

$$I_{compavg} = 4.19$$

Step 5 Absolute Pressure

$$P_{s1abs} = P_{s1avg} + 101$$

$$P_{s2abs} = P_{s2avg} + 101$$

$$P_{s3abs} = P_{s3avg} + 101$$

$$P_{s4abs} = P_{s4avg} + 101$$

Step 6 Enthalpy

$$h_1 = h(R134a, T=T_{s1avg}, P=P_{s1abs})$$

$$h_2 = h(R134a, T=T_{s2avg}, P=P_{s2abs})$$

$$h_3 = h(R134a, T=T_{s3avg}, P=P_{s3abs})$$

$$h_4 = h_3$$

Step 6 Cont. Specific Volume

$$V_1 = v(R134a, T=T_{s1avg}, P=P_{s1abs})$$

$$V_2 = v(R134a, T=T_{s2avg}, P=P_{s2abs})$$

$$V_3 = v(R134a, T=T_{s3avg}, P=P_{s3abs})$$

$$V_4 = v(R134a, T=T_{s4avg}, P=P_{s4abs})$$

Step 6 Cont. Entropy

$$s_1 = s(R134a, T=T_{s1avg}, P=P_{s1abs})$$

$$s_2 = s(R134a, T=T_{s2avg}, P=P_{s2abs})$$

$$s_3 = s(R134a, T=T_{s3avg}, P=P_{s3abs})$$

$$s_4 = s(R134a, T=T_{s4avg}, P=P_{s4abs})$$

Quality at state 4

$$x_4 = x(R134a, T=T_{s4avg}, h=h_4)$$

Step 8

$$w_c = h_2 - h_1$$

$$q_{cond} = h_2 - h_3$$

$$q_{evap} = h_1 - h_4$$

$$COP_R = \frac{q_{evap}}{w_c}$$

Note: The reason COP_R is negative is because $T_{s2} < T_{s1}$, making w_c negative

$$T_H = 17 + 273$$

$$T_C = 3.15 + 273$$

$$COP_{MaxR} = \frac{T_C}{T_H - T_C}$$

Step 10

$$P_{comp} = 110 \cdot \frac{I_{compavg}}{1000}$$

Step 11

$$P_{compActual} = P_{comp} \cdot 0.25$$

$$m_{ref} = \frac{P_{compActual}}{h_2 - h_1}$$

Appendix B EES Unformatted Equations

"Atomospheric Temperature"

```
P_a=101
{P_s1=1
P_s2=1
P_s3=1
P_s4=1
T_s1=1
T_s2=1
T_s3=1
T_s4=1
I_compressor=1}
```

"Step 4 Average Values"

```
P_s1avg=300
P_s2avg=440
P_s3avg=440
P_s4avg=1475
T_s1avg=15.35
T_s2avg=15.1
T_s3avg=14.5
T_s4avg=3.15
I_compavg=4.19
```

"Step 5 Absolute Pressure"

```
P_s1abs=P_s1avg+101
P_s2abs=P_s2avg+101
P_s3abs=P_s3avg+101
P_s4abs=P_s4avg+101
```

"Step 6 Enthalpy"

```
h_1=Enthalpy(R134a,T=T_s1avg,P=P_s1abs)
h_2=Enthalpy(R134a,T=T_s2avg,P=P_s2abs)
h_3=Enthalpy(R134a,T=T_s3avg,P=P_s3abs)
h_4=h_3
```

"Step 6 Cont. Specific Volume"

```
V_1=Volume(R134a,T=T_s1avg,P=P_s1abs)
V_2=Volume(R134a,T=T_s2avg,P=P_s2abs)
V_3=Volume(R134a,T=T_s3avg,P=P_s3abs)
V_4=Volume(R134a,T=T_s4avg,P=P_s4abs)
```

"Step 6 Cont. Entropy"

```
s_1=Entropy(R134a,T=T_s1avg,P=P_s1abs)
s_2=Entropy(R134a,T=T_s2avg,P=P_s2abs)
s_3=Entropy(R134a,T=T_s3avg,P=P_s3abs)
s_4=Entropy(R134a,T=T_s4avg,P=P_s4abs)
```

"Quality at state 4"

```
x_4=Quality(R134a,T=T_s4avg,h=h_4)
```

"Step 8"

```
w_c = h_2-h_1
q_cond=h_2-h_3
q_evap=h_1-h_4
COP_R=(q_evap)/(w_c)
"Note: The reason COP_R is negative is because T_s2<T_s1, making w_c negative"
T_H=17+273
T_C=3.15+273
COP_MaxR=(T_C)/((T_H)-(T_C))
```

"Step 10"

```
P_comp=110*I_compavg/1000
```

"Step 11"

```
P_compActual=P_comp*0.25
m_ref=(P_compActual)/(h_2-h_1)
```

APPENDIX C

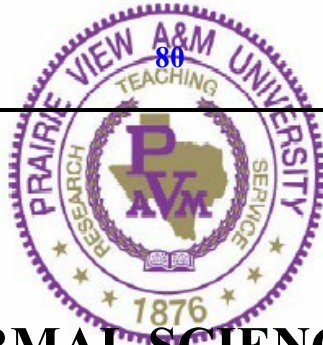
Group Member Evaluation

The group should complete the table below for the members of the group who actively participated in the work. Distribute a total of 100 points to all of the members in your group. The total for all of the members in the group should not exceed 100 points.

Name of Group Member	Points	Signature	Comments
Leonardo Herrera	16.67		
Carrington Julian	16.67		
Drake Cheatum	16.67		
Alvin Ibeabuchi	16.67		
Chris Nylander	16.67		
Liana Bellamy	16.67		
Total (Should be 100 Points)	100		

AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**



MCEG 3102 THERMAL SCIENCE LABORATORY

Fall 2021 Section P01

LABORATORY REPORT ON

“Performance of a Refrigeration System with AEV”

**Conducted on
October 6, 2021**

**Submitted by
Andrew Vaughn, Chibuike Ejimadu, Zion
Brown, Cori Yancy, & Idris Agboola**

**On
October 23, 2021**

To

**Dr. Shahin Shafiee
*Thermal Science Laboratory Instructor***

MECHANICAL ENGINEERING DEPARTMENT
MEASUREMENT LABORATORY LABORATORY
GRADING SHEET
FALL 2021 SECTION P01

Title of Experiment: Performance of a Refrigeration System with AEV

Name: Andrew Vaughn, Chibuike Ejimadu, Zion Brown, Cori Yancy, & Idris

Agboola Date Lab was Performed: 10/06/21

Report Due Date: 10/23/21

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (by your conduct and observations).	3		
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report) Front End of Report (4 points).	4		
General report format (4 points)	4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters using consistent units and significant figures.	22		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw / derived) in tabular and graphical form to meet the objectives and to aid in interpretation.	14		
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends.	14		
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		

Percentage for this Performance Criteria			
TOTAL FOR THIS LAB			

October 23, 2021

Dr. Shahin Shafiee
Mechanical Engineering
Department Prairie View A&M
University

Dear Dr. Shafiee,

The attached technical laboratory project report contains the detailed results of the laboratory project work on the performance of a refrigeration system with an automatic expansion valve that was performed on October 6th, 2021. The report contains the objectives of the experiment, the theories on the thermodynamic properties and performance of a refrigeration system, the equations used for analysis of the data, the raw experimental data, graphical presentation of the important results, discussion, and interpretation of results.

Please contact the group leader of the Thermal Science Laboratory Group by e-mail at avaughn12@pvamu.edu, if you have any questions about the report.

Sincerely, Andrew

Vaughn



ABSTRACT

1. The purpose of the experiment

The purpose of the experiment is to show how the system operates with an automatic expansion valve. This is achieved by plotting the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h and p-v diagrams and compare these with those from thermodynamics predictions. Students then will determine the power requirement for the compressor, calculate the heat rejected by the condenser, calculate the heat absorbed by the evaporator, calculate the maximum theoretical and actual coefficients of performance for the cycle, and calculate the compressor efficiency.

2. The brief description of the method used

The experiment was conducted using the Amatrol T7082 Thermal System Trainer. Within that system, the widely used refrigerant 134a was used as the liquid coolant in the analysis of a Vapor Compression Refrigeration System. This lab used the Thermostatic Expansion Valve instead of a capillary tube for the expansion of the refrigerant. Once the apparatus was started, it was used to record measurements of pressure, temperature and currents at each stage needed to perform the lab analysis. This process was repeated until the results became steady state.

3. The significant results of the tests

The results shown in Figures 5.1, 5.2, and 5.3 indicate that the refrigerant enters with low pressure and temperature before it can be expanded and have the heat absorbed. Pressure has a directly proportional relationship to enthalpy and regarding temperature, there is also a directly proportional relationship to entropy.

4. The major conclusions drawn from the results

In line with the objectives, the system uses an automatic expansion valve to have a constant pressure. Pressure has different relationships with volume and entropy just as there is a relationship with temperature and entropy. The ideal vapor compression refrigeration cycle uses the four processes to stabilize the system so heat can either be absorbed or released.

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

The Carnot thermodynamic cycle is commonly applied to most refrigeration units. In this chapter, the theory and process that was performed for the experiment will be shown as well as the raw experimental data.

1.1 Objectives of the Experiment

Using the thermodynamic theory of the vapor compression refrigeration cycle, the properties and efficiencies of the cycle of a refrigeration unit with an AEV was studied with the following objections.

The objectives of this experiment were to:

1. Show how the refrigeration system operates with an automatic expansion valve.
2. To plot the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h, and p-v diagrams and compare these with those from thermodynamic predictions.
3. To determine the power requirement for the compressor.
4. To calculate the heat rejected by the condenser.
5. To calculate the heat absorbed by the evaporator.
6. To calculate the maximum theoretical and actual coefficients of performance for the cycle.
7. To calculate the compressor efficiency.

1.2 Theory Associated with Experiment

In this experiment, the understanding of the refrigeration thermodynamic cycle, mechanical efficiency of an electric compressor, and the automatic expansion valve in a refrigerating cycle are necessary for understanding and calculations.

Refrigeration Thermodynamic Cycle

The thermodynamic cycle of refrigeration is based off a reversed Carnot cycle, a theoretical thermodynamic cycle that exists between two heat reservoirs, high and low, that is perfectly isentropic.

In the traditional Carnot cycle, which acts as a heat engine, the difference in energy between the two heat reservoirs is converted into mechanical work. Reversing this cycle creates a temperature difference between the two reservoirs is created by adding mechanical work.

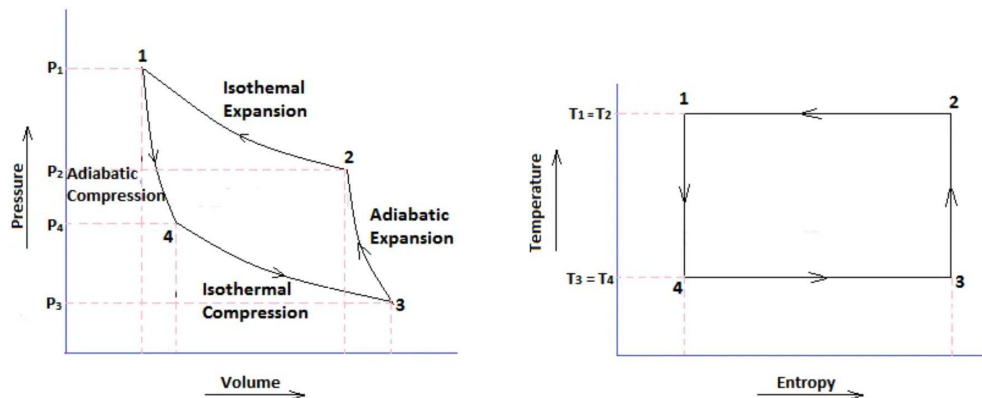


Figure 1.1 Reverse Carnot Cycle

This figure above shows the reverse Carnot Cycle between the 4 states on a pressure vs. specific volume graph and a temperature vs. entropy graph. It is annotated to show the processes between states.

Figure 1.1 shows the reverse Carnot cycle used in refrigeration. On the right side of the figure, the processes needed for the cycle between the states is shown. Between states 1 and 4, the medium is compressed adiabatically, or without the increase in entropy. This decreases energy in the medium through the decrease in pressure. This fluid with a decrease in energy is then allowed to lose pressure again from states 4 to 3, but with the ability to absorb the heat in the ambient, superheating the fluid into a vapor state. The superheated vapor is then further compressed, adding pressure from states 3 to 2, without any loss of heat to further increase the energy. Finally, from states 2 to 1, the fluid condenses, allowing the loss of heat into the ambient before it reaches state 1 again.

In reality, no process is truly adiabatic or isentropic, never being without heat fluctuation or the increase in entropy. The Carnot cycle is purely theoretical and cannot be approximated in practice, particularly processes 4-1 and 2-3. To increase efficiencies, the fluid is vaporized fully before state 3 in figure 1.1, and the 4-1 process is converted into a throttling process, to better allow the decrease in pressure of the vapor. This new cycle is referred to as the ideal vapor-compression refrigeration cycle. This cycle is the one used in practical applications.

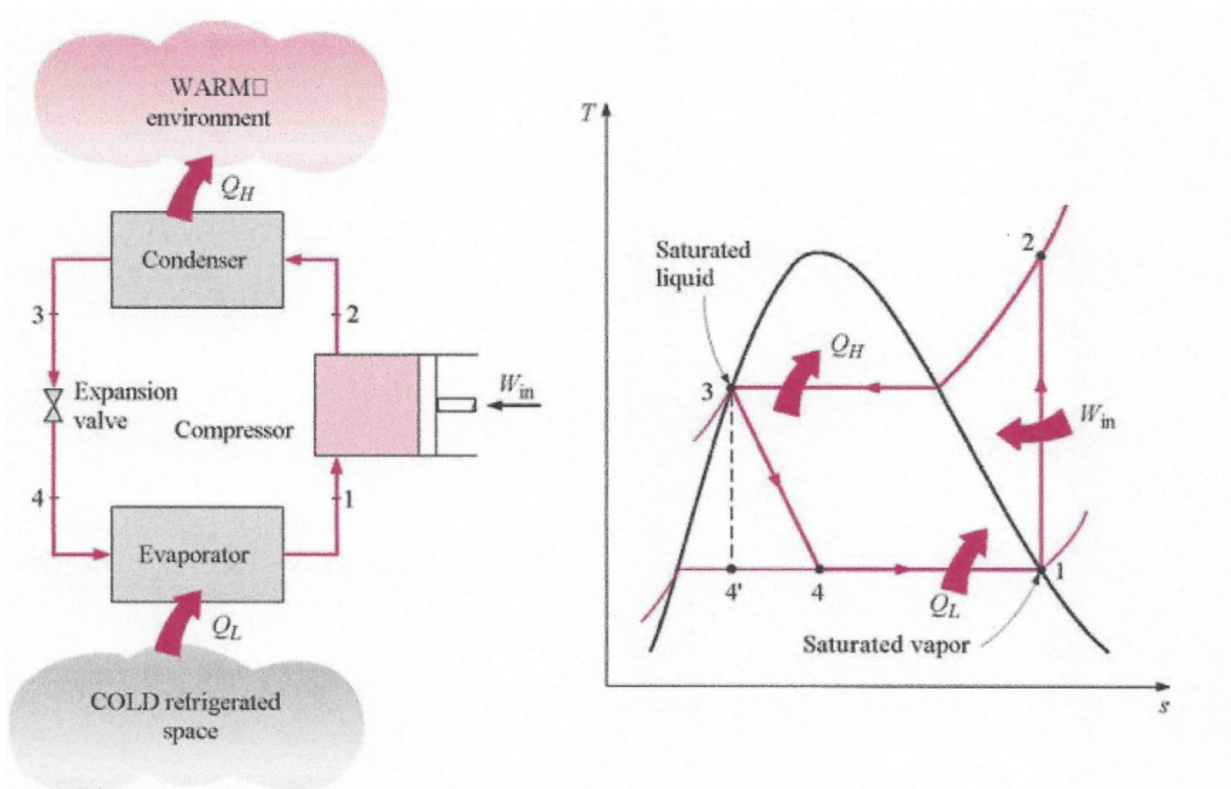


Figure 1.2 Ideal Vapor-Compression Refrigeration Cycle

This Figure shows the theoretical cycle with the devices necessary for the processes between the states on the left. On the right, the thermodynamic cycle is shown on a temperature vs entropy graph.

In the ideal vapor-compression refrigeration cycle shown in Figure 1.2, the devices necessary for the refrigeration cycle are shown. From states 1-2, for the isentropic compression process, a vapor compressor is used. From states 2-3, the constant-pressure heat rejection, where the heat is released into the ambient, the process is done with a condenser. The process from states 3-4, the expansion of the fluid, is performed using the expansion valve or throttle valve mentioned earlier. Process 4-1, the heat-absorption at constant pressure, is done using an evaporator. In this

process, the heat inside a designated area is absorbed between states 4-1, and then expelled into the ambient in process 2-3.

For the process between states 1-2, adiabatic compression is done with the use of a compressor. This increases the pressure and temperature of the refrigerant which increases its internal energy. The process is adiabatic because no heat is intentionally added to the refrigerant and all work done on the refrigerant is mechanical work.

After, from state 2-3, the process of the isobaric rejection of heat which is achieved with a condenser. This device is a long coil of pipe which allows for heat to be rejected into the ambient in an isobaric, or constant pressure, process so that the energy loss is only due to heat loss.

From state 3-4, the refrigerant undergoes isenthalpic expansion, where the pressure is quickly lowered to lower the internal energy of the refrigerant. This drastic loss in pressure and temperature allows the refrigerant to accept more heat from the inside of the low temperature well as the refrigerant is well below the temperature of the low temperature well. This can be done with several devices such as an expansion valve, capillary tube, or automatic expansion valve or AEV.

Finally, from state 4-1, the refrigerant begins absorbing heat in an isobaric process from the low temperature well via an evaporator. In this device, the refrigerant has lower internal energy which allows it to accept more energy, through heat, from the temperature well. The evaporator is much like the condenser in that it is a long winding pipe allowing it to have more surface area within the low temperature well.

For this cycle, the coefficient of performance is calculated using amount of heat lost from states 1-4, calculated from the difference in enthalpy of states 1 and 4, over the amount of work put into the system, calculated via the difference between the enthalpy of states 2 and 1. The formula is shown below.

$$COP_{RR} = \frac{q_{14}}{W_{12,34}} = \frac{h_1 - h_4}{h_2 - h_1}$$

In practical applications, no process can be wholly isentropic, therefore the process between 1-2, the compressor, has an increase in entropy which changes the cycle on the temperature vs entropy graph. In addition, the states between the end of a process and beginning of the next may have a fluctuation in energy due to increase heat or entropy.

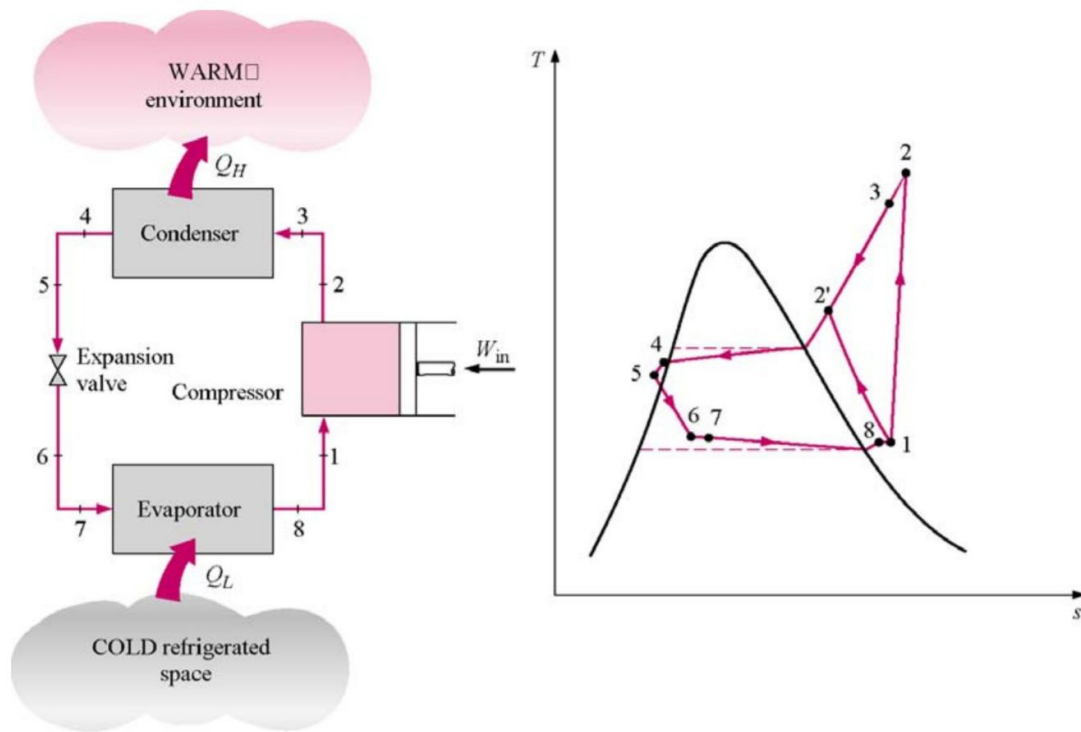


Figure 1.3 Actual Vapor-Compression Refrigeration Cycle

This Figure shows the practical cycle with the devices necessary for the processes between the states on the left. On the right, the thermodynamic cycle is shown on a temperature vs entropy graph. Additional state numbers are added to allow for the differences in the entropy and heat between the processes. State 2' represents the actual state of the refrigerant fluid leaving the actual practical compressor.

The actual vapor-compression refrigeration cycle, the increase in entropy or energy during the compression process changes the amount of work necessary for the cycle to operate. This increase, caused by friction, heat increase, or other outside factors, can actually decrease the amount of work needed in the cycle. The amount of work needed may be far lower than the work the compressor provides into the system which ultimately may decrease the COP, meaning the process is less efficient.

Compressor Efficiency

In the calculation of efficiency, the ratio of power in the theoretical isentropic compressor over the actual power used. The theoretical power of the compressor can be calculated by the difference between the enthalpies in states 1 and 2 multiplied by the mass flow, assuming that the entropy remains constant between these two states, while the actual power is calculated by Ohm's law, multiplying the current used by the compressor and the voltage. This formula is shown below.

$$\eta_{\text{compressor}} = \frac{W_{\text{theoretical}}}{W_{\text{actual}}} = \frac{m(h_2 - h_1)}{I \cdot V}$$

Automatic Expansion Valve

In order to meter out a specified amount of refrigerant into an evaporator (before state 7 in Figure 1.3), certain devices can be used. One such device is an automatic expansion valve or AEV. An AEV operates by a spring being engaged or released between the pressures of the

refrigerant before and after entering the AEV. Because pressures can fluctuate in a fluid due to the change in heat, an AEV can better regulate the amount of fluid between the differences in heat. When the pressure is lowered in an evaporator, the pressure can be maintained at a constant level via the position of the needle of the AEV moving from the change in pressure. The resistance of the needle is changed via moving the adjusting screw to increase or decrease force exerted by the adjusting spring, shown in Figure 1.4.

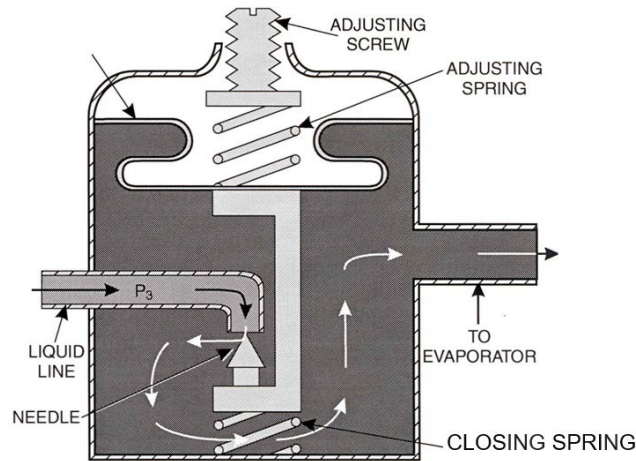


Figure 1.4 Automatic Expansion Valve

This figure shows a schematic for an automatic expansion valve, with P_3 representing the pressure condenser that is being expelled into the evaporator, exiting on the right side of the diagram.

1.3 Apparatus and Uncertainty in Reading Instruments

In this experiment, the Amatrol T7082 Thermal System Trainer was used. The fluid used in the cycle was Refrigerant 134a which is the most used in practice.

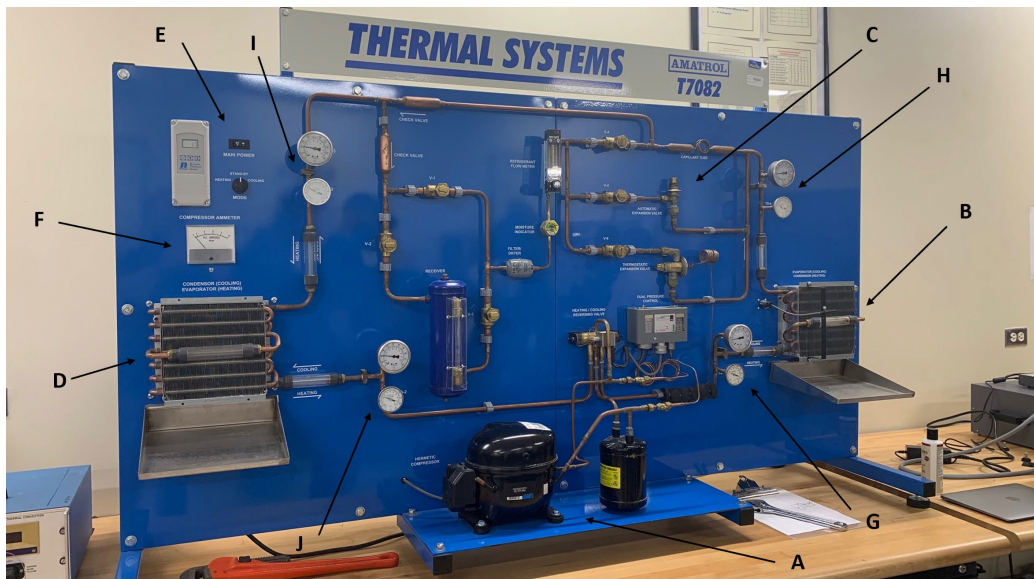


Figure 1.5 Amatrol T7082 Thermal System Trainer

In this figure, the apparatus used for the experiment, the Amatrol T7082, is shown with important components of the apparatus labeled and named in Table 1.1

Table 1.1 Legend of Components of Amatrol T7082

Letter	Component Name
A	Compressor
B	Evaporator
C	Capillary Tube & AEV
D	Condenser
E	Electronic Temperature Control & Power Switch
F	Compressor Ammeter
G	PS1 & TS1 Gauge
H	PS2 & TS2 Gauge
I	PS3 & TS3 Gauge
J	PS4 & TS4 Gauge

For the Amatrol T7082 Thermal System Trainer, the apparatus is set up to resemble the actual vapor-compression refrigeration cycle, with devices to allow for the analysis of the different states of the cycle. For this experiment, the refrigeration cycle was used causing the refrigerant to flow clockwise.

The Compressor, shown in Figure 1.6, represents the process between states 1-2 for this experiment, where the adiabatic compression takes place. The refrigerant enters from the right and flows to the left toward the condenser. For these processes, there are temperature and pressure gauges which were used for the experimental data. These gauges are shown in Figure 1.7.



Figure 1.6 Compressor of Amatrol T7082

This figure shows the compressor of the experimental apparatus, representing the process between states 1-2.



Figure 1.7 Example Temperature and Pressure Gauges of Amatrol T7082

In this figure, the temperature and pressure gauges used for the experimental readings is shown. The temperature was read in $^{\circ}\text{C}$ and the pressure was read in bar and converted to kPa.

The Condenser, where the heat rejection process occurs, of the apparatus was located between the readings for PS2/TS2 and PS3/TS3. This device is shown in Figure 1.8.



Figure 1.8 Amatrol T7082 Condenser

In this figure, the condenser of the experimental device is shown.

The expansion devices of the AEV and capillary tube are shown in Figure 1.9. Both devices are used with certain valves on the device used to focus this experiment.

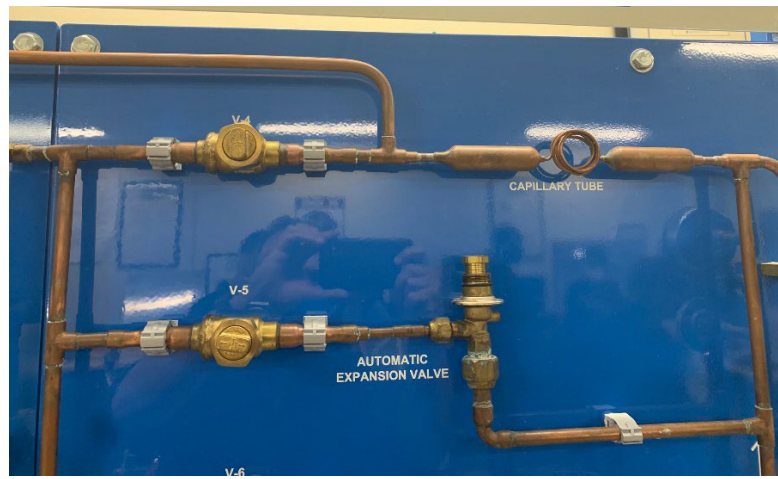


Figure 1.9 Amatrol T7082 Capillary Tube and AEV

This figure shows the two refrigerant expansion devices used for this experiment.

The isobaric heat absorption process for this cycle takes place in the evaporator of this device, shown in Figure 1.10.

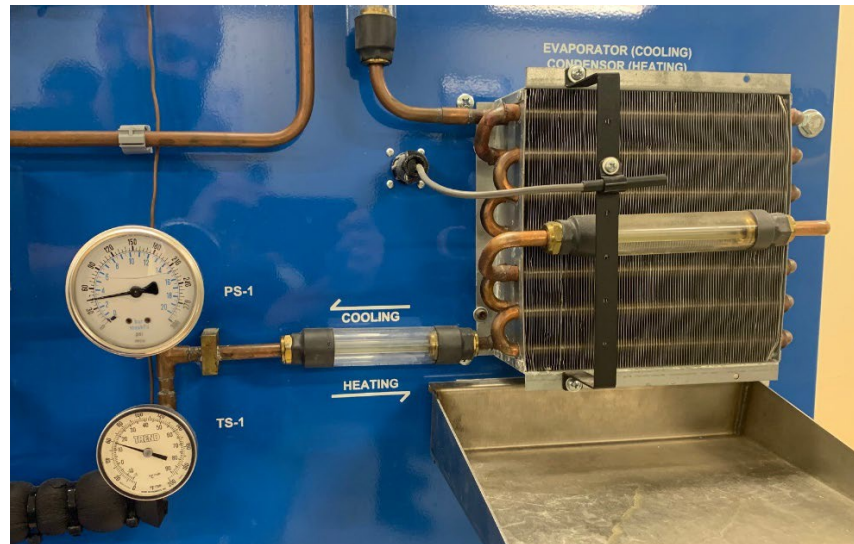


Figure 1.10 Amatrol T7082 Evaporator

In this figure, the evaporator for the refrigeration process of the experimental device is shown.

The apparatus is controlled using the electronic temperature control device shown in Figure 1.11. This device allows the apparatus to use the heating or refrigeration cycles with specified temperatures. It also displays the ambient temperature of the laboratory. The main power switch is to the right of this device as well as the compressor ammeter where the current of the compressor can be measured.



Figure 1.11 Amatrol T7082 Electronic Temperature Control

This figure shows the electronic temperature control of the apparatus. Also shown in this figure is the main power switch, heating and cooling switch, and compressor ammeter.

The uncertainty of the measurements of this apparatus are shown in Table 1.2, determined via the ability to read the pre-installed gauges.

Table 1.2 Uncertainty of Readings

Name of Instrument	Variable Read Using Instrument and Units	Uncertainty in Reading the Instrument and Units
Electronic Temperature Controller Display	Room Temperature ($^{\circ}\text{C}$)	$\pm 0.5\text{ }^{\circ}\text{C}$
Evaporator Outlet Pressure Gauge	Evaporator Outlet Pressure PS1 (kPa)	$\pm 25\text{ kPa}$
Evaporator Outlet Temperature Gauge	Evaporator Outlet Temperature TS1 ($^{\circ}\text{C}$)	$\pm 0.5\text{ }^{\circ}\text{C}$
Condenser Inlet Pressure Gauge	Condenser Inlet Pressure PS2 (kPa)	$\pm 25\text{ kPa}$
Condenser Inlet Temperature Gauge	Condenser Inlet Temperature TS2 ($^{\circ}\text{C}$)	$\pm 0.5\text{ }^{\circ}\text{C}$
Condenser Outlet Pressure Gauge	Condenser Outlet Pressure PS3 (kPa)	$\pm 25\text{ kPa}$
Condenser Outlet Temperature Gauge	Condenser Outlet Temperature PS3 ($^{\circ}\text{C}$)	$\pm 0.5\text{ }^{\circ}\text{C}$
Evaporator Inlet Pressure Gauge	Evaporator Inlet Pressure PS4 (kPa)	$\pm 25\text{ kPa}$
Evaporator Inlet Temperature Gauge	Evaporator Inlet Temperature PS4 ($^{\circ}\text{C}$)	$\pm 0.5\text{ }^{\circ}\text{C}$
Compressor Current	Compressor Current Reading (Amps)	$\pm 0.2\text{ A}$

1.4 Experimental Safety

Although Refrigerant 134a is a safe, stable, non-explosive fluid for refrigeration cycles basic safety measures were implemented. Electrical wiring was checked for any fraying. The area around the apparatus was kept organized and clutter free. The number of students around the apparatus was

monitored closely to prevent overcrowding. In addition to this, the experimental apparatus was not allowed to run longer than 2 hours to prevent any damage to the apparatus or cause any chance of electrical failings.

1.5 Experimental Procedure

After the instructor determined the apparatus was properly prepared for operation and the group became familiarized with the apparatus, the following steps were taken in the procedure.

1. The power switch was confirmed to be in the OFF position.
2. The mode switch was confirmed to be set on STAND-BY.
3. The dual pressure controller on the apparatus was properly set using the following parameters. The dual pressure controller had configurations only in English units despite the lab being done using SI units:
 - The cut-out scale was set to 5 psi using a standard screwdriver to adjust its screw.
 - The cut-in scale was set to 45 psi.
 - The high-pressure cut-out setting to the right of the pressure controller was set to 200 psi.
4. The refrigerant valves on the T7082 were set to the following positions:
 - V1 – open
 - V2 – closed
 - V3 – closed
 - V4 – closed
 - V5 – open
 - V6 – closed
5. The electrical cord for the apparatus was plugged into the standard wall outlet.
6. The power switch was turned to the ON position, noting the LCD on the electronic controller display showing the room temperature. This temperature was recorded for the experiment as T_{room}.
7. The electronic temperature controller was set using the following sub-steps:
 - The SET button was pressed on the controller.
 - The up and down arrow keys were used to select °C on the LCD.
 - The SET button was pressed again to the set temperature mode. The arrow keys were used to set the disengaging temperature, lower than the room temperature, at 13 °C to ensure the cycle will run constantly for the experiment.
 - The SET button was pressed once again to set the temperature differential mode using the arrow keys to 6 °C. This is the difference the engaging temperature was larger than the disengaging temperature, ensuring the temperature was higher than the room temperature.
 - The SET button was pressed again to enter heating/cooling mode selection, using the arrow keys to select “C1” on the LCD.
 - The SET button was pressed one final time to show the ambient room temperature again.
8. The mode switch was turned to the COOLING position, causing the blowers and the compressor to turn on.
9. The apparatus was allowed to operate for 10 minutes to reach steady state conditions with no bubbles visibly flowing through the flow meter.
10. The AEV's plastic cover of the adjustment screw was removed.
11. Using a 3/4 inch open end wrench, the screw on the AEV was adjusted so that the vapor pressure settles to 240 kPa on PS4.
12. The following data was recorded on the device for the experiment.
 - The pressure gauges (PS1, PS2, PS3, PS4) and the temperature gauges (TS1, TS2, TS3, TS4) were located on the apparatus, noting that the pressure reading needed to be multiplied by 100 to convert it to kPa.

- The data on each gauge was recorded 6 separate times as well as the compressor current, with 5 minutes given between readings.

1.6 Presentation of Raw Experimental Data

The apparatus was allowed to reach steady state and given time between each set of readings to produce 6 iterations of data as shown in Table 1.3.

Table 1.3 Raw Experimental Data with Uncertainty

Pressure and Temperature Gauge Readings	Iterations					
	1	2	3	4	5	6
PS1 (bar)	3.00 ± 0.25	3.00 ± 0.25	3.00 ± 0.25	3.00 ± 0.25	3.00 ± 0.25	3.00 ± 0.25
TS1 (°C)	15.5 ± 0.5	15.5 ± 0.5	15.5 ± 0.5	15.0 ± 0.5	15.7 ± 0.5	15.0 ± 0.5
PS2 (bar)	4.20 ± 0.25	4.30 ± 0.25	4.30 ± 0.25	4.30 ± 0.25	4.40 ± 0.25	4.40 ± 0.25
TS2 (°C)	15 ± 0.5	15.5 ± 0.5	15.5 ± 0.5	15 ± 0.5	15.2 ± 0.5	15.0 ± 0.5
PS3 (bar)	4.40 ± 0.25	4.40 ± 0.25	4.40 ± 0.25	4.20 ± 0.25	4.40 ± 0.25	4.40 ± 0.25
TS3 (°C)	14.5 ± 0.5	14.5 ± 0.5	14.5 ± 0.5	15.0 ± 0.5	14.5 ± 0.5	14.5 ± 0.5
PS4 (bar)	3.30 ± 0.25	3.40 ± 0.25	3.40 ± 0.25	3.40 ± 0.25	3.30 ± 0.25	3.00 ± 0.25
TS4 (°C)	14.5 ± 0.5	14.5 ± 0.5	14.5 ± 0.5	14.5 ± 0.5	14.75 ± 0.5	14.75 ± 0.5
I Compressor (A)	4.00 ± 0.2	4.10 ± 0.2	4.15 ± 0.2	4.15 ± 0.2	4.20 ± 0.2	4.18 ± 0.2
T Room (°C)	17 ± 0.1					

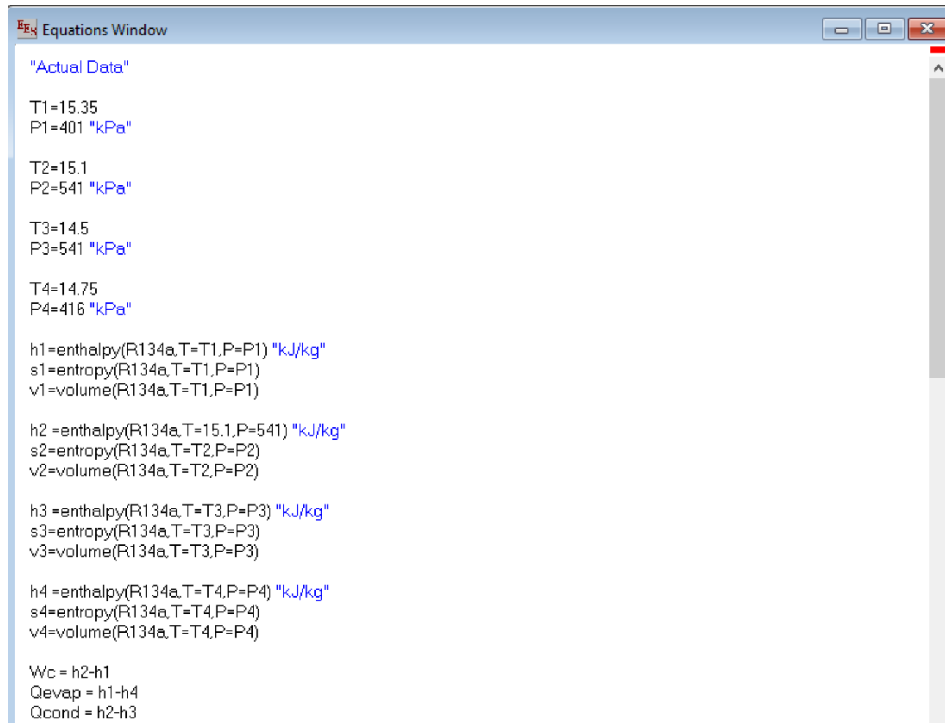
CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

This chapter contains the total analysis of the data using the Engineering Equation Solver (EES) program, the results of the total analysis, uncertainty in the computed results, and the analysis results of the data computed through EES. The sample analysis was omitted as all the analysis was able to be provided as a whole and no other iterations were completed.

2.1 Detailed Sample Analysis

The detailed sample analysis was done with the mean value of the 5th and 6th iteration of the raw experimental data using EES. Figure 2.1 and 2.2 show the formatted and unformatted step by step analysis done.



```

EES Equations Window

"Actual Data"

T1=15.35
P1=401 "kPa"

T2=15.1
P2=541 "kPa"

T3=14.5
P3=541 "kPa"

T4=14.75
P4=416 "kPa"

h1=enthalpy(R134a,T=T1,P=P1) "kJ/kg"
s1=entropy(R134a,T=T1,P=P1)
v1=volume(R134a,T=T1,P=P1)

h2=enthalpy(R134a,T=15.1,P=541) "kJ/kg"
s2=entropy(R134a,T=T2,P=P2)
v2=volume(R134a,T=T2,P=P2)

h3=enthalpy(R134a,T=T3,P=P3) "kJ/kg"
s3=entropy(R134a,T=T3,P=P3)
v3=volume(R134a,T=T3,P=P3)

h4=enthalpy(R134a,T=T4,P=P4) "kJ/kg"
s4=entropy(R134a,T=T4,P=P4)
v4=volume(R134a,T=T4,P=P4)

Wc = h2-h1
Qevap = h1-h4
Qcond = h2-h3

```

```

EES Equations Window
COP_theo = Qevap/Wc

"Theoretical Data"

h1_theo = h1
s1_theo = s1
v1_theo = v1

h2_theo = h2
s2_theo = s1
v2_theo = v2

h3_theo = h3
s3_theo = s3
v3_theo = v3

h4_theo = h3_theo
s4_theo = 0.275 "kJ/kg-k"
v4_theo = 0.00279 "m^3/kg"

TL = (14.5 + 273)
TH = (15.35 + 273)

COP_theo = TL / (TH-TL)

v = 110 "volts"

I = 4.19 "Amps"

Pcomp = (V*I)/1000 "kW"

Eff = 0.25
m_ref = (eff*V*I)/(Wc) "kg/s"

```

Figure 2.1 Unformatted EES Program Equations

```

EES Formatted Equations

Actual Data
T1 = 15.35
P1 = 401 kPa
T2 = 15.1
P2 = 541 kPa
T3 = 14.5
P3 = 541 kPa
T4 = 14.75
P4 = 416 kPa
h1 = h ( R134a , T=T1 , P=P1 ) kJ/kg
s1 = s ( R134a , T=T1 , P=P1 )
v1 = v ( R134a , T=T1 , P=P1 )
h2 = h ( R134a , T=15.1 , P=541 ) kJ/kg
s2 = s ( R134a , T=T2 , P=P2 )
v2 = v ( R134a , T=T2 , P=P2 )
h3 = h ( R134a , T=T3 , P=P3 ) kJ/kg
s3 = s ( R134a , T=T3 , P=P3 )
v3 = v ( R134a , T=T3 , P=P3 )
h4 = h ( R134a , T=T4 , P=P4 ) kJ/kg
s4 = s ( R134a , T=T4 , P=P4 )

```

The screenshot shows the 'Formatted Equations' window in EES software. The equations are as follows:

$$s4 = s(R134a, T=T4, P=P4)$$

$$v4 = v(R134a, T=T4, P=P4)$$

$$Wc = h2 - h1$$

$$Q_{evap} = h1 - h4$$

$$Q_{cond} = h2 - h3$$

$$COP_{actual} = \frac{Q_{evap}}{Wc}$$

Theoretical Data

$$h1_{theo} = h1$$

$$s1_{theo} = s1$$

$$v1_{theo} = v1$$

$$h2_{theo} = h2$$

$$s2_{theo} = s1$$

$$v2_{theo} = v2$$

$$h3_{theo} = h3$$

$$s3_{theo} = s3$$

$$v3_{theo} = v3$$

$$h4_{theo} = h3_{theo}$$

$$s4_{theo} = 0.275 \text{ kJ/kg-k}$$

$$v4_{theo} = 0.00279 \text{ m}^3/\text{kg}$$

$$TL = 14.5 + 273$$

$$s3_{theo} = s3$$

$$v3_{theo} = v3$$

$$h4_{theo} = h3_{theo}$$

$$s4_{theo} = 0.275 \text{ kJ/kg-k}$$

$$v4_{theo} = 0.00279 \text{ m}^3/\text{kg}$$

$$TL = 14.5 + 273$$

$$TH = 15.35 + 273$$

$$COP_{theo} = \frac{TL}{TH - TL}$$

$$v = 110 \text{ volts}$$

$$I = 4.19 \text{ Amps}$$

$$P_{comp} = \frac{v \cdot I}{1000} \text{ kw}$$

$$Eff = 0.25$$

$$m_{ref} = \frac{Eff \cdot v \cdot I}{Wc} \text{ kg/s}$$

Figure 2.2 Formatted EES Program Equations

2.2 Detail Computer Analysis of All Data

As the data was done using the average of two iterations, the sample analysis can be obtained by the analysis of the experiment as a whole using Figure 2.1 and 2.2.

2.3 Uncertainty Analysis of Major Computed Results

The uncertainty in the experimentally calculated enthalpies, coefficient of performance, and compressor work was calculated using the uncertainty analysis feature of EES as shown in Figure 2.3. The uncertainty is shown in the figure after each derived value.

Unit Settings: SI C kPa kJ mass deg		
Variables±Uncertainty	Partial derivative	% of uncertainty
<u>COP_{actual} = -0.004957±0.003476</u>		
P1 = 401±0.25	$\partial \text{COP}_{\text{actual}} / \partial P1 = 0.0001312$	0.01 %
P2 = 541±0.25	$\partial \text{COP}_{\text{actual}} / \partial P2 = 0$	0.00 %
P3 = 541±0.25	$\partial \text{COP}_{\text{actual}} / \partial P3 = 0$	0.00 %
P4 = 416±0.25	$\partial \text{COP}_{\text{actual}} / \partial P4 = -0.0001351$	0.01 %
T1 = 15.35±0.5	$\partial \text{COP}_{\text{actual}} / \partial T1 = -0.004883$	49.33 %
T2 = 15.1±0.5	$\partial \text{COP}_{\text{actual}} / \partial T2 = -2.868\text{E-}18$	0.00 %
T3 = 14.5±0.5	$\partial \text{COP}_{\text{actual}} / \partial T3 = 0$	0.00 %
T4 = 14.75±0.5	$\partial \text{COP}_{\text{actual}} / \partial T4 = 0.004947$	50.65 %
<u>Qevap = 0.9372±0.6587 [kJ/kg]</u>		
P1 = 401±0.25	$\partial \text{Qevap} / \partial P1 = -0.02492$	0.01 %
P2 = 541±0.25	$\partial \text{Qevap} / \partial P2 = 0$	0.00 %
P3 = 541±0.25	$\partial \text{Qevap} / \partial P3 = 0$	0.00 %
P4 = 416±0.25	$\partial \text{Qevap} / \partial P4 = 0.02553$	0.01 %
T1 = 15.35±0.5	$\partial \text{Qevap} / \partial T1 = 0.9277$	49.58 %
T2 = 15.1±0.5	$\partial \text{Qevap} / \partial T2 = 0$	0.00 %
T3 = 14.5±0.5	$\partial \text{Qevap} / \partial T3 = 0$	0.00 %
T4 = 14.75±0.5	$\partial \text{Qevap} / \partial T4 = -0.9353$	50.40 %
<u>Wc = -189.1±0.4639 [kJ/kg]</u>		
P1 = 401±0.25	$\partial \text{Wc} / \partial P1 = 0.02492$	0.02 %
P2 = 541±0.25	$\partial \text{Wc} / \partial P2 = 0$	0.00 %
P3 = 541±0.25	$\partial \text{Wc} / \partial P3 = 0$	0.00 %
T1 = 15.35±0.5	$\partial \text{Wc} / \partial T1 = 0.9277$	49.58 %
T2 = 15.1±0.5	$\partial \text{Wc} / \partial T2 = 0$	0.00 %
T3 = 14.5±0.5	$\partial \text{Wc} / \partial T3 = 0$	0.00 %
T4 = 14.75±0.5	$\partial \text{Wc} / \partial T4 = -0.9353$	50.40 %
<u>Wc = -189.1±0.4639 [kJ/kg]</u>		
P1 = 401±0.25	$\partial \text{Wc} / \partial P1 = 0.02492$	0.02 %
P2 = 541±0.25	$\partial \text{Wc} / \partial P2 = 0$	0.00 %
P3 = 541±0.25	$\partial \text{Wc} / \partial P3 = 0$	0.00 %
P4 = 416±0.25	$\partial \text{Wc} / \partial P4 = 0$	0.00 %
T1 = 15.35±0.5	$\partial \text{Wc} / \partial T1 = -0.9277$	99.98 %
T2 = 15.1±0.5	$\partial \text{Wc} / \partial T2 = 0$	0.00 %
T3 = 14.5±0.5	$\partial \text{Wc} / \partial T3 = 0$	0.00 %
T4 = 14.75±0.5	$\partial \text{Wc} / \partial T4 = 0$	0.00 %
No unit problems were detected.		
Calculation time = 2 sec.		

Figure 2.3 Uncertainty Analysis

2.4 Detailed Computer Analysis of all Data and Presentation of Tables of Derived Results The EES table was created using the one mean value for the steady state value of the experiment. The results of the calculations were made via EES, showing the enthalpies, the theoretical and actual coefficients of performance, and the compressor work.

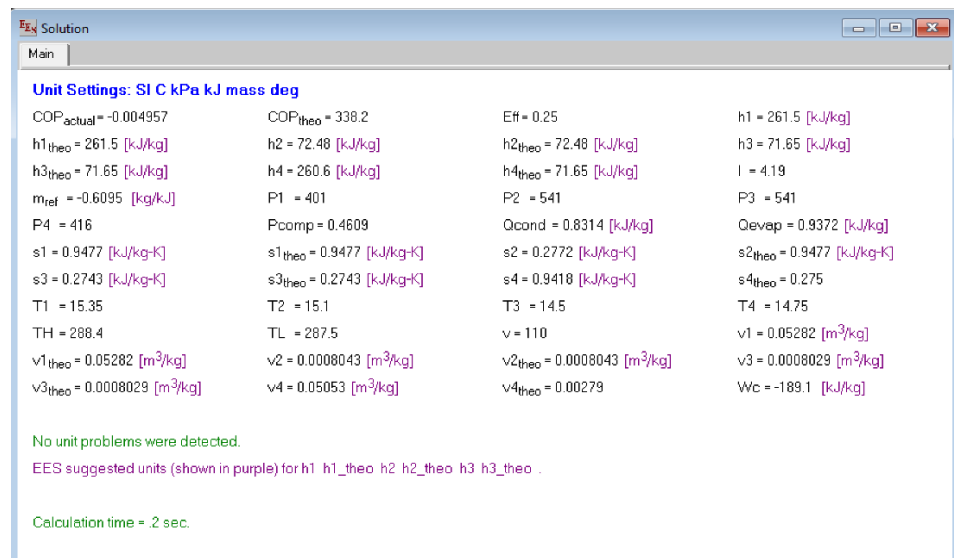


Figure 2.4 Results of Analysis of Experimental Data

CHAPTER 3

ABILITY TO INTERPRET EXPERIMENTAL DATA

This chapter contains graphical representation of the experimental data as well as interpretation of the experimental results. Following these, concluding remarks are provided based on each experimental objective. The chapter ends with recommendations and an Appendix containing the EES code used for analysis.

3.1 Presentation of Graphs and Figures

Figure 3.1 shows the pressure (P) vs. enthalpy (h) plot of the experimental data with the addition of the saturation curve provided by EES. Figure 3.2 shows the same states of the experiment on a Temperature (T) vs entropy (s) plot and Figure 3.3 shows the four states on a Pressure (P) vs specific volume (v) plot.

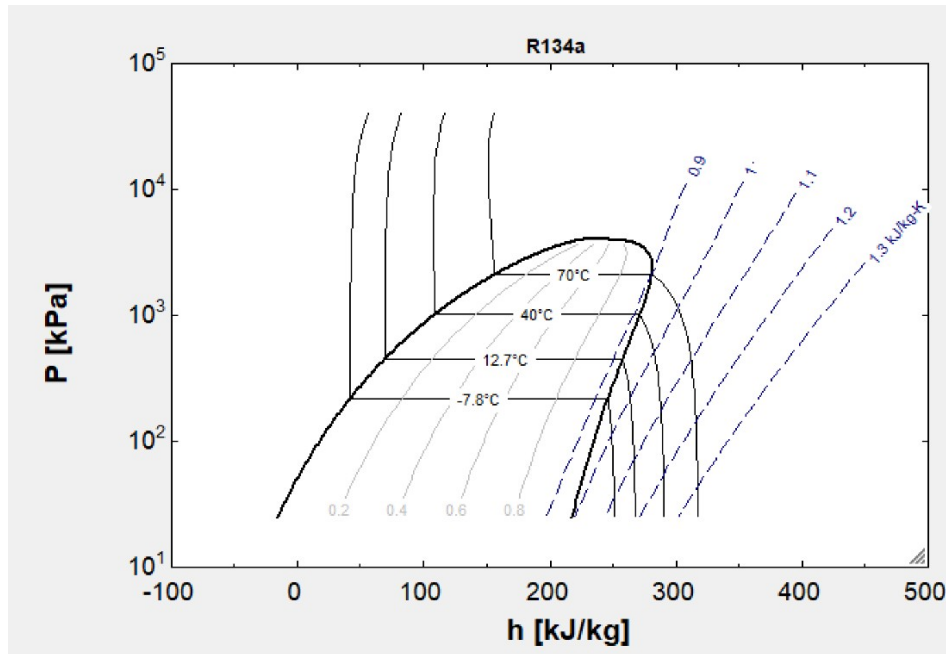


Figure 3.1 p-h Diagram for Analyzed Data of R134a

You must include the diagrams for the cycle that you tested and compare it with theoretical calculations. Then the results must be discussed.
For instance, any conclusions on COP?

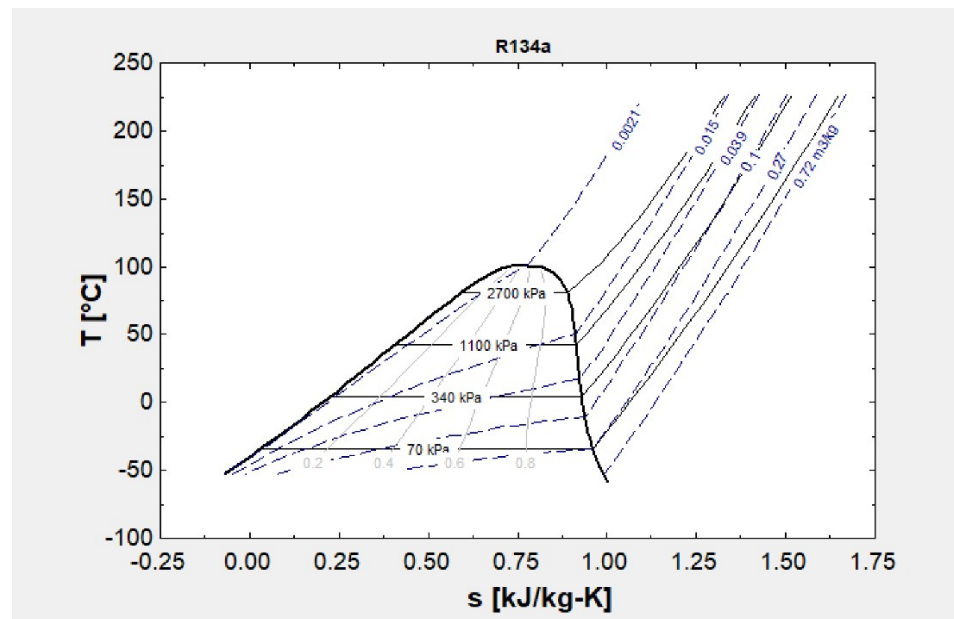


Figure 3.2 T-s Diagram for Analyzed Data of R134a

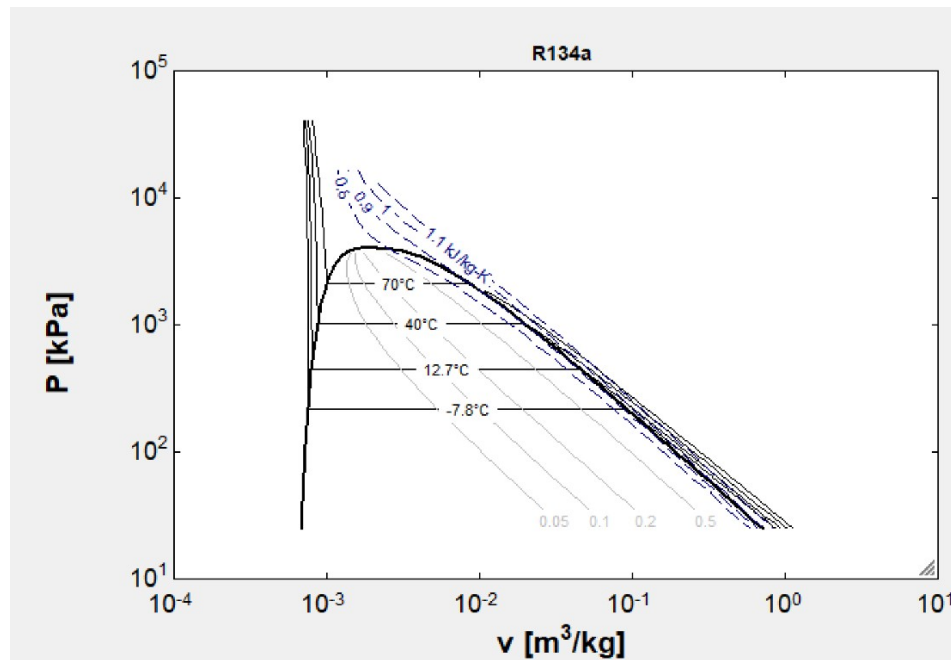


Figure 3.3 p-v Diagram for Analyzed Data of R134a

3.2 Conclusions Based on each Objective and the Result

In the theory of the experiment, the automatic expansion valve in an actual vapor-compression refrigeration cycle was explained. In the recorded data of the experiment, the results did not show these same trends which was caused by possible errors in recording data.

After comparing the diagram using the thermodynamic 7th edition textbook, it was concluded the experimental values and calculated results of the data do not accurately represent an actual vapor-compression refrigeration cycle. The values for state 2 enthalpy were lower than that of

state 1, and through the theory of refrigeration cycles, this is inaccurate as it must be larger after the use of a compressor. This error was estimated to be from inaccurate data recording or the system unable to reach a steady state.

The power requirement of the compressor was also determined to be inaccurate as the data used was assumed to be incorrect. This is also the case with the heat rejected by the condenser, the heat absorbed by the evaporator, the COP of the actual system, and the compressor efficiency.

3.3 Recommendations

After completing the experiment, the inconsistencies of the thermodynamic property trends in association with the theoretical were inconsistent. It is the recommendation to more accurately read the lab handout and instructions, properly record the data as well as record many different iterations of the data to add more validity.

REFERENCES

- Çengel, Y. and Boles, M., 2011. *Thermodynamics*. 7th ed. New York, NY: McGraw-Hill.
- Engineering, B.H. *Constant pressure expansion valve or automatic expansion valve*. 2009 [cited 2021 April 18]; Available from: <https://www.brighthubengineering.com/hvac/58467-constant-pressure-expansion-valve-or-automatic-expansion-valve/>.

APPENDIX A EES Formatted Equations

```

Formatted Equations

Actual Data
T1 = 15.35
P1 = 401 kPa
T2 = 15.1
P2 = 541 kPa
T3 = 14.5
P3 = 541 kPa
T4 = 14.75
P4 = 416 kPa
h1 = h ( R134a , T=T1 , P=P1 ) kJ/kg
s1 = s ( R134a , T=T1 , P=P1 )
v1 = v ( R134a , T=T1 , P=P1 )
h2 = h ( R134a , T=15.1 , P=541 ) kJ/kg
s2 = s ( R134a , T=T2 , P=P2 )
v2 = v ( R134a , T=T2 , P=P2 )
h3 = h ( R134a , T=T3 , P=P3 ) kJ/kg
s3 = s ( R134a , T=T3 , P=P3 )
v3 = v ( R134a , T=T3 , P=P3 )
h4 = h ( R134a , T=T4 , P=P4 ) kJ/kg
s4 = s ( R134a , T=T4 , P=P4 )

Formatted Equations
s4 = s ( R134a , T=T4 , P=P4 )
v4 = v ( R134a , T=T4 , P=P4 )
Wc = h2 - h1
Qevap = h1 - h4
Qcond = h2 - h3
COPactual =  $\frac{Q_{evap}}{Wc}$ 

Theoretical Data
h1theo = h1
s1theo = s1
v1theo = v1
h2theo = h2
s2theo = s1
v2theo = v2
h3theo = h3
s3theo = s3
v3theo = v3
h4theo = h3theo
s4theo = 0.275 kJ/kg-k
v4theo = 0.00279 m3/kg
TL = 14.5 + 273

```

```

s3theo = s3
v3theo = v3
h4theo = h3theo
s4theo = 0.275 kJ/kg-k
v4theo = 0.00279 m3/kg
TL = 14.5 + 273
TH = 15.35 + 273
COPtheo =  $\frac{TL}{TH - TL}$ 
v = 110 volts
I = 4.19 Amps
Pcomp =  $\frac{v \cdot I}{1000}$  kw
Eff = 0.25
mref =  $\frac{Eff \cdot v \cdot I}{Wc}$  kg/s

```

APPENDIX B EES Unformatted Equations

```

EES Equations Window

"Actual Data"

T1=15.35
P1=401 "kPa"

T2=15.1
P2=541 "kPa"

T3=14.5
P3=541 "kPa"

T4=14.75
P4=416 "kPa"

h1=enthalpy(R134a,T=T1,P=P1) "kJ/kg"
s1=entropy(R134a,T=T1,P=P1)
v1=volume(R134a,T=T1,P=P1)

h2=enthalpy(R134a,T=15.1,P=541) "kJ/kg"
s2=entropy(R134a,T=T2,P=P2)
v2=volume(R134a,T=T2,P=P2)

h3=enthalpy(R134a,T=T3,P=P3) "kJ/kg"
s3=entropy(R134a,T=T3,P=P3)
v3=volume(R134a,T=T3,P=P3)

h4=enthalpy(R134a,T=T4,P=P4) "kJ/kg"
s4=entropy(R134a,T=T4,P=P4)
v4=volume(R134a,T=T4,P=P4)

Wc = h2-h1
Qevap = h1-h4
Qcond = h2-h3

EES Equations Window

COP_actual = Qevap/Wc

"Theoretical Data"

h1_theo = h1
s1_theo = s1
v1_theo = v1

h2_theo = h2
s2_theo = s1
v2_theo = v2

h3_theo = h3
s3_theo = s3
v3_theo = v3

h4_theo = h3_theo
s4_theo = 0.275 "kJ/kg-k"
v4_theo = 0.00279 "m^3/kg"

TL = (14.5 + 273)
TH = (15.35 + 273)

COP_theo = TL / (TH-TL)

v = 110 "volts"

I = 4.19 "Amps"

Pcomp = (v*I)/1000 "kW"

Eff = 0.25
m_ref = (eff*v*I)/(Wc) "kg/s"

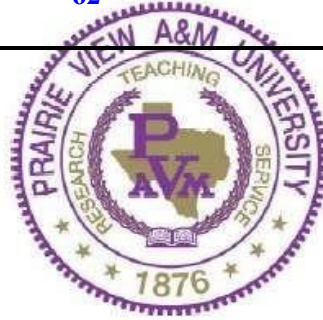
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X | Line: 35 Char: 1 | Wrap: On | Insert | Caps Lock: Off | SI C kPa kJ mass deg | Warnings: On | Unit Chk: Auto | Complex: Of

BELOW AVERAGE

**MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY**

62



**MCEG 3021 THERMAL SCIENCE
LABORATORY
Fall 2021**

**LABORATORY REPORT ON
“Refrigeration Cycle”**

**Conducted on
October 7th, 2021**

**Submitted by
Taylore Davis
Devonte Mitchell
Ethan Philips
William Scott
Allun Ward**

**On
October 23rd, 2021**

**To
Dr. Shahin Shafiee
*Thermal Science Laboratory Instructor***

MECHANICAL ENGINEERING DEPARTMENT
THERMALSCIENCE LABORATORY LABORATORY
GRADING SHEET
FALL 2021 SECTION P01

Title of Experiment: _____

Name: _____

Date Lab was Performed: _____

Report Due Date: _____

<i>Ability to Conduct Experiments</i>	MAX	Your Score	Comments
Ability to demonstrate general lab safety (your conduct and observations).	3		
Ability to follow the procedure and properly rephrasing the procedure to reflect what you did during the experiment.	7		
Ability to demonstrate knowledge of how equipment function, their limitations, and the uncertainty associated with reading the instruments.	5		
Ability to collect and record the raw data using appropriate units of measurement and identify the dependent and independent variables in the experiment.	5		
Total for Ability to Conduct Experiments	20		
Percentage for this Performance Criteria			
<i>Ability to Analyze and Interpret experimental Data in a Formal Report</i>			
Report format (Ability to properly format and present a technical report)			
Front End of Report (4 points).	4		
General report format (4 points)	4		
Provides appropriate abstracts for the experimental report	5		
Theory and equations for experimental and theoretical analysis of experimental data especially when requested for	5		
Ability to analyze the data using appropriate software to generate the required parameters	12		
Correct solutions with consistent units and significant figures.	10		
Use of statistical analysis as needed including uncertainty analysis	5		
Ability to present the data (raw /derived) in tabular form to meet the objectives and to aid in plotting the results interpretation.	4		
Ability to present the data (raw /derived) in well labeled graphical form to meet the objectives and to aid in interpretation.	10		
Ability to discuss the raw and derived data/graphs and assess the validity of the results in relation to the underlying theory and expected trends. (Interpretation of experimental data & results)			
Effect of independent (X-axis) variable on the dependent (Y-axis variable). 4 Points			
Effect of parametric variable change on the dependent (Y-axis variable). 4 Points			
Comparison of experimental results with theoretical results/prediction/trend. 4 Points			
Statement on goodness or reasonableness of results. 2 Points			
Ability to draw appropriate and reasonable conclusions in relations to each of the experimental objectives. One conclusion statement for each objective.	7		
Total for Ability to Analyze and Interpret experimental Data	80		
Percentage for this Performance Criteria			
TOTAL FOR THIS LAB			

Letter of Transmittal
October 20th, 2021

Dr. Shahin Shafiee

Mechanical Engineering Department
Prairie View A&M University

Dear Dr. Shafiee:

The attached technical laboratory report contains the detailed results of the Refrigeration Cycle laboratory work done on October 7th, 2021. The report contains objectives of the experiment, the theory on refrigeration cycle, the equations used for analysis of the data, the raw experimental data, graphical presentation of the important results, discussion and interpretation of the results and recommendations.

Please contact me at 346-714/9529 or by email at award18@pvamu.edu if you have questions regarding the report.

Sincerely,

Chapter 3 is incomplete.

Allun D. Ward

Abstract

1. The purpose of the experiment

The purpose of the experiment was to observe the different stages of the refrigeration cycle and study the four major components: Compressor, Condenser, Capillary Tube, and Expansion device.

2. The brief description of method used

The experiment was conducted using the Amatrol T7082 Thermal System. The current was pumped through the compressor and the expansion valves until finally it was completed at the evaporator. The pressures and the temperatures at 8 different parts of the system were recorded at a fixed room temperature of 17 C.

3. The significant results of the tests

The significant results of the experiment were that as the temperature was higher the pressure was low. As the temperature was low the pressure was high. However, as the current flowing through the system reached the end, the pressure and temperature increased from the other three readings. The pressure from PS3 increased from 4.4 to 14.5 for PS4. TS3 decreased from 14.5 to 3.3.

4. The major conclusions drawn from the results

In conclusion, the pressure and temperature are complete opposites from one another. As one is high the other is low. Also, the pressure and temperature changes significantly as it reaches the evaporator.

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CHAPTER 1

ABILITY TO CONDUCT EXPERIMENTS

The experimental objectives and the theory associated with the refrigeration cycle are discussed in this chapter in addition to the detailed experimental procedure and the data collected during the experiment. Other topics discussed in this section include the uncertainties in the measured variables and safety issues observed during the lab.

1.1 Objectives of the Experiment

The objectives of this experiment are to:

1. show how the system operates with an automatic expansion valve.
2. plot the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h and p-v diagrams and compare these with those from thermodynamics predictions.
3. determine the power requirement for the compressor.
4. calculate the heat rejected by the condenser.
5. calculate the heat absorbed by the evaporator.
6. calculate the maximum theoretical and actual coefficients of performance for the cycle.
7. calculate the compressor efficiency.

1.2 Theory Associated with Experiment

When a current is compressed no matter the substance during its process its properties are changing. The temperature can change, the pressure can change etc. There were various mechanisms used during the experiment that changed the properties of the substance. Those Mechanisms are discussed below.

Compressor

The first process encountered by the refrigerant is an adiabatic compression. Here, the refrigerant in the vapor state is compressed to higher pressure in the compressor. The compressor is located between states 2 and 1. It is used to increase the pressure and temperature of the refrigerant, it should operate with refrigerant vapor only. This compression is adiabatic since only work is performed on the vapor and no heat is transferred in or out at this time. However, the compression itself causes a dramatic increase in the vapor temperature (based on the Ideal Gas Law).

Condenser

The second process is the transfer of heat out of the refrigerant at constant pressure (i.e. isobaric process). During this process, the vapor condenses to the liquid state. This is carried out in the condenser. The condenser is located between states 1 and 4. It is a heat exchanger to remove heat from the refrigerant vapor in order to condense it into liquid. The heat removed is used to achieve the space heating required.

Capillary tube

The next process involves what is known as an "isenthalpic expansion" of the refrigerant from state 4 to state 3. The saturated liquid refrigerant at high pressure passes through an expansion valve where the pressure is immediately lowered. Because the pressure changes so quickly, a portion of the liquid instantly boils off into vapor (this is also known as "flashing"). This is because the liquid at

high pressure contains too much heat to remain completely as a liquid at the lower pressure. This is located between states 4 and 3. The process in the throttle valve is a constant enthalpy process. This expansion is called "isenthalpic" because the enthalpy of the refrigerant is the same before and after the expansion valve. Recall that enthalpy represents the total energy contained in the refrigerant. When the refrigerant passes through the expansion valve, the energy must remain the same since no heat or work is added to the system. During the expansion, both the pressure and temperature of the refrigerant are dramatically decreased. This new temperature is now below that of the storage space being cooled. The refrigerant begins as a saturated liquid at high pressure at state 4. During the expansion, the refrigerant decreases in pressure at constant enthalpy.

Automatic Expansion Valve

An automatic expansion valve (AEV) is another refrigerant control used to meter out a specific amount of refrigerant to the evaporator. The closing spring supplies a fixed amount of force against the needle valve. The adjusting spring force is modified by using an adjusting screw. As the screw is adjusted in or out, the position of the needle valve changes allowing a greater or lesser amount of refrigerant to flow toward the evaporator. The amount of flow is determined by the low side pressure.

High and Low Pressure Liquids Automatic expansion valves are useful because they are able to adjust to heat loads. This is a big advantage over the capillary tube you studied earlier. As the heat load is increased in the evaporator, the refrigerant is evaporated at a higher rate. This tends to lower the pressure in the evaporator. To compensate for this condition, the automatic expansion valve will shift the position of the needle valve to allow more refrigerant to enter the evaporator and thus maintain the pressure at a constant level. This is all done automatically with no need for monitoring.

Evaporator

The final process is the transfer of heat into the refrigerant at constant pressure (i.e. another isobaric process). During this process, the liquid evaporates into the vapor state. This change of phase is carried out at constant pressure. This allows the heat present in the thermal storage area to be absorbed at constant fixed pressure and temperature. The vapor begins as a two-phase mixture at state 3. As heat is added to the refrigerant, the remaining liquid is vaporized to a saturated vapor further heat absorption will superheat the vapor until state 2 is reached.

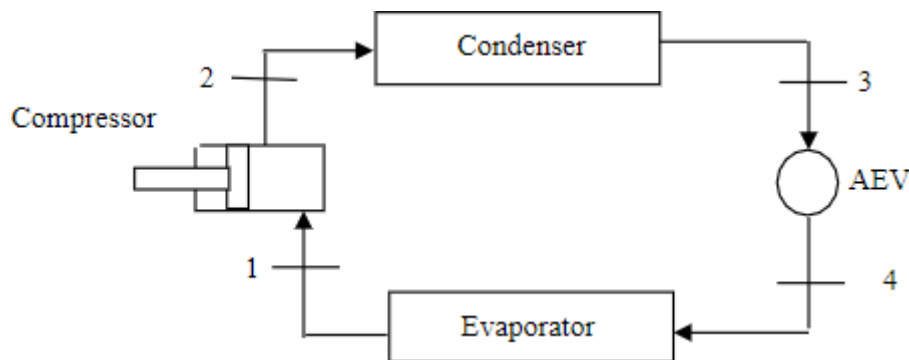


Figure 1.1 The Refrigeration Cycle

The absolute value of the power requirement by the compressor can be computed by

$$W = h_2 - h_1$$

The heat rejected by the condenser can be computed by

$$Q_{\text{cond}} = h_2 - h_3$$

The heat absorbed by the evaporator can be obtained by

$$Q_{\text{evap}} = h_1 - h_4$$

The coefficient of performance, COP, of the refrigeration system is given by

$$\text{COPR} = q_{\text{evap}} / w_C$$

1.3 Apparatus and Uncertainty in Reading Instruments

The experimental setup used was the Amatrol T7082 Thermal System as shown below in figure 1.2. This mechanism has components that create the refrigeration cycle.

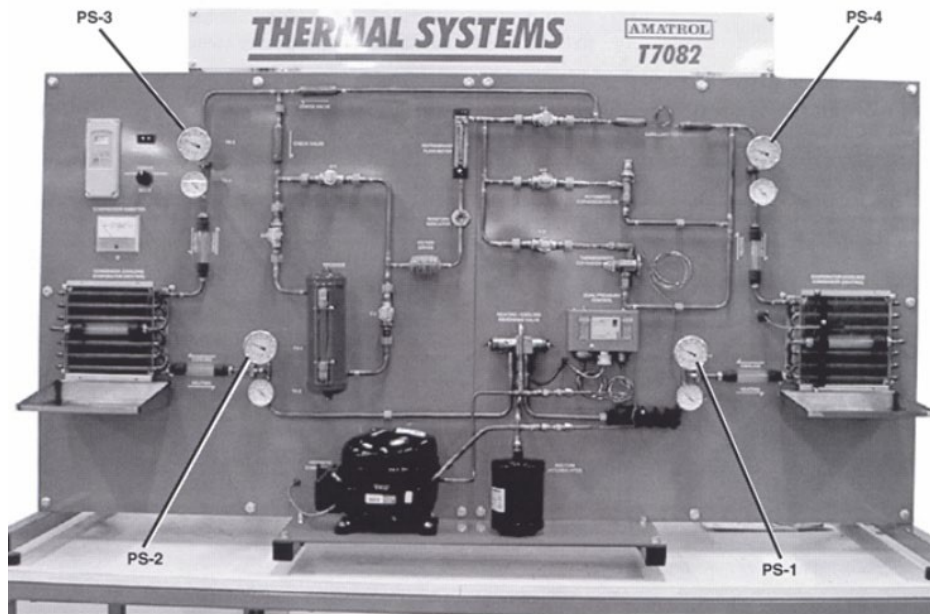


Figure 1.2 The Amatrol T7082 Thermal System Unit

Name of Instrument	Variable Read Using Instrument and Units	Uncertainty in Reading the Instrument and Units
Electronic temperature controller display	Room temperature ($^{\circ}\text{C}$)	
Evaporator Outlet Pressure Gauge	Evaporator Outlet Pressure PS1 (kPa)	
Evaporator Outlet Temperature Gauge	Evaporator Outlet Temperature TS1 ($^{\circ}\text{C}$)	
Condenser Inlet Pressure Gauge	Condenser Inlet Pressure, PS2 (kPa)	
Condenser Inlet Temperature Gauge	Condenser Inlet Temperature TS2 ($^{\circ}\text{C}$)	
Condenser Outlet Pressure Gauge	Condenser Outlet Pressure PS3 (kPa)	
Condenser Outlet temperature Gauge	Condenser Outlet temperature TS3 ($^{\circ}\text{C}$)	
Evaporator Inlet Temperature Gauge	Evaporator Inlet Temperature PS4 (kPa)	
Evaporator Inlet Temperature Gauge	Evaporator Inlet Temperature TS4 ($^{\circ}\text{C}$)	
Compressor Current	Compressor Current Reading (Amps)	

Table 1.1 Uncertainty in the Reading Experimental Variables on Instruments

You need to work on formatting. Some of the text is off margins!

1.4 Experimental Safety

It is important to understand and know the functions of the Amatrol T7082 Thermal System device. To know the on and that should be during this experiment include wearing the appropriate clothing and personal protective equipment as well items are returned to their original location and all devices are properly disconnected. Safety concerns during this experi Another safety concern was the amount of students gathered observing the experiment. This is why it was important for

1.5 Experimental Procedure

PROCEDURE:

1. Familiarize the refrigeration system with the description in Figure 1
2. Have your instructor make sure the trainer is properly prepared for operation.
3. Locate the power switch and make sure that it is in the OFF position.
4. Locate the mode switch and make sure that it is set on STAND-BY.
5. Perform the following sub-steps to make sure the dual pressure controller is properly set. Note that that dual pressure controller has only and English gauge for the pressure in psi even though this lab is in SI units:
 - A. Locate the cut-out scale and make sure it is set to 5 psi. If it is not, use a standard screwdriver to turn its adjusting screw.
 - B. Locate the cut-in scale and make sure it is set to 45 psi. Adjust if necessary.
 - C. Locate the high pressure cut-out setting on the right side of the pressure controller and make sure it is set to 200 psi. Adjust if necessary.
6. Reset the refrigerant valves to the following positions (if necessary):
 - VI - open
 - V2 - closed
 - V3 - closed
 - V4 - closed
 - V5 - open
 - V6 - closed
7. Locate the electric cord and plug it into a standard wall outlet.
 8. Turn the power switch to the ON position. You should see the LCD on the electronic temperature controller display the room temperature.
 1. **Record the room temperature being displayed** by the electronic temperature controller. You will use this temperature to determine the theoretical coefficient of performance in the next skill. $T_{room} =$
 2. Perform the following sub-steps to ensure that the electronic temperature controller is set properly.
- A. Press the button marked SET on the controller.
 - A. Use the up and down arrow keys to select °C on the LCD.
 - C. Press the SET button once again to enter into the set temperature mode. Use the arrow keys to select 13°C for the set point. The compressor will disengage when this temperature is reached. This is set lower than the room temperature so that the unit will run constantly.
 - B. Press the SET button once more to enter the temperature differential mode. Use the arrows to set this to 6°C. This tells the controller at what temperature above set point to engage the compressor (19°C in this case).
 - C. Press the SET button again to enter into the heating/cooling mode selection. Use the arrow keys to select "C1" on the LCD. This sets the controller for cooling mode.

- D. Finally, press the SET button once more and check the LCD to make sure the ambient temperature is being displayed.
11. Turn the mode switch to the COOLING position. The blowers should come on and the compressor should engage as well. Notice the direction of the fluid flow. You should observe that it now flows in the opposite direction from the heating mode.
 12. Allow the trainer to operate until it comes to steady state conditions (10 – 15 minutes). There should be no bubbles flowing through the flow meter.
 13. The AEV should have a plastic cover sitting on the adjustment screw. Remove it at this time.
 14. Use a 3/4 inch open end wrench to adjust the screw in or out so the vapor pressure settles to 240 kPa (35 psi) as read on PS-4.
 15. Perform the following sub-steps to determine the pressures and temperatures at each of the four locations. These are needed to determine the specific enthalpies at these locations in order to compute the coefficient of performance.
 - A. Locate pressure and temperature gauges PS-I and TS-I. through PS4, TS4. Note the pressure is in bar and needs to be multiplied by 100 to convert it to kPa.
 - B. Record at least six different readings of each pressure, temperature, rotameter ball height, and compressor current using the Table 2. (convert the indicated gauge pressure to absolute pressure before using them to determine the specific enthalpies).

Pressure and Temperature Gauge Readings	1	2	3	4	5	6
Evaporator Outlet Pressure PS1 (kPa)						
Evaporator Outlet Temperature TS1 (°C)						
Condenser Inlet Pressure, PS2 (kPa)						
Condenser Inlet Temperature TS2 (°C)						
Condenser Outlet Pressure PS3 (kPa)						
Condenser Outlet temperature TS3 (°C)						
Evaporator Inlet Temperature TS4 (°C)						
Evaporator Inlet Pressure PS4 (kPa)						
Compressor Current Reading (Amps)						

Table 1.2 Pressure and Temperature Readings

*Take the average of the last two steady state readings

1.6 Presentation of Raw Experimental Data

The raw measured experimental results are presented in Figure 1.3. The readings are from Pressure and Temperature Gauge Reading. A total of six takes were taken for the given data below.

Pressure and Temperature Gauge Readings	1	2	3	4	5	6
PS1 (bar)	3	3	3	3	3	3
TS1 (°C)	15.5	15.5	15.5	15	15.7	15
PS2 (bar)	4.2	4.3	4.3	4.3	4.4	4.4
TS2 (°C)	15	15.5	15.5	15	15.2	15
PS3 (bar)	4.4	4.4	4.4	4.2	4.4	4.4
TS3 (°C)	14.5	14.5	14.5	15	14.5	14.5
PS4 (bar)	14.5	14.5	14.5	14.5	14.75	14.75
TS4 (°C)	3.3	3.4	3.4	3.4	3.3	3
Compressor (A)	4	4.1	4.15	4.15	4.2	4.18

Troom = 17 °C

Figure 1.3 Raw Experimental Data

CHAPTER 2

ABILITY TO ANALYZE EXPERIMENTAL DATA

This chapter contains a detailed sample analysis using the Engineering Equation Solver (EES) program, the results of the sample analysis, uncertainty in selected computed results, and analysis results of the remaining data computed using the Solve Table feature of EES.

2.1 Detailed Sample Analysis

The detailed sample analysis was done using the first row data in Table 2.1 for all raw data. The step by step analysis done using the EES program [2] is provided sequentially and in details below. All the variables their definitions as provided in theory section of the report.

```

PS1_4 = 3
PS1_5 = 3
TS1_4 = 15.7
TS1_5 = 15
PS2_4 = 4.4
PS2_5 = 4.4
TS2_4 = 15.2
TS2_5 = 15
PS3_4 = 4.4
PS3_5 = 4.4
TS3_4 = 14.5
TS3_5 = 14.5
PS4_4 = 3.3
PS4_5 = 3
TS4_4 = 14.75
TS4_5 = 14.75
l_compressor4 = 4.2
l_compressor5 = 4.3
P_a = 1.01

```

You needed to convert pressures to Pa or kPa. That's the reason for your incorrect results.

-10

```

PS1_g = average(PS1_4,PS1_5)
PS1 = PS1_g+P_a
TS1 = average(TS1_4,TS1_5)
PS4_g = average(PS4_4,PS4_5)
PS4 = PS4_g+P_a
TS4 = average(TS4_4,TS4_5)
PS3_g = average(PS3_4,PS3_5)
PS3 = PS3_g+P_a
TS3 = average(TS3_4, TS3_5)
PS2_g = average(PS2_4,PS2_5)
PS2 = PS2_g+P_a

TS2 = average(TS2_4,TS2_5)
l_Compressor = average(l_Compressor4,l_Compressor5)

h1 = enthalpy(R134a,T = TS1,P = PS1)
v1 = volume(R134a,T = TS1,P = PS1)
s1 = entropy(R134a,T = TS1,P = PS1)

h2 = enthalpy(R134a,T = TS2,P = PS2)
v2= volume(R134a,T = TS2,P = PS1)
s2 =entropy(R134a,T = TS2,P = PS2)

h3 = enthalpy(R134a,T = TS3,P = PS3)
v3= volume(R134a,T = TS3,P = PS3)
s3 = entropy(R134a,T = TS1,P = PS3)

h4 = h3

hf4 = 57.93
hg4 = 253.065
hfg4= hg4 - hf4

```

```

sf4 = 0.2263
sfg4 = 0.7028
s4 = x4*sfg4+sf4

T[1..5] = [TS1,TS2,TS3,TS4,TS1]
P[1..5] = [PS1,PS2,PS3,PS4,PS1]
h[1..5] = [h1,h2,h3,h4,h1]
v[1..5] = [v1,v2,v3,v4,v1]
s[1..5] = [s1,s2,s3,s4,s1]

w_c = h2-h1
q_cond = h2-h3
q_evap = h1-h4
COP_R= q_evap/w_c

T_H = 295
T_L = average(TS1,TS4)+273
COP_max = T_L/(T_H-T_L)

V = 110
P_comp = (V*I_Compressor)/1000

ETA_c = 0.25
h2s = ETA_c*(h2-h1)+h1
m_ref = (P_comp*ETA_c)/(h2s-h1)

```

Figure 2.1 Formatted EES Program Equation

2.2 Sample Solution Results with Units

The EES sample analysis solution is provided table 2.1 for all raw and computed variables in alphabetical order. The units are also shown on each variable.

Unit Settings: SI C kPa kJ mass deg

$COP_{max} = 41.45$	$COP_R = -3.115$	$\eta_c = 0.25$	$h1 = 270.2$	$h2 = 269.9$	$h2s = 270.1$	$h3 = 269.5$
$h4 = 269.5$	$hf4 = 57.93$	$hfg4 = 195.1$	$hg4 = 253.1$	$I_{compressor} = 4.25$	$I_{compressor4} = 4.2$	$I_{compressor5} = 4.3$
$m_{ref} = -2.019$	$PS1 = 4.01$	$PS1_4 = 3$	$PS1_5 = 3$	$PS1_g = 3$	$PS2 = 5.41$	$PS2_4 = 4.4$
$PS2_5 = 4.4$	$PS2_g = 4.4$	$PS3 = 5.41$	$PS3_4 = 4.4$	$PS3_5 = 4.4$	$PS3_g = 4.4$	$PS4 = 4.16$
$PS4_4 = 3.3$	$PS4_5 = 3$	$PS4_g = 3.15$	$P_a = 1.01$	$P_{comp} = 0.4675$	$q_{cond} = 0.4897$	$q_{evap} = 0.7212$
$s1 = 1.345$	$s2 = 1.32$	$s3 = 1.321$	$s4 = 0.9881$	$sf4 = 0.2263$	$sfg4 = 0.7028$	$TS1 = 15.35$
$TS1_4 = 15.7$	$TS1_5 = 15$	$TS2 = 15.1$	$TS2_4 = 15.2$	$TS2_5 = 15$	$TS3 = 14.5$	$TS3_4 = 14.5$
$TS3_5 = 14.5$	$TS4 = 14.75$	$TS4_4 = 14.75$	$TS4_5 = 14.75$	$T_H = 295$	$T_L = 288.1$	$V = 110$
$v1 = 5.857$	$v2 = 5.852$	$v3 = 4.327$	$v4 = 0.06432$	$vf4 = 0.0007814$	$vfg4 = 0.05862$	$vg4 = 0.0594$
$w_c = -0.2315$	$x4 = 1.084$					

[Click on this line to see the array variables in the Arrays Table window](#)

9 potential unit problems were detected.

Check Units

Calculation time = 156 ms

Table 2.1 Resulting solution Answers of Sample Analysis

2.3 Uncertainty Analysis of Major Computed Variables

The uncertainty in the experiment calculated refrigeration cycle using uncertainty analysis in EES for the firstrow of the experimental data is shown in table 2.2.

Unit Settings: SI C bar kJ mass deg		
Variables±Uncertainty	Partial derivative	% of uncertainty
$COP_R = -61.9 \pm 0$		
$h_f = 129.5 \pm 0.5$	$\partial COP_R / \partial h_f = 0$	0.00 %
$h_g = 276.6 \pm 0.5$	$\partial COP_R / \partial h_g = 0$	0.00 %
$q_{evap} = 207.5 \pm 0$ [kJ/kg]		
$h_f = 129.5 \pm 0.5$	$\partial q_{evap} / \partial h_f = 0$	0.00 %
$h_g = 276.6 \pm 0.5$	$\partial q_{evap} / \partial h_g = 0$	0.00 %
$w = -3.353 \pm 0$ [kJ/kg]		
$h_f = 129.5 \pm 0.5$	$\partial w / \partial h_f = 0$	0.00 %
$h_g = 276.6 \pm 0.5$	$\partial w / \partial h_g = 0$	0.00 %

11 potential unit problems were detected.

Compilation time = 94 ms Calculation time = 63.47 s

Uncertainty analysis?

-5

Table 2.2

ion Cycle

2.4 Detailed Computer Analysis

EES tables were created, and the remaining rows of raw experimental data was put in the table. The EES results of the repeated calculations for all other data points were made using the solve table feature in the EES program.

CHAPTER 3 ABILITY TO INTERPRET EXPERIMENTAL DATA

This chapter gives a detailed explanation of graphs and figures produced from the experimental results. Also included in this chapter are conclusions gained from the set objectives and recommendations that can be applied going forward.

3.1 Presentation of Graphs/Figures, Discussion and Interpretation of Results Presented by each Graph/Figure

Chapter 3 is incomplete.

-20

3.2 Conclusions Based on each Objective and the Results

Conclusions based on the seven objectives are detailed below:

1. Show how the system operates with an automatic expansion valve.
It can be concluded that the automatic expansion valve works in correlation with the prefixed constant pressure in the evaporator. When the cooling decreases so does the pressure in the evaporator, while still maintaining constant pressure in the evaporator allowing it to open up more and provide more liquid refrigerant.

2. Plot the actual refrigeration cycle of the T7082 Thermal Systems trainer on T-s, p-h and p-v diagrams and compare these with those from thermodynamics predictions.

3. Determine the power requirement for the compressor.

The compressor is a device that increases the pressure of a substance by reducing the volume of that substance. In order to compute the power required by the compressor in this experiment we used the equation $w = h_2 - h_1$

4. Calculate the heat rejected by the condenser.

After completing this experiment it became clear the function of the condenser is to transfer heat from the refrigerant to another source like water or air. Heat of rejection is the energy removed from a refrigerant during the condensing process and this was computed by using equation $q_{\text{cond}} = h_2 - h_3$

5. Calculate the heat absorbed by the evaporator.

The purpose of an evaporator is to cool the refrigerant down so that heat can be absorbed. We were able to calculate the amount of heat being absorbed by the evaporator using the formula $q_{\text{evap}} = h_1 - h_4$.

6. Calculate the maximum theoretical and actual coefficients of performance for the cycle.

Once the maximum possible coefficient for the refrigeration cycle was calculated the value was higher than the actual system proving that the maximum value is getting closer. The coefficient of performance was computed by using equation $\text{COP}_R = q_{\text{evap}} / w_c$

7. Calculate the compressor efficiency.

The compressor efficiency is the ratio of work required to adiabatically compress a gas. The assumed compressor efficiency used during this experiment was 25%.

3.3 Recommendations

During experimental calculation the given pressure and temperature gauge readings of PS1-PS3 and TS1-TS3 have a consistent difference of about one, but the pressure gauge value of PS4 spikes to 14.5 and the temperature reading of TS4 has a dramatic drop to 3.3. With the drastic change in temperature and pressure gauge reading, it can be recommended that the closer in values all the temperature and pressure readings are, the more consistent the final graphs will appear. Another recommendation for the experimental procedures could be a more hands on approach that allows each group member to record their own data and then come together later to consolidate and compare results. When more than one person is responsible for recording data the accuracy of measurements are significantly improved.

REFERENCES

- [1] J. P. Holman; Experimental Methods for Engineers, Seventh Edition, McGraw Hill, 2001
- [2] Engineering Equation Solver (EES) for Microsoft Windows, F-Charts Software,

Appendices for fomatted and unformatted equations?

-3