ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

FAKULTA STROJNÍ

EVALUATION AND COMPARISON OF MATHEMATICAL MODELS FOR THERMAL CONDUCTIVITY AND DYNAMIC VISCOSITY OF REFRIGERANTS SUPERHEATED VAPOR

BACHELOR THESIS

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BACHELOR'S THESIS ASSIGNMENT

I. Personal and study details

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Assessment and Comparison of Mathematical Models for Thermal Conductivity and Dynamic Viscosity of Refrigerants Superheated Vapour

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Guidelines:

Literature search for publications discussing mathematical modeling of the thermal conductivity and dynamic viscosity of superheated refrigerants.
Evaluate each found mathematical model against semi-real data.

Bibliography / sources:

The Properties of Gases & Liquids, Reid, Prausnitz, Poling
The Corresponding-States Principle and its Practice (Thermodynamic, Transport and Surface Properties of Fluids)

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III. Assignment receipt

The student acknowledges that the bachelor's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor's thesis, the author must state the names of consultants and include a list of references.

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October 20, 2022

REVISION OF BACHELOR THESIS

Based on the decision of the State Final Examination commission of 31 August 2022, the student is obliged to revise the bachelor thesis according to the original assignment.
The student Mr. Dabhi Monilkumar Nalinkumar (personal ID number 456169) was informed that the deadline for submitting the bachelor thesis is January 10, 2023.

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SUMMARY

In this thesis, the mathematical equations for the specified properties of thermal conductivity and dynamic viscosity for the superheated refrigerants are evaluated and compared. The reader is acquainted with the fundamentals of refrigerants, their properties, their effects, the changes of state in certain temperatures and pressure, and the means used to derive the mathematical equations for thermal conductivity and dynamic viscosity. This paper is divided into four chapters of comprehensive research. The first chapter provides an introduction to the topic at hand and discusses its relevance. The second chapter explains dynamic viscosity and thermal conductivity. The third chapter gives insight into the work done over the years and a brief explanation of the work which will be used later for the statistical analysis. The dataset that was computed by using various equations is statistically analyzed in the third chapter and compared to the supplied reference values. The conclusion and the theory regarding each refrigerant at various pressures and temperatures are presented in the final chapter.

Declaration

I declare that my Bachelor Thesis is titled: " Evaluation and Comparison of Mathematical Models for Thermal Conductivity and Dynamic Viscosity of Refrigerants Superheated Vapor", developed independently under the supervision of the Ing. Šulc Vladimír, Ph.D., using the data gained and found in various literature and this list is given at the end of my bachelor thesis.

Prague 10.01.2023 Monilkumar Nalinkumar Dabhi

Thank You

I would like to thank my supervisor for the bachelor thesis, Mr. Ing. Šulc Vladimír, Ph.D. for providing me the consultations regarding the issues and helping me with all the doubts.

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LIST OF USED SYMBOLS

λ……………………..Thermal Conductivity (W*(m*K)^-1)

η……………………..Dynamic Viscosity (Pa*s)

T………………………Temperature (K)

T^*……………………..Reduced Temperature (K)

T_{crit}……………………Critical Temperature (K)

ρ ………………………Density (kg/m^3)

ρ_{crit} ……………………Critical Density (kg/m^3)

P………………………..Pressure (Pa)

v ………………………..Specific Volume (m^3/kg^1)

M ……………………….Molecular weight (k/mol)

R ………………………..Universal gas constant (=8.314 J/K^1*mol^1)

n…………………………number of data points

Y_i ………………………..observed values

$Y^{\wedge}_I$ ………………………..predicted values

Ω …………………………collision integral (K)

σ……………………………length (nm)

η_o …………………………viscosity at zero density (Pa*s)

r ……………………………radius (mm)

q ……………………………length (mm)

1. Introduction

Engineers and scientists alike must be aware of the Thermodynamic and transport properties and sometimes chemical composition of gases and liquids. Likewise, in order to design goods, processes, and industrial equipment efficiently, mechanical or process engineers need to have a thorough understanding of how fluids behavior. Periodically, even theoretical physicists must compare their theoretical understanding against the findings of experiments.[1]

Understanding the concepts of thermodynamic and transport characteristics as well as how they operate will be helpful for this research project. It is imperative to have knowledge of the characteristics of dynamic viscosity and thermal conductivity, as well as their values for various components, is necessary for this research. Having insights of refrigerants and their characteristics is crucial since this thesis depends on them in their super-heated condition. A specific statistical model is utilized for the statistical analysis carried out for the obtained values, and the list of refrigerants used for it will be discussed later in the article. The primary goal of this work is to determine the dynamic viscosity and thermal conductivity values using the equations derived by examining various publications and comparing them to the reference values given by the author's supervisor. For the essential heat transfer calculations, it is crucial to understand the refrigerant's dynamic viscosity and thermal conductivity values.

2. Dynamic Viscosity and Thermal Conductivity

In this section, the definition and meaning of thermal conductivity and dynamic viscosity is discussed briefly.

Dynamic Viscosity: The fluid will advance with a velocity gradient with its peak velocity at a particular point where any kind of shearing stress is administered to any fraction of a restrained fluid. The ratio that is achieved by dividing the local shear stress per unit area at a specific point by the velocity gradient can be termed the viscosity of the medium. As a result, viscosity is known to be a measure of the internal fluid resistance, which results in resisting any compelling adjustment in the motion of the fluid. The conclusion of applying any applied shearing force on the fluid is to obtain a large velocity gradient at a minimal viscosity. Increased viscosity leads each fluid layer to exert more frictional drag on neighboring levels, lowering the velocity gradient. [1]

Thermal Conductivity: The inherent capacity of any material to transmit or regulate heat is defined as thermal conductivity, which with convection and radiation are known to be three methods of heat transfer. The mechanism of heat transfer is evaluated in terms of appropriate rate equations and the equation used in thermal conductivity is established on the basis of Fourier’s law of heat conduction. It is also described as the amount of heat that can be carried per unit time per unit area through a plate of unit thickness of a certain material, with the faces of the plate varied by one unit of temperature. Thermal conductivity develops on the fundamentals of molecular turbulence and connection; it does not necessarily lead to the development of the bulk movement of the gas itself. The movement of heat takes place simultaneously with the temperature gradient, navigating through high temperature and high molecular energy to a zone with lower temperature and low molecular energy. This transmission takes place until the state of thermal equilibrium is obtained. [5]

3. Mathematical models: Dynamic viscosity and Thermal conductivity

The research that many people have conducted over the years to identify specific equations and mathematical models for dynamic viscosity and thermal conductivity is covered in this section. Each article that contains the necessary data will be thoroughly discussed in order to obtain the final equations needed for the statistical analysis.

3.1 Properties of Gases and Liquids by Bruce E. Poling, John M. Prausnitz, and John P. Connel

This book can be not be used for this paper as the main issue is that this book's theoretical approach is its only foundation, and the equations it offers are the outcomes of numerous experiments that different people conducted using different techniques, compiling their findings. The fact that it is unknown what element was employed to develop these equations, however, makes it futile for this paper. There is no mention of where these equations were created and tested, and the analysis that must be done at the end will take place in a remarkably hot environment. Because more exact information about the element and the area they dealt with is needed for this literature, it is concluded that they are valuable for understanding and theoretical approaches but not for the purpose of analyzing the mathematical model statistically. Additionally, while the equations in this book are more chemically oriented, the equations needed for this thesis are thermodynamically orientated.[1]

3.2 Dynamic Viscosity and Thermal Conductivity: Prediction of Refrigerants and Refrigerants mixture, G. Latini, P. Pierpaloi, and F. Polonara

This article is discarded for this thesis paper as the primary worry identified here after a thorough review of this literature is that this experiment was carried out by the original author for liquid refrigerants, even though the equations are valuable. This poses a problem, however, because the demand is for superheated refrigerant in gaseous form, rendering the equations as well as this article futile for the statistical analysis in these paper. [7]

3.3 Thermophysical Properties of fluids: Dynamic Viscosity and thermal conductivity, G. Latini

This article is not used for this paper as when reading it carefully, it becomes clear that the equations employed here use hard-sphere diameters for dynamic viscosity and thermal conductivity, just like those in the book "Properties of gases and liquids: fifth edition." (1) Due to this reason, this article is more convenient on the chemical side and as result these equations are ineffective for this paper. [23]

3.4 The mathematical theory of Non- Uniform gases: An Account of the Kinetic Theory of Viscosity, Chapman. S, Cowling T.G.,1964

This article is discarded as it is not providing full details for the equations of dynamic viscosity and thermal conductivity which is required for this paper. This body of material serves as the foundation for many contemporary books and articles that seek to determine the values of thermal conductivity and dynamic viscosity for a variety of refrigerants in both the liquid and gaseous states. In the literature, it is shown how to grasp these qualities in various ways and how these methods were precisely derived after extensive calculations and experimentation. In order to adequately illustrate the ideas of dynamic viscosity and thermal conductivity, it provides information about the derivations made using the matrix approach and walks through many properties and linkages between them. Similar to the book "Properties of gases and liquids: the fifth edition," (1) it clarifies the principles. People have used this material over the years to create new techniques and work on equation assessment, but it does not contain the equations or information required for this paper. [6]

3.5 Viscosity of Mixed Refrigerants: R404A, R407C, R410A, and R507C, V.Z. Geller, Thermophysics Research Center, D. Bivens, E.I. du Pont de Nemours & Company, A. Yokozeki, E.I. du Pont de Nemours & Company

After a thorough review of this literature, it is clear that the equations supplied are helpful for conducting the essential calculations for the statistical analysis. On the other hand, there is also the matter of the constants that the author discovered in his research for various refrigerants. The issue faced with this is that the values of these constants are only provided for the analysis of these specific refrigerants and are not known for other refrigerants. Due to constants not having values for other refrigerants, the calculations of dynamic viscosity are restricted to only the refrigerants stated. As a result, while this literature meets the requirements, it is ultimately not fulfilling the purpose of this research and thus discarded. [17]

3.6 Thermodynamics Interaction Studies: Solid, Liquid, and Gases, Juan Carlos and Moreno

Although it provides useful information for comprehending the ideas, the essential component for this paper—the equations for thermal conductivity and dynamic viscosity is absent, as a result this article is not used. This book examines thermodynamics in great detail and discusses how it relates to chemistry. It reveals all of the thermodynamic characteristics of the three various states of matter's molecular investigations and explains how these thermodynamic qualities interact. It provides succinct explanations of the thermodynamic properties and how various matter states and modifications affect them. However, the analysis of the data derived from the calculations cannot be done without the appropriate equations which impacts the calculations. [8]

3.7 Thermodynamic Properties of Environmentally Acceptable Refrigerants: Equations of State and Tables for Ammonia, R 22, R 134a, R 152a and R 123, Prof. Dr. -Ing E.h. Hans Dieter Baehr, Dr.-Ing. Reiner Tillner-Roth

It is vital to note after reading this article that while the literature is helpful in discussing thermodynamic parameters such as specific heat and enthalpy, it is also ignorant of dynamic viscosity and thermal conductivity. There are no equations or descriptions of the transport properties provided. Due to this reasons, these article is discarded from this paper. [12]

3.8 Functional Equations of Calculating the Properties of Low-GWP R1234z(E) Refrigerant, Piotr Zyczkowski, Marek Borowski, Rafal Luczak, Zbigniew Kuczera and Boguslaw Ptaszynski

This was particularly written for a certain refrigerant and computed its qualities, as the title says. When reading the paper, it can be seen that it includes both the values needed to calculate thermal characteristics and the type of experiment that was used to obtain them. It discusses how to calculate values for thermodynamic and thermokinetic properties and provides equations for both. However, neither dynamic viscosity nor thermal conductivity is mentioned, and neither has an equation. Thus, this article serves no function for this task.

3.9 Properties of R-22 (Chlorodifluromethane) , IRC.

This article is not used for this research paper as it does not have any equations related to dynamic viscosity or thermal conductivity. The only information that this article contains is the tables of thermodynamic values. Other than this table there is nothing else noteworthy in this article.

3.10 The Transport Properties of Non-Polar Gases, Joseph O. Hirschfelder, R. Byron Bird and Ellen L. Spotz

After reading this book it is noted that the book by Chapman and S. Cowling [12] and this one share many similarities. It provides the derivation of equations and discusses the concepts of dynamic viscosity and thermal conductivity. The main drawback to using this article for this project is that it focuses more on the chemical knowledge and that some of the equations involve parameters that are either not available or are not used in these specific calculations. Due to this reasons this article is not used for this research paper.

3.11 Properties of Gases, Lower S. K

After reading this book, it is clearly noted that there are not equations provided for either thermal conductivity or dynamic viscosity. As a result this article is not used for this work. The basic characteristics of gases are discussed in this book by Lower S.K., as well as how temperature and pressure affect the gaseous state and its properties. It goes into great detail explaining how the ideal gas equation is created, as well as the kinetic theory of gases [2] and empirical gas laws [2]. In addition to equations obtained for the gaseous state, it provides a brief overview of the gases and their properties. However, the primary issue is that dynamic viscosity and thermal conductivity are not mentioned, and neither are there any formulae for them.

3.12 Transport Properties of Ions in Gases, Edward. A. Mason and Earl. W. Mcdaniel

After reading it, the fundamental problem is that, once again, neither the equations for thermal conductivity nor the equation for dynamic viscosity are supplied, which is what this task requires. As a consequence, this literature was not employed for these research projects. As implied by the title, Edward A. Mason and Earl W. McDaniel's book "Transport characteristics of Ions in Gases" (3) shows how ions and gas molecules interact with one another. It goes into great detail about the theories for molecules and ions as well as the occurring processes.

3.13 Physics of Fluids, Cleveland O' Neal Jr. and Richard Brokaw

As mentioned by the title, this literature offers a thorough investigation of the physical characteristics of fluids. It provides a physics-based explanation of the characteristics of fluids and how they relate to one another. Unfortunately, this article does not contain information on the gaseous state for these properties required for this research paper and as a result this article is not used.

3.14 Silane: Chemistry, applications and performance, Katsuro Moriguchi and Susume Utaggwe

The characteristics of organic molecules in both their gaseous and fluid forms are explained in this article. More information is revealed at the molecular level, and a brief description of the chemicals and their genesis is provided. Although helpful in the subject of chemistry, it falls short when it comes to describing the thermal qualities in terms of fundamental thermodynamics. The article is disregarded and not taken into account for the final computations because there is no description of thermal conductivity and dynamic viscosity at the level needed for this work.

3.15 Viscosity of refrigerants and other working fluids from residual entropy scaling, Ian Bell

Following a review of the equations' functions and explanations, it is observed that these equations can be applied to the determination of dynamic viscosity in the final computations. The equations make it simple to obtain all the required parameters. These equations may therefore be utilized to generate dynamic viscosity for the statistical analysis's final calculations using the chosen refrigerants.

There is an equation of dynamic viscosity available in this article which is connected directly to temperature and density of the refrigerant. The equation for estimating viscosity at a specific temperature range is given below.

$$\boldsymbol{\eta} = \frac{\mathbf{26.692.10^{-9}}\sqrt{\boldsymbol{T}.(\mathbf{1000}.\boldsymbol{M})}}{\boldsymbol{\sigma}^{\mathbf{2}}.\,\Omega^{\mathbf{2.2}}} \qquad (\mathbf{1.1}) \qquad [\mathbf{14}]$$

Where, η = Dynamic Viscosity (Pa*s) , T = temperature (K), Ω = collision integral (K).

The collision integral Ω can be calculated using the following equation, known as the Neufeld equation.[14]

$$\Omega^{2.2} = 1.16145(T^{*})^{-0.14874} + 0.52487\exp(-0.77320T^{*}) + 2.16718\exp(-2.43787T^{*}) \qquad (1.2) \qquad [14]$$

Where σ (nm) and reduced temperature T* (K) is given by following equations.

$$\sigma = \frac{8.09}{(\rho_{crit})^{\frac{1}{3}}} \qquad (1.3) \quad [14]$$

$$T^{*} = \frac{T}{\frac{T_{crit}}{1.2593}} \qquad (1.4) \qquad [14]$$

Where ρ_{cric} is the critical density (mol/m^-3) and T_{crit} (K) is the critical temperature. Very low density viscosity measurements are frequently associated with the length and energy scaling parameters.[14]

This model was applied to the following list of refrigerants.

- R134a
- R125
- R152a
- R32
- R1233zd
- R1234yf
- R1234ze
- R124
- R22
- R245fa

In a single-parameter corresponding states framework, a rarely explored relationship between the thermodynamic property entropy and the transport property viscosity was applied over the entire fluid region. Except for R22, which had an average absolute departure of 15.2 percent, the present formulas' average absolute deviations ranged from 2.2 percent to 7.4 percent. This model is approximately 40 times faster than extended equivalent states in terms of calculation speed.[14]

3.16 Prediction of the Thermal Conductivity of Refrigerants by Computational Methods and Artificial Neural Network, Forouzan Ghaderi, Amir H. Ghaderi, Noushin Ghaderi and Bijan Najafi

It is concluded through a careful examination that all the variables required for equations are easily obtainable, and that the equation provides the essential justification for achieving thermal conductivity. This equation may be used to determine the outcomes of computations since it offers thermal conductivity across a wide temperature range.

Since refrigerants are crucial to the refrigeration industry, it is important to fully comprehend and explain their transport properties. When compared to the time it would take to complete the work in a laboratory, computational methods that allow for the prediction of transport parameters serve as important tools.[15] At low and moderate density levels, the thermal conductivity of six refrigerants containing R12 (dichlorodifluoromethane), R14 (carbon tetrafluoride), R32 (difluoromethane), R143a (1, 1, 1trifluoroethane), R115 (chloropentafluoroethane), and R152a (1, 1difluoroethane) was calculated using the RF method. A modified RF theory[15] was used for greater density ranges, extending beyond the RF theory's validity range and allowing the construction of corresponding state correction functions. The residual thermal conductivity was calculated as well. The graphs were confirmed using the corresponding states principle. The refrigerant parameters λ^* and ρ^* were also discovered.[15]

3.16.1 Thermal Conductivity

The Rainwater-Friend theory (15) was used to compute the thermal conductivity of refrigerants of moderate density (up to 2 mol.dm3). The thermal conductivity has been treated as a function of second virial coefficients in this method.[15]

$$\lambda = \lambda_0(1 + N_A \sigma^3 B_\lambda^* \rho) \quad (2.1) \quad [15]$$

The Lennard-Jones potential was utilized to determine B_λ over the lowered temperature (T^*) in the RF approach.[15] λ_0 represents thermal conductivity in zero density limits, ρ is the molar density, N_A represents Avogadro's constant, and σ is the collision diameter in this equation. Realistic potentials and the lowered second thermal conductivity virial coefficient (B^*) are dealt with in RF theory (Rainwater, 1981; Rainwater and Friend, 1987). B^* is made up of three statements.

$$B_\lambda^* = B_\lambda^{*(2)} + B_\lambda^{*(3)} + B_\lambda^{*(M-D)} \qquad (2.2) \qquad [15]$$

Where $B_\lambda^{*(2)}$, $B_\lambda^{*(3)}$, $B_\lambda^{*(M-D)}$ are Monomer-monomer collisions, triple molecular collisions, and monomer-dimer collisions are the three types of collisions, respectively. $B^*(T^*)$ of a gas determined by its potential and decreased temperature, and is expressed as:

$$B^* = a_0 + \frac{a_1}{T^*} \qquad (2.3) \qquad [15]$$

Where the value of coefficients $a_0 = 2.14610 \times 10^{-1} \pm 7.5 \times 10^{-3}$

$a_1 = 5.359 \pm 1.3 \times 10^{-2}$.

Combining this equation with Mason-Monchick theory and Enskog theory we get the final equation for calculating Thermal conductivity. [15]

$$\lambda = \frac{15.R}{4.M}.\eta_0 \qquad (2) \qquad [15]$$

where R = universal gas constant (J/ K*mol)

M = molecular weight (kg/mol)

η_0 = viscosity at zero density (Pa*s)

λ = thermal conductivity (W*/m*K)

3.17 Thermophysical properties of HFC-143a and HFc-152a, W.M. Haynes

The equation for thermal conductivity cannot be used for the final calculations because it has a parameter radius that is on the molecular level indirectly and relies more on chemistry knowledge than on thermodynamic methods, whereas the equations for dynamic viscosity can be used because the parameters used in them are easily accessible and fall under thermodynamic properties. Therefore, for the final computations from this literature, only equations for dynamic viscosity are considered.

Selected thermodynamic parameters of HFC-143a and HFC-152a were measured as part of this research, as well as the advancement of high-accuracy modified Benedict-Webb-Rubin (MBWR) equations of state.[19] It also consists of a few measurements of the transport parameters (viscosity and thermal conductivity) of HFC-143a and HFC-152a, as well as the construction of thorough correlations for those qualities. The experimental assessments of transport properties covering the vapor states across the different range of temperatures is done in this article.[19]

3.17.1 HFC-143a

A torsionally oscillating quartz crystal viscometer and a capillary viscometer were used to evaluate the shear viscosity of compressed fluid (vapor) HFC-143a at temperatures ranging from 255.6 to 337.8 K (0.4 to 148.4°F).[19] The equation was used to correlate the saturation data.

$$\eta = 3.563 * 10^{-8} e^{\frac{53191}{T^2}} (V - 5.1608 * 10^{-4}) \qquad (3) \quad [19]$$

where η = Dynamic Viscosity (Pa/s) , T = temperature (K) , V = specific volume (m^3/kg).

The data discrepancy from this equation and the literature accordingly are displayed in the figure 6.

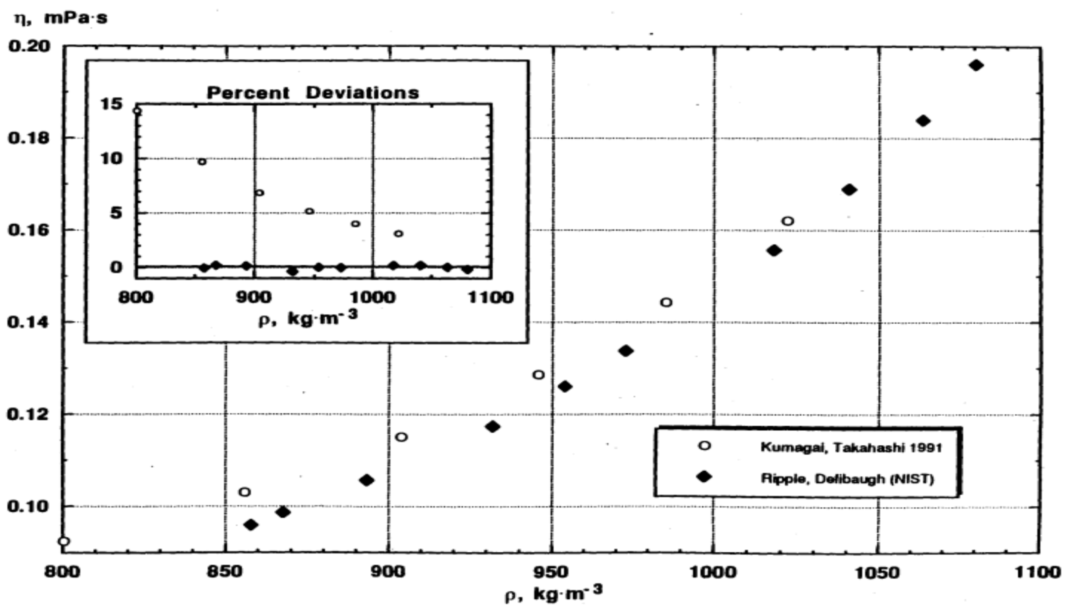

Figure 1. Comparison of experimental viscosity from values derived from equation.[19]

The residual notion was used to correlate the vapor viscosity. Figure 7 illustrates the calculated viscosity of HFC-143a vapor as a function of temperature and density.

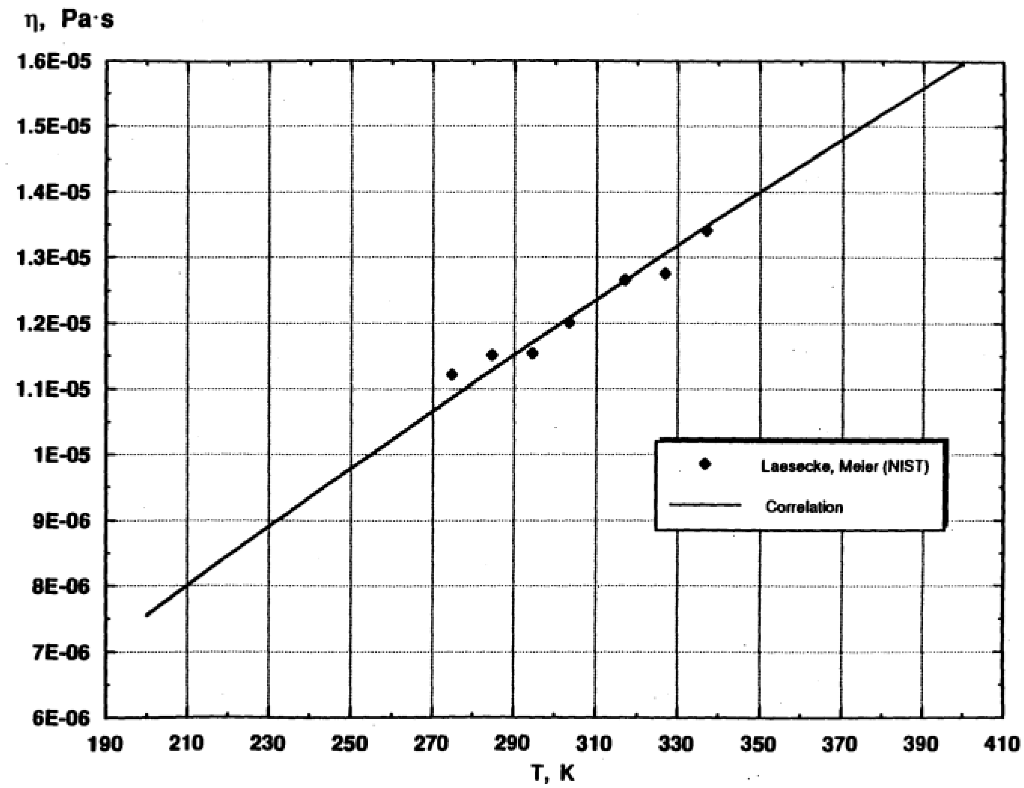

Figure 2. Viscosity of HFC-143a vapor as function of temperature and density.[19]

3.17.2 HFC-152a

HFC-152a viscosity was measured in the compressed fluid (vapor) and saturated liquid regions between 254.7 and 330.9 K (-1.2 and 136°F) using a torsionally oscillating quartz crystal viscometer for the vapor measurements and a capillary viscometer for the saturated liquid measurements.

$$\boldsymbol{\eta = 4.536 * 10^{-8} (V - 8.2740 * 10^{-4})} \qquad (4) \quad [19]$$

where η = Dynamic Viscosity (Pa/s) , V = specific volume (m^3/kg).

Krauss (1994) created a residual concept connection for the viscosity of HFC-152a based on published data. Figure 8 shows the study that corresponds to this equation.

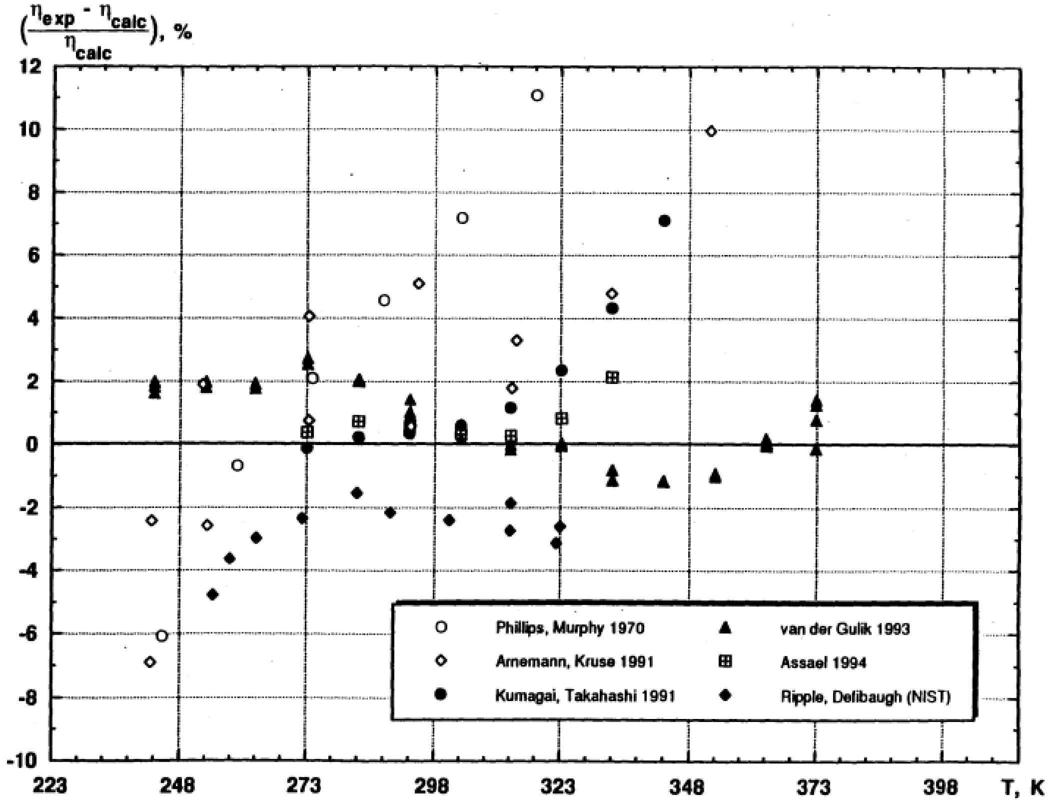

Figure 3. Viscosity of HFC-152a vapor as function of temperature.[19]

3.17.3 Thermal Conductivity

The transient hot-wire apparatus employed in this study has already been thoroughly documented [1,2]. The low-temperature device uses bare 12 m platinum hot wires and operates between 30 and 330 K at pressures up to 70 MPa. The high-temperature instrument uses anodized 25 m tantalum hot wires and operates between 300 and 500 K at pressures up to 70 MPa. Both instruments are absolute and include two hot wires to eliminate axial conduction faults. The temperature range investigated in this study necessitated the use of both instruments, allowing for a consistency check around 300 K. These instruments have a repeatability of 0.3 percent and a nominal uncertainty of less than 1% for measuring thermal conductivity.[19]

Both the finite wire heat capacity and the finite outer boundary corrections become quite substantial in the dilute gas limit. This is due to the fact that in the limit of zero density, the gas thermal diffusivity is divergent. As a result, the identical two hot-wire cells are used to report thermal conductivity values acquired from absolute steady-state observations. This enables the measurement of dilute gas thermal conductivity at extremely low temperatures (vapor pressures less than 1 bar). The values of steady-state thermal conductivity are calculated as follows[19]:

$$\lambda = \frac{q \ln\left(\frac{r_2}{r_1}\right)}{2\pi(T_1 - T_2)} \qquad (5) \qquad [19]$$

where λ is thermal conductivity (W*/m*K), q is unit length, r_1 and r_2 external and internal radius (mm) and T_1 and T_2 is the temperature (K) in its hot wire and initial temperature.

The uncertainty in these steady-state thermal conductivity values is 2%.[29]

4. Statistical Methods and Models

The field of science known as statistics offers strategies for interpreting data. Some people are dubious about statistically based conclusions. Extreme skeptics describe the discipline as a subtype of lying—something employed for deceit rather than for beneficial purposes. They typically talk from ignorance. Business, healthcare, agriculture, social sciences, natural sciences, and applied sciences like engineering all use statistical approaches. Because statistical analyses are so frequently used in a variety of professions, there is a growing understanding that statistical literacy—knowing the objectives and procedures of statistics—should be a fundamental element of any comprehensive educational program. [24]

Analysis of the data collected through equations and comparison with the data the supervisor provided as the reference are essential steps in determining the final results. The statistical model Multiple Linear Regression [25] will be used to analyze the multiple data sets for dynamic viscosity and thermal conductivity for the available data.

Below is a detailed explanation of both the Multiple Linear Regression Model:

4.1 Multiple Linear Regression Model:

A single dependent variable and several independent variables can be analyzed using the statistical technique known as multiple regression. In order to forecast the value of the single dependent value, multiple regression analysis uses independent variables whose values are known. Each predictor value is given a weight, with the weights indicating how much each predictor contributed to the final forecast. [25] When one variable depends on a group of other factors, this method can be used to examine multivariate time series data. To assess the association between two or more independent variables and one dependent variable, multiple linear regression is utilized. [25]

Another term called Mean Square error and its equation will be used in final analysis to analyze the error about which equation is suited for what range of temperature and how much error it shows. The mean squared error (MSE) or mean squared deviation (MSD) of an estimator (a process for estimating an unobserved variable) in statistics measures the average of the squares of the errors—that is, the average squared difference between the estimated and actual values. MSE is a risk function that represents the expected value of squared error loss. Because of randomness or because the estimator does not account for information that could give a more accurate estimate, MSE is almost always strictly positive (rather than zero). [25]

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \widehat{Y}_i)^2 \qquad (5) \qquad [25]$$

Where MSE = mean squared error

n = number of data points

Y_i = observed values

$Y^{\wedge}_I$ = predicted values

This equation will be used to estimate which equations are near to the specified values and in which temperature range the error rate is relatively low. The ultimate hypothesis and outcomes will be determined based on the analysis.

5. Selection of Refrigerants

Following careful deliberation and review of several texts such as Refrigeration Processes. A Practical Handbook on the Physical Properties of Refrigerants and their Applications [13] by N. S. Billington, a list of refrigerants was chosen to undertake the statistical analysis. This list was compiled using prior refrigerants as well as their replacements. R-22, which was more often utilized in the early 2000s, has now been replaced by R-407c due to its toxicity to the environment. Reasons like this were considered when selecting the refrigerants. Not only were the most recent refrigerants picked, but previously utilized refrigerants were also chosen after extensive investigation. Because the refrigerants replaced share some basic structure or components, it aids in studying and determining the qualities of new refrigerants.

The supervisor gave the author a list of refrigerants that had been chosen based on the worldwide list of refrigerants and those that were most commonly utilized in industry. The supervisor also gave the author the reference values for statistical analysis for dynamic viscosity and thermal conductivity along with other relevant data for comparative reasons to assess the results generated by the calculations from the equation for the refrigerants.

The below mentioned list compromises of the refrigerants used for the analysis.

1) R22

2) R134a
3) R143a
4) R152a
5) R290
6) R404A
7) R407C
8) R410A
9) R507C
10) R513A
11) R717
12) R744
13) 1234yf
14) 1234ze

As part of the assignment, the analysis was carried out in Excel using calculations in which the theoretical values were provided and utilized as a reference to notice and analyze the errors with the values acquired from the equations' calculations.

6. Findings and Conclusions

This paper was created with the goal of investigating the findings of numerous researchers that computed the thermal conductivity and dynamic viscosity of various refrigerants in the super-heated area of the gaseous component over the years. Several equations were evaluated based on the information obtained from various books and publications, and they were then used to collect data for various properties and statistically analyze the results. MSE (Mean Square Error) and the percentage of errors between equation values and reference values were employed in the statistical study. From the computed data, the average, maximum, and minimum values were extracted from the excel spreadsheet and examined appropriately. The Excel document contains the graphs for reference and supplementary data.

The choice of the equations for the computations took into account the relationship of the equation with either temperature or pressure. Another need was to see if all of the equation's parameters were available or fell under the category of thermodynamic properties; if not, then the parameter would be classified as falling under the category of chemistry and would be disregarded. Since dynamic viscosity and thermal conductivity depend on temperature, pressure, or additional thermal parameters like specific heat, no further criteria were taken into account. Three equations for dynamic viscosity and one equation for thermal conductivity were discovered and utilized in the final computations with these conditions in mind. The majority of the equations featured molecular properties, which are better suited to a chemical approach, making it difficult to establish an equation for thermal conductivity. In contrast, thermodynamic approaches need equations to include characteristics relating to heat transfer.

Five distinct pressure values are taken for the calculations for each refrigerant separately using the Excel file that was provided as the reference data. In order to statistically examine the numbers derived from the calculations, the dynamic viscosity and thermal conductivity values from this table are used and the multiple linear regression model was utilized. To determine the overall level of error, the Mean Square error is determined, and then each pressure range is individually examined.

The statistical analysis of the work is described below.

6.1 R22

There are five different pressure ranges for R22 refrigerant, and each pressure range is analyzed individually for both Dynamic Viscosity and Thermal Conductivity. The second worksheet is to analyze the error for the entire pressure range, from the first value to the last to know how much error each equation, and which equation is the closest to the reference value.

6.1.1 Dynamic Viscosity and Thermal Conductivity of R22 at 0.096 MPa

Dynamic Viscosity: The analysis has been done with three equations for dynamic viscosity. It is evident from the graph of the reference data that the dynamic viscosity rises in a straight line when the temperature rises sharply. When comparing the results of each equation independently, equation 4 matches the reference graphic the best, with an average error of 6.36% and a mean square error of 1.42E-12. Since the error curve rises as temperature rises, the beginning point temperature of -40 degrees Celsius has the lowest error of 4.15% and the temperature of 260 degrees Celsius has the maximum error of 9.65%. In contrast, equation 3's results show a u-shaped curve, suggesting that viscosity first decreases until the temperature reaches 50 degrees Celsius before progressively increasing. The lowest inaccuracy, 3.93%, is measured at the highest temperature, or 260 degrees Celsius. While the lowest temperature, or -40 degrees Celsius, has the largest inaccuracy of 1.18E02%. For the solutions to equation 3, the mean square error is 2.58E-11 and the standard deviation is 32% between two dynamic viscosity curves. Both the error curve and the dynamic viscosity curve are growing with increasing temperature for the graph of equation 1's findings. The mean square error is 1.21E-10, and the average error between two dynamic viscosity curves is 60.2%. Due to the nature of the error curve, the lowest error, which is measured at -40 degrees Celsius, is 36.6%, and the maximum error, which is measured at 260 degrees Celsius, is 80.6.

Thermal Conductivity: This illustrates that, similar to the reference data set, the data derived from the equation 2 has a graph that shows the value of thermal conductivity increasing as the temperature increases. At a starting temperature of -40 degrees Celsius, the thermal conductivity curves cross, resulting in the lowest inaccuracy of 0.856%. The largest inaccuracy, 43.7%, is recorded at a temperature of 260 degrees Celsius due to the shape of the error curve. Thermal conductivity reference values and equation values differ on average by 25.7%, with a mean square error of 3.97E-05.

R22 at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.58E-11	**1.42E-12**	**1.21E-10**	**3.97E-05**
Average Error %	32 %	63.6 %	60.2 %	25.7 %
Mini Error %	3.93 %	4.15 %	36.6 %	0.856 %
Max Error %	1.18E02 %	9.65 %	80.6 %	43.7 %

6.1.2 Dynamic Viscosity and Thermal Conductivity of R22 at 0.179 MPa

Dynamic Viscosity: After examining the data for the refrigerant R22 at a pressure of 0.179 MPa, it was discovered that while the dynamic viscosity curves are growing with temperature, the error curve for equation 4 is decreasing, and the error curve appears to be rising for the equations 3 and 1 results. The dynamic viscosity curves seem to cross at a temperature of -20 degrees Celsius, according to equation 3 findings, which is why it had the lowest error of 0.426%. At a temperature of 260 degrees Celsius, the largest inaccuracy, 44.2%, is noted. The mean square error for the solutions to equation 3 is 4.06E-11, while the average error between the dynamic viscosity curves is 32.4%. The average error between dynamic viscosity curves for equation 1's values is 61.8%, and the mean square error is 1.28E-10. The temperature with the lowest inaccuracy, 41%, is 0 degrees Celsius, while the temperature with the biggest error, 80.3%, is 260 degrees Celsius. The average error between dynamic viscosity curves for equation 4's values is 51.8%, and the mean square error is 5.18E-11. The lowest error, 41.2%, is recorded at the greatest temperature, 260 degrees Celsius, while the largest error, 44.9%, is recorded at the temperature of -20 degrees Celsius because the error curve flattens out as the temperature rises.

Thermal Conductivity: Similar to the previous pressure value, the graph of thermal conductivity has a mean square error of 4.25E-05 and an average error percentage of 27.1%. The error percentage increases along with the temperature and reaches its highest value at 260 degrees Celsius when it was measured at 43.7%. The observed inaccuracy is lowest at 6.06% due to the beginning values, i.e., the thermal conductivity curves crossing at -20 degrees Celsius.

R22 at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	4.06E-11	5.18E-11	1.28E-10	4.25E-05
Average Error %	32.4 %	43.2 %	61.8 %	27.5 %
Mini Error %	0.426 %	41.2 %	41 %	6.06 %
Max Error %	44.2 %	44.9 %	80.2 %	43.7 %

6.1.3 Dynamic Viscosity and Thermal Conductivity of R22 at 0.379 MPa

Dynamic Viscosity: All of the graphs show comparable results for the dynamic viscosity of refrigerant R22 at a pressure of 0.379 MPa, with the error curve and the dynamic viscosity curve rising with a rise in temperature. The mean square error and average error percentage for the results of equation 3 are 5.37E-11 and 39.4%, respectively. The starting point temperature of 0 degrees Celsius results in the lowest error of 19.3%, while 260 degrees records the maximum error of 47.7%. The results of equation 4 show that the beginning point temperature has the lowest error, 25.1%, and the highest temperature has the biggest error, 37.6%. The mean square error value for the solutions to equation 4 is 3.30E-11, while the average error between two dynamic viscosity curves is 32%. The mean square error for the equation 1 finding is 1.35E-10, while the average error between the dynamic viscosity curves from reference values and equation 1 values is 63.1%. At 0 degrees Celsius, the error is recorded at a minimum of 45.4%, while at 260 degrees Celsius, the error is recorded at a maximum of 79.7%.

Thermal Conductivity: The Thermal Conductivity results at this pressure value are identical to those from earlier pressure ranges, suggesting that while Thermal Conductivity values rise with rising temperatures, the error percentage between equation values and reference values also rises. The mean square error between them is 4.59E-05, whereas the average error is 29.3%, with the lowest error at 0 Celsius and the biggest error at 260 Celsius being 11.6% and 43.6%, respectively.

R22 at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.37E-11	3.30E-11	1.35E-10	4.59E-05
Average Error %	39.4 %	32 %	63.1 %	29.3 %
Mini Error %	19.3 %	25.1 %	45.4 %	11.6 %
Max Error %	47.7 %	37.6 %	79.7 %	43.6 %

6.1.4 Dynamic Viscosity and Thermal Conductivity of R22 at 0.896 MPa

Dynamic Viscosity: Equation 4 produced the best results for this pressure range, with an average error of 7.1% and a mean square error of 2.65E-12. It exhibits the same trend as earlier pressure ranges in that the dynamic viscosity rises as the temperature rises. Equation 4's error ranges from 0.17% at 50 degrees Celsius to 13.4% at 260 degrees Celsius, with 0.17% being the lowest and 13.4% being the highest respectively. The second-best results are shown by equation 4, which has a mean square error of 1.01E-11 and an average error of 18.9%. At 20 degrees Celsius, the error percentage was highest (40.2), while at 260 degrees Celsius, it was lowest (7.98%). On the other hand, equation 1's output has the largest mean square error (1.41E-10) and an average error of 63.5%. At 260 degrees Celsius, the biggest error was reported at 78.2%, and at 20 degrees Celsius, the lowest error was 49%. Different error rates are depicted in each of the three graphs, with equation 3 showing an error rate that decreases as temperature rises and equation 1 showing an error rate that rises as temperature rises. The error decreases from 20 degrees to 50 degrees Celsius, when the error percentage is recorded at its lowest, and from that point on, the error likewise increases as the temperature rises, according to the graph provided by equation 4.

Thermal Conductivity: The answers of equation 2 for thermal conductivity have an average error of 31.3% and a mean square error of 5.01E-05. The error ranged from 18.7% at 20 degrees Celsius to 43.3% at 260 degrees Celsius, with 260 degrees Celsius recording the largest error. The findings show that mistake rates rise with temperature, and this was also observed for earlier pressure readings.

R22 at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.01E-11	2.64E-12	1.41E-10	5.01E-05
Average Error %	18.9 %	7.1 %	63.5 %	31.3 %
Mini Error %	7.98 %	0.171 %	49 %	18.7 %
Max Error %	40.2 %	13.4 %	78.2 %	43.3 %

6.1.5 Dynamic Viscosity and Thermal Conductivity of R22 at 3.17 MPa

Dynamic Viscosity: The results shown by equations 3 and 4 have a similar pattern, with the highest error percentage reported at the start of the temperature range and a decreasing trend as the temperature rises. In contrast, the findings of equation 1 have the opposite effect because the error is greatest at the lowest temperature and decreases as the temperature rises. With this recording, it should be noticed that equation 1's results, which have an average error of 57.8% and a mean square error of 1.43E-10, are the ones that come the closest to the reference data. While the mean square errors for equations 8 and 9 are 2.17E-10 and 2.25E-10, respectively, with average errors of 74.1% and 75.7%. The error for equation 1 ranges from 41.2% at 80 degrees Celsius to 70.3% at 260 degrees Celsius. The results for equations 8 and 9 are the opposite, with the lowest error values at 260 degrees Celsius and the highest values at 80 degrees Celsius, respectively, of 72.7% and 71.8%.

Thermal Conductivity: It can be seen in the graph produced by the solutions to equation 2 and the thermal conductivity reference dataset that the error rate drops from 80 Celsius to 150 Celsius before increasing once more as the temperature rises. The numbers and the graph, which show that the lines for equation 2 and the reference data connect at a temperature of 150 degrees Celsius and have the lowest error of 0.745%, serve as additional evidence of this. In contrast, the mean square error for thermal conductivity is 4.88E-5. At 260 degrees Celsius, the error rate is the highest, coming in at 20.9%.

R22 at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.17E-10	2.25E-10	1.43E-10	4.88E-05
Average Error %	74.1 %	75.7 %	57.8 %	9.62 %
Mini Error %	72.7 %	71.8 %	41.2 %	0.745 %
Max Error %	78.6 %	83.1 %	70.3 %	20.9 %

6.1.6 Dynamic Viscosity and Thermal Conductivity of R22 for the entire pressure range

Dynamic Viscosity: This section statistically analyzes the dynamic viscosity from the initial pressure value of 0.096 MPa to 3.17 MPa. When comparing the mean square error and error percentage figures for the three equations, equation 4's findings have the lowest mean square error at 5.17E-11, while equation 1's results have the highest mean square error at 1.32E-10. Equation 4 has the lowest average percentage error, at 30%, while equation 1 has the most inaccuracy, at 61.4%. In contrast, equation 3 has a mean square error of 5.96E-11 and an average error of 37.2%.

Thermal Conductivity: Similarly, the findings of equation 2 for thermal conductivity throughout the whole pressure range show an average error of 25.6% and a mean square error of 4.49E-5.

6.1.7 Conclusion

The findings of equation 4 for the refrigerant R22 initially were the closest to the values used as references over the whole pressure range of 0.096 MPa to 3.17 MPa, according to the statistical analysis for dynamic viscosity. The mean square error is 5.172E-11, while the average error is 30%. If the results from each of the five pressure values are taken into account separately, however, it becomes clear that equation 4 has the lowest average error rate for pressure values of 0.096 MPa, 0.379 MPa, and 0.896 MPa, while equation 3 provides the lowest error at 0.179 MPa and equation 1 provides the lowest average error at the highest pressure of 3.17 MPa. From this, it can be concluded that equation 4 is best used for the lower pressure values since the starting temperatures are low while equation 1 can be used for higher temperatures at high pressures. Since there was only one equation to examine, equation 2 yields an average error of 25.6% over the full pressure range for thermal conductivity in general. With the exception of the graph of 3.17 MPa thermal conductivity values, where the error is forming a V-shape, it can be seen from the graphs that the error grows with temperature for all pressure levels. It follows that equation 2 provides thermal conductivity values that are near to reference values up to a temperature of 150 degrees Celsius for any pressure values, beyond which the error grows with pressure. Therefore, equation 2 can be used to calculate the thermal conductivity of refrigerant R22 under a super-heated condition, whereas equation 4 can be used to calculate the dynamic viscosity, and further development should be made in the future to obtain accurate results for these transport properties.

6.2 R134

R134 refrigerant comes in five different pressure ranges, and each pressure range is studied separately for both Dynamic Viscosity and Thermal Conductivity. The second worksheet examines the error in general over the full pressure range, from the first to the last value, to determine how much error each equation has for the entire pressure range and which equation is closest to the reference value.

6.2.1 Dynamic Viscosity and Thermal Conductivity of R134 at 0.096 MPa

Dynamic Viscosity: The dynamic viscosity of R134 at this pressure value yields very different numbers and graphs for all three equations. For equation 3, it is noted that whereas the reference data exhibits a steep increase in dynamic viscosity with increasing temperature, the data produced by the equation while increasing in dynamic viscosity with increasing temperature, do not grow to the extent of the reference line. As a result, the average error recorded by equation 3 is 26.7%, with the largest error of 68.4% recorded at -20 degrees Celsius and the lowest error of 0.372% recorded at 120 degrees Celsius. The graph indicates that equation 4 has a rise in dynamic viscosity for the dataset given by both reference and equation values, with the important distinction being that at higher temperatures over 120 degrees Celsius, the reference has a rapid increase while the equation values have a continuous increase. The average error in equation 4 is 11.1%, with a mean square error of 1.34E-11. The biggest error is 39.4% at 180 degrees Celsius and the lowest is 3.86% at 70 degrees Celsius. In contrast, the average error in equation 1 is 79.4%, with a mean square error of 1.43E-10. The highest error was 96.3% at 90 degrees Celsius, while the lowest error was 31.6% at 180 degrees Celsius. All three equations have the same graphic figure, with dynamic viscosity increasing steadily while reference values increase steeply with increasing temperature, while the error rate varies, with equation 3 having a decrease in error until 120 degrees Celsius and then increasing in error, while equation 4 has almost identical to equation 3 with the only difference being a steep increase at higher temperatures, while equation 1 has a steep increase at higher temperatures.

Thermal Conductivity: The graph of thermal conductivity for equation 2 demonstrates a considerable drop in error rate until 120 degrees Celsius, after which the error rate increases with temperature. While the values of thermal conductivity are relatively similar and have the same graphic line, there is a significant divergence in the values at the highest temperature. The average error rate is 24.2%, with a mean square error of 2.79E-05. The lowest error is reported at 130 degrees Celsius, with an error of 0.539%, and the biggest error is recorded at -20 degrees Celsius, with an error of 56.5%.

R134 at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.17E-11	1.34E-11	1.43E-10	2.78E-05
Average Error %	26.7 %	11.1 %	79.4 %	24.2 %
Mini Error %	0.372 %	3.86 %	31.6 %	0.539 %
Max Error %	68.4 %	39.4 %	96.3 %	56.5 %

6.2.2 Dynamic Viscosity and Thermal Conductivity of R134 at 0.179 MPa

Dynamic Viscosity: The shapes of the graphs and values presented by different equations in comparison to reference values for dynamic viscosity are relatively similar to those at prior pressure values. The error rate in Equation 3 decreases until the temperature reaches 140 degrees Celsius, beyond which it increases. While the error rate in equation 4 exhibits an unusual curve, with a steady increase in error with increasing temperature until 90 degrees Celsius, then rapidly reducing until 120 degrees Celsius, and then increasing again with temperature. Similarly, equation 1 indicates a rise in error rate with increasing temperature until 110 degrees Celsius, after which it decreases. Equation 3 has an average error of 28.4% with a 1.85E-11 mean square error, having the lowest error of 0.608% at 140 degrees Celsius and a maximum error of 70.1% at -10 degrees Celsius. Whereas equation 4 has an average error of 5.58% with a mean square error of 5.06E-12 and a maximum error of 28.7% at 180 degrees Celsius, it has the lowest error of 5.62E03% at 120 degrees Celsius. The results of equation 1 show an average error of 85.1% with a mean square error of 1.62E-10, with the lowest error observed at 180 degrees Celsius at 44.6% and the largest error at 100 degrees Celsius at 99.3%.

Thermal Conductivity: Up until 140 degrees Celsius, the error rate significantly decreases on the graph of thermal conductivity for equation 2, after which it rises with temperature. Even though the thermal conductivity numbers are quite similar and share a common visual line, the values at the highest temperature significantly diverge. The mean square error is 1.95E-05, with an average error rate of 21.9%. At 140 degrees Celsius, the error is recorded as being 1.43%, whereas at -10 degrees Celsius, the error is reported as being 51.2%.

R134 at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.85E-11	5.06E-12	1.62E-10	1.95E-05
Average Error %	28.4 %	5.58 %	85.1 %	21.9 %
Mini Error %	0.608 %	0.0056 %	44.6 %	1.43 %
Max Error %	70.1 %	28.7 %	99.3 %	51.2 %

6.2.3 Dynamic Viscosity and Thermal Conductivity of R134 at 0.379 MPa

Dynamic Viscosity: The equations' conclusions for dynamic viscosity at 0.379 MPa pressure are comparable to those at the two earlier pressure levels. The error rate for equation 3 decreases until 160 degrees Celsius and then increases with temperature in all three graphs, whereas equation 4's error rate increases until 100 degrees Celsius, then decreases until 140 degrees Celsius and increases once more with temperature increase. The error rate for equation 1 follows a similar pattern, increasing until a temperature of 110 degrees Celsius and then decreasing as the temperature rises. Equation 3 has an average error of 24.8% with a mean square error of 1.35E-11, equation 4 has an average error of 4.89% with a mean square error of 1.76E-12, and equation 1 has an average error of 90.7% with a mean square error of 1.89E-10. The error rate for equation 3 is found to be 2.69% at a temperature of 160 degrees Celsius and 55% at a temperature of 10 degrees Celsius. At 180 degrees Celsius, Equation 4's error is at its highest, whereas at 140 degrees Celsius, it is at its lowest. Equation 1's maximum error, 1.02E2%, is recorded at two temperature levels of 110 and 120 degrees Celsius, while its minimum error, 60.8%, is noted at 180 degrees Celsius.

Thermal Conductivity: The error rate is substantially lower on the thermal conductivity graph for equation 2 up to 150 degrees Celsius, after which it increases with temperature. The readings at the highest temperature greatly diverge from the thermal conductivity numbers, despite the fact that they are relatively close and have a common visual line. With an average error rate of 18.3%, the mean square error is 1.95E-05. The error is reported to be 0.926% at 150 degrees Celsius while it is 40.3% at 10 degrees Celsius.

R134 at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.35E-11	1.76E-12	1.89E-10	1.28E-05
Average Error %	24.8 %	4.89 %	90.7 %	18.3 %
Mini Error %	2.69 %	0.989 %	60.8 %	0.926 %
Max Error %	55 %	18.5 %	1.02E02 %	40.3 %

6.2.4 Dynamic Viscosity and Thermal Conductivity of R134 at 0.879 MPa

Dynamic Viscosity: In comparison to reference values for dynamic viscosity, the forms of the graphs and values produced by the various equations resemble those for equations 8 and 1 at earlier pressure settings. Equation 3's error rate goes down until the temperature hits 160 degrees Celsius, after which it goes up. Equation 4's error rate displays a peculiar pattern, with a continuous decrease in error as temperature rises until 140 degrees Celsius, then a sharp rise with temperature. Similar to equation 2, equation 1 shows that the error rate increases with temperature up to 130 degrees Celsius, at which point it starts to decline. Equation 3 has a maximum error of 14.7% at 40 degrees Celsius and a minimum error of 1.3% at 160 degrees Celsius. It has an average error of 7.78% and a mean square error of 1.57E-12. Equation 4 has the lowest error at 140 degrees Celsius, with a mean square error of 3.92%, a maximum error of 16.3% at 40 degrees Celsius, and an average error of 8.8%. The results of equation 1 reveal an average error of 95.4% and a mean square error of 2.24E-10. The lowest error was found at 180 degrees Celsius and was measured at 86.3%, while the biggest error was measured at 120 and 130 degrees Celsius and was measured at 1.04E02%.

Thermal Conductivity: Up to 170 degrees Celsius, the error rate for equation 2 is lower on the thermal conductivity graph, but it then rises with temperature. Although they are close and have a common visual line, the results at the maximum temperature substantially deviate from the thermal conductivity figures. The mean square error is 8.0E-06 with a 13.9% average error rate. The lowest error, at 170 degrees Celsius, is recorded at 0.0683%, while the biggest error is measured at 40 degrees Celsius with a value of 25.9%.

R134 at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.57E-12	2.09E-12	2.24E-10	8.00E-06
Average Error %	7.78 %	8.88 %	95.4 %	13.9 %
Mini Error %	1.3 %	3.92 %	86.3 %	0.0683 %
Max Error %	14.7 %	16.3 %	1.04E02 %	25.9 %

6.2.5 Dynamic Viscosity and Thermal Conductivity of R134 at 3.17 MPa

Dynamic Viscosity: Similar behavior can be seen in all three graphs for the dynamic viscosity at this pressure setting, with the dynamic viscosity rising as the temperature rises. Equation 3 displays a mean square error of 3.30E-10 and an average error of 97.8%. While the mean square error for equation 4 is 2.10E-10 with an average inaccuracy of 73.9%. On the other hand, equation 1 has a mean square error of 2.20E-10 and an average error of 82.9%. Equation 3 reported the lowest error at 90 degrees Celsius, which was 44.7%, and the highest error at 170 degrees Celsius, which was 1.30E02. The lowest error for equation 4 is 14.4% at a temperature of 90 degrees Celsius, and the maximum error is 1.15E02% at a temperature of 170 degrees

Celsius. According to equation 1, the lowest error was reported at 90 degrees Celsius and the maximum error was recorded at 170 degrees Celsius. The lowest error was 71.2%.

Thermal Conductivity: The average error for the thermal conductivity values shown by the equation and the reference value is 9.86%, with the lowest error of 8.38% occurring at 100 degrees Celsius and the maximum error of 11.7% occurring at 170 degrees Celsius. This demonstrates that the error rate's curve decreases up to 100 degrees Celsius before increasing as temperature rises. Equation 2's mean square error is 6.00E-06.

R134 at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.30E-10	2.10E-10	2.20E-10	6.00E-06
Average Error %	97.8 %	73.9 %	82.9 %	9.86 %
Mini Error %	44.7 %	14.4 %	71.2 %	8.38 %
Max Error %	1.30E02 %	1.15E02 %	97.2 %	11.7 %

6.2.6 Dynamic Viscosity and Thermal Conductivity of R134 for the entire pressure range

Dynamic Viscosity: The dynamic viscosity is statistically analyzed in this section for the pressure range of 0.096 MPa to 3.17 MPa. The results of equation 4 have the lowest mean square error of 2.82E-11, whereas the results of equation 1 have the highest mean square error of 1.81E-10, when the mean square error and error percentage values for the three equations are compared. The average percentage error is lowest in equation 4, at 14.8%, and highest in equation 1, at 86.5%. In contrast, equation 3 has an average error of 31% and a mean square error of 4.89E-11.

Thermal Conductivity: The results of equation 2 for thermal conductivity across the entire pressure range reveal an average error of 18.9% and a mean square error of 1.66E-5.

6.2.7 Conclusion

According to the statistical analysis for dynamic viscosity, the results of equation 4 for the refrigerant R134 first came the closest to the values used as references for the whole pressure range of 0.096 MPa to 3.17 MPa. The average error is 14.8%, and the mean square error is 2.82E-11. When comparing the findings separately, equation 4's dynamic viscosity curves are extremely similar to one another and to the reference values, providing the lowest average error for pressure values of 0.096 MPa, 0.179 MPa, 0.379 MPa, and 3.17 MPa. As a consequence, equation 4 is thought to be the most reliable in producing results that are similar to reference values and may be used to determine the dynamic viscosity for this refrigerant. Because there is only one equation available for the examination of thermal conductivity, equation 2 produces an average error of 18.9% across the whole pressure range for thermal conductivity in general. The graphs show that the error decreases with temperature for all pressure levels, with the exception of the graph showing the thermal conductivity values for 3.17 MPa pressure, where the error does not form a V-shape at the higher temperature. This leads to the conclusion that the equation can be used at temperatures up to roughly 80 degrees Celsius. As a result, equation 2 may be used to determine the thermal conductivity of refrigerant R134 in a super-heated condition, whereas equation 4 can be used to determine the dynamic viscosity.

6.3 R143a

There are five different pressure levels for the R143a refrigerant, and the dynamic viscosity and thermal conductivity of each pressure range are tested independently. In order to establish how much error each equation has throughout the entire pressure range and which equation is closest to the reference value, the second worksheet checks the error across the entire pressure range, from the first to the last value.

6.3.1 Dynamic Viscosity and Thermal Conductivity of R143a at 0.096 MPa

Dynamic Viscosity: It appears that equations 4 and 1 have graphs that are quite similar to each other after analyzing the dataset for all three equations and the reference line with their graphs. Both dynamic viscosities and error percentages increase with increasing temperature in these equations, and their graphs also show that. In contrast, the graph shown by equation 3 has a u-shaped curve for the findings, while the graph shown by the reference dataset has a straight line with an incline. Equation 3's error percentage line is also different, with the error decreasing as temperature rises. Equation 3 has a maximum error of 1.53E02% at -40 degrees Celsius and a minimum error of 23.1% at 260 degrees Celsius. According to this, equation 3 has a mean square error of 5.10E-11 and an average error of 54.9%. The mean square error for equation 4 is 1.42E-11, with an average error of 25%. At 260 degrees Celsius, equation 4's error is at its highest and lowest values; at -40 degrees Celsius, it is at its lowest. While equation 1's mean square error is 9.05E-11, its average error was 59.7%. At 260 degrees Celsius, equation 1 has the maximum error of 80.1%, while at -40 degrees Celsius, the lowest error of 36.1%.

Thermal Conductivity: The reference dataset in the graph showing thermal conductivity for R143a at the specified pressure range shows that it rises as temperature rises, and comparable conclusions are found from the data derived from equation 2. As temperature rises, the error rate on the opposite side decreases until it reaches 160 degrees Celsius when the lowest error of 0.195% is recorded and the lines of the equation's data and the reference data cross. From this temperature, the error rate rises as the temperature rises. The initial temperature, when it is the lowest at -40 degrees Celsius, has the biggest error, which is 67.9%. The mean square error is 2.07E-05, and the overall error is 22.7%.

R143a at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.10E-11	1.42E-11	9.05E-11	2.07E-05
Average Error %	54.9 %	25 %	59.7 %	22.7 %
Mini Error %	23 %	20.8 %	36.1 %	0.195 %
Max Error %	15.3E02 %	29.8 %	80.1 %	67.9 %

6.3.2 Dynamic Viscosity and Thermal Conductivity of R143a at 0.179 MPa

Dynamic Viscosity: For this pressure value, it is clear that the dynamic viscosity in the graphs provided by equations 4 and 1 have similar results, with the viscosity increasing with an increase in temperature. The main distinction is the error rate; while the error in equation 4's graph decreases with an increase in temperature, it does the exact opposite in equation 1's graph, where the error increases with an increase in temperature. The mean square error for equation 4 is 2.26E-11, with an average error of 33.4%. On the other hand, equation 1 has a mean square error of 9.29E-11 and an average error of 60.4%. The lowest error for equation 4 is reported at the maximum temperature, which is 260 degrees, Celsius, at 30.4%, and the biggest error is recorded at -30 degrees Celsius, at 36.7%. The answers of equation 1 are radically different; the biggest error was found at 260 degrees Celsius, where it was 79.8%, and the lowest error was found at -30 degrees Celsius, where it was 38.7%. Regarding graph 3, it is observed that the dataset's equation-calculated curve has a u-shape, with a value that decreases to 10 degrees Celsius and climbs as temperature rises. Similar results are seen for the error percentage, where the lowest error is observed at 10 degrees Celsius and is 1.11%. The temperature at which the curves from the dataset for equation 3 and the reference both meet is the other important component. The mean square error is 1.61E-11, and the average error rate is 22.7%.

Thermal Conductivity: Thermal conductivity for R143a at the prescribed pressure range is shown in the graph as a reference dataset, and it is clear from the data obtained from equation 2 that it increases as temperature increases. The error rate on the opposing side drops as the temperature rises, reaching a minimum error of 0.13% at 160 degrees Celsius, where the lines of the equation's data and the reference data cross. The error rate increases as the temperature rises from this point. The beginning temperature, which is at a minimum of -40 degrees Celsius, has the most error (60.8%). The overall error is 20.9%, with a mean square error of 1.967E-05.

R143a at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.61E-11	2.26E-11	9.29E-11	1.96E-05
Average Error %	22.7 %	33.4 %	60.4 %	20.9 %
Mini Error %	1.11 %	30.4 %	38.7 %	0.13 %
Max Error %	34.1 %	36.7 %	79.8 %	60.8 %

6.3.3 Dynamic Viscosity and Thermal Conductivity of R143a at 0.379 MPa

Dynamic Viscosity: All three equations' dynamic viscosity curves and reference lines point to the same conclusion, namely that dynamic viscosity rises as temperature rises. The error curve, which is similar for equations 8 and 1 but completely different for equation 4, is the main difference in the graphs. The lowest error, 64.1%, was observed at the greatest temperature, 260 degrees Celsius, while the highest error, 68.4%, was recorded at the lowest temperature, -10 degrees Celsius. Equation 4 has an average error of 65.9% and a 9.52E-11 mean square error. For equation 3, the mean square error is 8.62E-11, the average error is 60.3%, the lowest error was 46.1% at -10 degrees Celsius, and the maximum error was 66% at the highest temperature on the scale. Equation 1 shows the maximum error of 79.2% at the highest temperature on the scale and the lowest error of 42.9% at the lowest temperature, much like equation 3 does. The mean square error for equation 1 is 9.79E-11, and the average error rate is 61.6%.

Thermal Conductivity: The graph of thermal conductivity for equation 2 is almost identical to the one for the prior pressure value of 0.179 MPa. The mean square value of the recorded errors is 1.76 E-5, and 17.8% on average. The error curve resembles the previous pressure value as well, with the error reducing as temperature rises until 160 degrees Celsius. At 160 degrees, the intersection of the thermal conductivity curves derived from reference and equation values, the lowest error of 2.54E-3% is observed. The lowest temperature value, which serves as the scale's zero degree Celsius, has the biggest inaccuracy of 49.3%.

R143a at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	8.62E-11	9.52E-11	9.79E-11	1.76E-05
Average Error %	60.3 %	65.9 %	61.6 %	17.8 %
Mini Error %	46.1 %	64.1 %	42.9 %	0.0025 %
Max Error %	66 %	68.4 %	79.2 %	49.3 %

6.3.4 Dynamic Viscosity and Thermal Conductivity of R143a at 0.896 MPa

Dynamic Viscosity: While the error curve for equations 4 and 1 grows with temperature, the error curve for this pressure value in graph 3 shows a reduction as the temperature rises. Equation 3 has an average error of 38.2% and a mean square error of 3.17E-11. The biggest mistake, 58.1%, is reported at the lowest temperature of 20 degrees Celsius, while the lowest error, 27.4%, is recorded at the highest temperature on the scale. The mean square error for equation 1 is 1.04E-10, with an average error of 62.2%. The lowest mistake, 47.1%, is reported at a temperature of 20 degrees Celsius, while the biggest error, 77.1%, is recorded at 260 degrees Celsius. Equation 4 has a mean square error of 1.75E-11 and an average error rate of 23.8%. The lowest mistake, or 7.05%, is recorded at 20 degrees Celsius, the lowest temperature on the scale, while the biggest error, or 33.7%, is recorded at 260 degrees Celsius.

Thermal Conductivity: The graph of thermal conductivity for equation 2 resembles the one for the earlier pressure value almost exactly. The recorded errors had a mean square value of 1.40 E-5, and 13.5%, on average. Similar to the previous pressure value, the error curve shows a decreasing trend as temperature increases up to 160 degrees Celsius. The lowest error, 0.462%, is shown at 160 degrees, where the thermal conductivity curves generated from reference and equation values intersect. The largest error is 32.5% at the lowest temperature value, which corresponds to the scale's 20 degree Celsius.

R143a at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.17E-11	1.75E-11	1.04E-10	1.40E-05
Average Error %	38.2 %	23.8 %	62.2 %	13.5 %
Mini Error %	27.4 %	7.05 %	47.1 %	0.462 %
Max Error %	58.1 %	33.7 %	77.1 %	32.5 %

6.3.5 Dynamic Viscosity and Thermal Conductivity of R143a at 3.17 MPa

Dynamic Viscosity: Even if the curves for dynamic viscosity are similar, the error curves in all three graphs are very different for this pressure amount. With a mean square error of 7.85E-11 and an average error of 45.9%, equation 3 shows an error curve that rises as temperature rises. The graph's beginning temperature of 70 degrees Celsius also serves as the intersection point for the dynamic viscosity calculated using the equation and the reference, and it also has the lowest error of 2.61%. At the highest temperature of 260 degrees Celsius, the highest error of 59.5% is noted. On the other hand, the error curve for equation 4 grows with increasing temperature after decreasing from a temperature range of 70 degrees to 90 degrees Celsius. The dynamic viscosity from equation 4 and the reference intersect at temperature 90 degrees Celsius, when the lowest error of 2.44% is noted. At the highest temperature on the scale, the biggest error, 64.9%, is noted. As a result, the largest error of 36.1% is recorded at the lowest temperature and the lowest error of 16.1% is recorded at the highest temperature point for equation 1. On the other hand, the error curve for equation 1 flattens out as the temperature rises. The mean square error of equation 1's results is 1.67 E-11, with an average error of 23.6%.

Thermal Conductivity: It should be noticed that the reference value curve for thermal conductivity at the specified pressure drops from 70 degrees Celsius to 90 degrees Celsius, but then begins to grow as the temperature rises. On the other side, the error curve is unusual since it first rises from 70 degrees to 90 degrees Celsius before dropping off very sharply until 180 degrees Celsius, where the lowest error of 0.695% is observed. The error rate then rises as temperature rises, reaching its maximum inaccuracy of 12.9% at 260 degrees Celsius, the highest temperature on the scale. The mean square error for the solutions to equation 2 and the reference is 7.10E-6, and the average error rate is 6.72%.

R143a at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	7.85E-11	6.72E-11	1.67E-11	7.10E-06
Average Error %	45.9 %	39.3 %	23.6 %	6.72 %
Mini Error %	2.61 %	2.44 %	16.1 %	0.695 %
Max Error %	59.5 %	64.9 %	36.1 %	12.9 %

<u>6.3.6 Dynamic Viscosity and Thermal Conductivity of R143a for the entire pressure range</u>

Dynamic Viscosity: In this section, the dynamic viscosity is statistically examined for the 0.096 MPa to 3.17 MPa pressure range for refrigerant R143a. When the mean square error and error percentage values for the three equations are compared, the results of equation 4 have the lowest mean square error (4.15E-11), while the results of equation 1 have the highest mean square error (8.41E-11). Equation 4 has the lowest average percentage error (2.44%) and equation 1 has the highest average percentage error (80.1%). In contrast, equation 3 has a mean square error of 5.10E-11 and an average error of 44.4%.

Thermal Conductivity: This section statistically analyzes the thermal conductivity for the refrigerant R143a over the pressure range of 0.096 MPa to 3.17 MPa. Similar average errors of 17.2% and mean square errors of 1.65E-5 are shown by equation 2's results for thermal conductivity over the whole pressure range.

<u>6.3.7 Conclusion</u>

The findings of equation 4 for the refrigerant R143a initially came the closest to the values used as references for the whole pressure range of 0.096 MPa to 3.17 MPa, much like the cases of the refrigerants R22 and R134. 37.3%% is the average error rate. The dynamic viscosity curves in equation 4 have the lowest average error for the pressure values of 0.096 MPa, 0.896 MPa, and 3.17 MPa when the results are compared independently. Therefore, equation 4 may be used to compute the dynamic viscosity for this refrigerant in contrast to equations 1 and 3 and is believed to be the most trustworthy in giving results that are similar to reference values. Equation 2 provides the lowest error % for the thermal conductivity results in the temperature range of 120 °K to 220 °K for all the pressure values, indicating that this equation is best suited for this temperature range. Additionally, the overall error percentage for all pressure values across the whole temperature range is less than 20%, demonstrating the applicability of this equation for calculating thermal conductivity for all pressure values across all temperature ranges. All of the equations for the results of dynamic viscosity for refrigerant R143a exhibit some average error in overall pressure values, with equation 4 having the lowest error. As a result, this equation has to be modified further to obtain accurate results. To get the thermal conductivity for the refrigerant R143a in a super-heated condition, equation 2 can be used and advanced further to obtained lower error percentage.

6.4 R152a

The R152a refrigerant has five different pressure levels, and each pressure range's dynamic viscosity and thermal conductivity are studied separately. The second worksheet examines the error across the entire pressure range, from the first to the last value, in order to determine how much error each equation has over the entire pressure range and which equation is closest to the reference value.

6.4.1 Dynamic Viscosity and Thermal Conductivity of R152a at 0.096 MPa

Dynamic Viscosity: When studying each set of data and graphs for the dynamic viscosity separately, it is discovered that while the graphs of equations 4 and 1 are similar, the graph of equation 3 is different. The dataset from equation 3 findings' dynamic viscosity curve displays a u-shaped curve as the reference curve continuously rises. When examining the error curve, it is shown that the error lowers as the temperature rises. For equation 3, the mean square error is 1.71E-10 and the average error percentage is 1.05E02. The maximum error, 2.06E02%, is recorded at the lowest temperature of -20 degrees Celsius, and the lowest error, 65.9%, is observed at the highest temperature of 260 degrees Celsius since the error curve decreases as the temperature rises. For the results shown by equation 4, the graphic figure demonstrates that both the results and the reference have a steady increase in dynamic viscosity. However, the error curve is shaped differently, showing a steep increase in error up to 90 degrees Celsius and then a steady increase up to 260 degrees Celsius. The mean square error for the solutions to equation 4 is 9.86E-11, and the average error percentage is 72.3%. The lowest error, 69.3%, is recorded at a temperature of -20 degrees Celsius, while the largest error, 75%, is recorded at a temperature of 260 degrees Celsius since the error rises as the temperature rises. The curves for values from equation 1 and reference interests are noted to have the lowest error rate of 5.31% at a starting temperature of -20 degrees Celsius for the results provided by equation 1. Temperature increases are accompanied by increases in dynamic viscosity and error percentage, with 260 degrees Celsius recording the highest error of 32.3%. The mean square error for the solutions to equation 1 is 1.12E-11, with an average error percentage of 20.3%.

Thermal Conductivity: At a temperature of 160 degrees Celsius, the curves from the results of the reference values and the values obtained from the solutions of equation 2 intersect each other for the thermal conductivity curve. At this exact temperature, the lowest error rate of 0.244% is noted. As a result, up to this temperature number, the error percentage curve drops as the temperature rises; but, after that point, the error percentage curve increases as the temperature rises. The maximum inaccuracy of value 60.7% is recorded at the starting point where the temperature is -20 degrees Celsius due to a decrease in error. The average error percentage for equation 2 is 16%, and the mean square error is 1.00E-5.

R152a at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.71E-10	9.86E-11	1.12E-11	1.00E-05
Average Error %	1.05E02 %	72.3 %	20.3 %	16 %
Mini Error %	65.9 %	69.3 %	5.31 %	0.244 %
Max Error %	2.06E02 %	75 %	32.2 %	60.7 %

6.4.2 Dynamic Viscosity and Thermal Conductivity of R152a at 0.179 MPa

Dynamic Viscosity: Reviewing the analysis's findings reveals that although the dynamic viscosities rise with temperature, the error curves for the three graphs are all different. For the equation 3 results, the intersection of the curves from equation 3 values and the reference at 130 degrees Celsius temperature yields the lowest error percentage of 0.393% at that specific location. Then, as the temperature rises, the error curve steepens, producing an average error of 12.1% and a mean square error of 3.17E-12. The biggest error, 43.3%, is recorded at the starting temperature of 0 degrees Celsius, the lowest temperature on the scale, due to the structure of the curve. For equation 4, lines constructed using reference values and dynamic viscosity data show a steady increase in value with temperature. The error line is consequently likewise a straight line, however, it is inversely proportional to this and it is getting smaller as the temperature rises. The mean square error for the results is 1.15E-12, with an average error of 8.07%. The biggest error, 10.7%, is recorded at the lowest temperature point and the lowest error, 6.11%, is recorded at the highest temperature point since it decreases as the temperature rises. According to equation 1's results, the dynamic viscosity and error rate both rise as temperature rises, with the biggest error occurring at 260 degrees Celsius and the lowest error occurring at 0 degrees Celsius. The maximum error was 32.2%. This result has a mean square error of 1.19E-11 and an average error percentage of 21.3%.

Thermal Conductivity: The thermal conductivity curves for the reference values and the values derived from the solutions of equation 2 intersect at a temperature of 160 degrees Celsius. It is noted that the lowest error rate of 0.158% occurs at this precise temperature. As a result, the error percentage curve decreases as the temperature rises up to this degree; but, after that, the error percentage curve grows as the temperature rises. At the initial point, where the temperature is 0 degrees Celsius, the maximum error of 44% is noted due to a reduction in error. The mean square error for equation 2 is 8.02E-6, and the average error percentage is 12.8%.

R152a at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.17E-12	1.15E-12	1.19E-11	8.02E-06
Average Error %	12.1 %	8.07 %	21.1 %	12.8 %
Mini Error %	0.393 %	6.11 %	8.25 %	0.158 %
Max Error %	43.3 %	10.7 %	32.2 %	44 %

6.4.3 Dynamic Viscosity and Thermal Conductivity of R152a at 0.379 MPa

Dynamic Viscosity: The results of the analysis show that the error curves for the three graphs are distinct despite the fact that the dynamic viscosities increase with temperature. The intersection of the curves from equation 3 values and the reference at 150 degrees Celsius temperature produces the lowest error percentage for the equation 3 results, which is 0.208% at that precise position. The average error is 9.26%, and the mean square error is 1.99E-12 as the temperature rises, as the error curve steepens. The nature of the curve causes the largest error, 31.1%, to be recorded at the scale's lowest beginning temperature of 20 degrees Celsius. For equation 4, lines derived from dynamic viscosity data and reference values exhibit a continuous increase in value with temperature. As a result, the error line is also a straight line, but it is decreasing as the temperature increases and is inversely proportional to this. The results have a mean square error of 6.40E-13 and an average error of 5.98%. Since errors decrease as temperature increases, the largest error, 10.5%, is recorded at the lowest temperature point and the smallest error, 3.11%, is recorded at the highest temperature point. The dynamic viscosity and error rate both increase with temperature, according to the conclusions of equation 1, with the largest error happening at 260 degrees Celsius and the smallest error occurring at 20 degrees Celsius. 32% was the maximum mistake. The mean square error and average error percentage for this finding are 1.27E-11 and 22.1%, respectively.

Thermal Conductivity: At a temperature of 160 degrees Celsius, the thermal conductivity curves for the reference values and the values obtained from the solutions of equation 2 intersect. It is noteworthy that at this specific temperature, the lowest error rate of 1.49E-02% occurs. As a result, the error percentage curve declines up to this point as the temperature rises, but after that point, it increases as the temperature rises. The largest error of 31.6% is noticed at the starting point, where the temperature is 20 degrees, Celsius, leading to a drop in error. The average error percentage for equation 2 is 10.1%, and the mean square error is 6.28E-6.

R152a at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.99E-12	6.40E-13	1.27E-11	6.28E-06
Average Error %	9.26 %	5.98 %	22.1 %	10.1 %
Mini Error %	0.208 %	3.11 %	11.9 %	0.014 %
Max Error %	31.1 %	10.5 %	32 %	31.6 %

6.4.4 Dynamic Viscosity and Thermal Conductivity of R152a at 0.896 MPa

Dynamic Viscosity: Even though the resulting viscosities are equal for the dynamic viscosity at the 0.896 MPa pressure, the graphic results from the three equations all show distinct error rates. Using the graph and numerical output of equation 3, the lines for dynamic viscosities and reference values are intersecting at temperatures of 60 and 70 degrees Celsius, with the latter temperature point having the lowest error rate of 0.453%. The maximum error rate of 45.3% is observed at 260 degrees Celsius because the error curve decreases from the starting point to 70 degrees Celsius before increasing as the temperature rises. Equation 3 has a mean square error of 2.05E-12 and an average error rate of 7.49%. Taking into account the findings of equation 4, the error curve shows a decreasing trend with temperature, with the largest error of 25.2% at the starting temperature of 40 degrees Celsius and the lowest error of 9.28% at the highest temperature of 260 degrees Celsius. According to these findings, the error rate decreases and both dynamic viscosity lines' values become closer as the temperature rises. With a mean square error of 4.23E-12, equation 4 has an average error of 14.7%. According to equation 1, the dynamic viscosity and error rate both rise as the temperature rises, with an average error rate of 22.3% and a mean square error of 1.30E-11, respectively. The end point error is measured at 260 degrees Celsius, with a value of 31.3%, and the starting point error is measured at the lowest temperature, with a value of 12.4%.

Thermal Conductivity: Both lines derived from estimated values from equation and values received from reference are intersecting at 150 and 160 degrees Celsius, respectively, for the thermal conductivity results given by equation 2. With the latter providing the lowest error rate at this time (0.598%). This results in the error curve growing from temperature 160 degrees Celsius to the end point and reducing up to 150 degrees Celsius. The mean square error of the curve is 4.45E-06, while the average error is 7.34%. The maximum error of 18.3% is noted at the starting point statistically since the error curve declines until a specific temperature threshold.

R152a at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.05E-12	4.23E-12	1.30E-11	4.45E-06
Average Error %	7.49 %	14.7 %	22.3 %	7.34 %
Mini Error %	0.453 %	9.28 %	12.4 %	0.598 %
Max Error %	13.7 %	25.2 %	31.3 %	18.3 %

6.4.5 Dynamic Viscosity and Thermal Conductivity of R152a at 3.17 MPa

Dynamic Viscosity: It is observed that the error curves for equations 3 and 4's graphs of the dynamic viscosity findings are decreasing until temperatures of 110 degrees Celsius for equation 3 and 130 degrees Celsius for equation 4, respectively. While the temperature-dependent error curve for the graph shown by equation 1 grows. Equation 3's dynamic viscosity reference value and equation value are connected at 110 degrees Celsius, which results in the equation's lowest error rate of 1.10% at that temperature. At the greatest temperature, 260 degrees Celsius, the highest error rate of 30.8% is given. Equation 3's results have an average error rate of 21.5%, and the mean square error is 1.59E-11. On the other hand, with the findings shown by equation 4, when both dynamic viscosities curve link with each other, the lowest error of 0.619% is found at the temperature of 130 degrees Celsius. The mean square error for the solutions to equation 4 is 1.60E-11, and the average error rate is 20.4%. The biggest error, which is 35.8%, is shown by the highest temperature point. On the contrary, because the error curve for the results shown by equation 1 is in the opposite direction, the starting point shows the lowest error rate at 4.91%, and the endpoint temperature shows the highest error at 26.8%. The mean square error for the outcomes shown by equation 1 is 1.09E-11, and the average error rate is 18.1%.

Thermal Conductivity: The thermal conductivity error curve for refrigerant R152a at pressure 3.17 MPa has a u-shape because it reduces with rising temperature up to 140 degrees Celsius before increasing. The temperature mentioned above has the lowest error, which is 2.79%. The endpoint temperature has the biggest error, which is 10.2%; however, the starting point temperature's error, which is 9.75%, is very near to this amount. The mean square error for both the thermal conductivities determined by the equation and the reference values is 4.98E-06, and the average error for the results is 5.96%.

R152a at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.59E-11	1.60E-11	1.09E-11	4.98E-06
Average Error %	21.5 %	20.4 %	18.1 %	5.96 %
Mini Error %	1.10 %	0.619 %	4.91 %	2.79 %
Max Error %	30.8 %	35.8 %	26.8 %	10.2 %

6.4.6 Dynamic Viscosity and Thermal Conductivity of R152a for the entire pressure range

Dynamic Viscosity: This section statistically analyzes the dynamic viscosity of the refrigerant R152a over the pressure range of 0.096 MPa to 3.17 MPa. When the results of the three equations are compared for mean square error and error percentage values, the results of equation 1 have the lowest mean square error (1.19E-11), and the results of equation 3 have the highest mean square error (4.47E-11). The average percentage error for equation 1 is the lowest (21%) and equation 3 has the highest average percentage error (34.2%). In contrast, equation 4 has an average error of 26% and a mean square error of 2.71E-11.

Thermal Conductivity: The thermal conductivity for the refrigerant R152a over the pressure range of 0.096 MPa to 3.17 MPa is statistically examined in this section. The mean square error for the full pressure range is 7.03E-06 with an average error of 11.1%.

6.4.7 Conclusion

Equation 1 is regarded as the best one out of the three for the refrigerant R152a since it has the lowest average error of 21% over pressure ranges of 0.096 MPa to 3.17 MPa. The answers to equation 1 give the lowest average, which is roughly less than 25%, and are pretty similar to the reference values, as shown by all the graphs. For any pressure value at the super-heated temperature range, equation 1 is thought to be the most appropriate one to compute the dynamic viscosity of the refrigerant R152a. Even after evaluating each number separately, equation 2's average error for thermal conductivity is 11% for the whole pressure range, with the lowest pressure value of 0.096 MPa having the largest average error of 16%. This shows that when pressure is increased, the error percentage decreases, and the numbers from equation 2 become more comparable to the reference values. Ultimately, it can be said that equation 1 may be used to compute dynamic viscosity since, in contrast to equations 3 and 4, it has the lowest error percentage for all pressure levels. While thermal conductivity may be determined using equation 2. To get the precise findings needed in the future, these equations can be revised further.

6.5 R290

The dynamic viscosity and thermal conductivity of the R290 refrigerant are examined independently for each of its five pressure ranges. In order to establish how much error each equation has throughout the entire pressure range and which equation is closest to the reference value, the second worksheet checks the error generally over the entire pressure range, from the first to the last value.

6.5.1 Dynamic Viscosity and Thermal Conductivity of R290 at 0.096 MPa

Dynamic Viscosity: The graph of data produced by the three equations is remarkably comparable for the dynamic viscosity at the specified pressure value, with the dynamic viscosity rising with increasing temperature and the error curve falling. For equation 3, the line derived from dynamic viscosity values is nearly a straight line, but the reference line shows a sharp increase at 210 degrees Celsius in temperature. This result has an average error rate of 3.39E04 and a mean square error of 8.30E04. The initial point, which has a temperature of -40 degrees Celsius, has the largest error, measuring 1.31E05%. On the other hand, the temperature of 250 degrees Celsius, which is interestingly the point at which the lines from the equation values and reference values connect, records the lowest inaccuracy of 5.86%. The results of equation 4 have an average error of 2.31E04% and a mean square error of 4.72E04. The largest error is recorded at the starting point with an error of 6.34E04%, and the lowest error percentage is recorded at a temperature of 320 degrees Celsius with a value of 1.31%. This is because the error curve decreases as the temperature rises. In line with the previous two figures, the graph produced by equation 1 shows that the error rate decreases as the temperature rises. The dynamic viscosity line predicted by reference values climbs gradually up to 180 degrees Celsius and then dramatically reduces after that. While the temperature range is covered by a steady increase in the line showing the results of equation 1. The mean square error for these results is 6.34E-04, while the overall error is 4.57E04 percent. The lowest error of 7.46% is recorded at the temperature of 290 degrees Celsius, which is also the intersection point for the lines of dynamic viscosity provided by reference and equation 1 values. Similar to other results, the starting point temperature, which is the lowest, also has the highest error of 1.24E05.

Thermal Conductivity: Equation 2 results for the thermal conductivity of R290 at the specified pressure are examined using reference values. This graph has a mean square error of 2.33E08 and an average error rate of 1.14E04%. It has been observed that thermal conductivity values rise with temperature and that the rise is rather abrupt once the temperature reaches 230 degrees Celsius. On the other hand, the error curve flattens out as the temperature rises. According to this, the highest error, which was recorded at a temperature of -40 degrees Celsius, was 3.82E04, while the lowest error, which was recorded at a temperature of 300 degrees Celsius, was 1.88% and this temperature point is the intersecting point for both curves.

R290 at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	8.30E-04	4.72E-04	6.34E-04	2.33E+08
Average Error %	3.39E04 %	4.57E04 %	4.57E04 %	1.14E04 %
Mini Error %	5.86 %	1.31 %	7.46 %	1.88 %
Max Error %	1.32E05 %	6.34E04 %	1.24E05 %	3.82E04 %

6.5.2 Dynamic Viscosity and Thermal Conductivity of R290 at 0.179 MPa

Dynamic Viscosity: The graphs for all three equations are comparable for this pressure value. The dynamic viscosity curve for equations 3 and 4 is given by values from equations and increases steadily up to 190 degrees Celsius before increasing steeply to the greatest temperature. On the other hand, the graph provided by equation 1 shows that the dynamic viscosity curve for the values shown in the equation increases steadily. On the other hand, the curve for dynamic viscosity shown by reference values climbs abruptly at a higher rate from the temperature of 230 degrees Celsius. The mean square error for the equation 3 curve is 2.91E-04, while the average error is 7.72E03. The largest error of 2.99E04 is recorded at a starting temperature of -20 degrees Celsius, and the lowest error of 6.24% is reported at a temperature of 300 degrees Celsius. The error rate then gradually increases after this point. The mean square error is 2.43E-04 and the average error is 5.54E03% for the graph of equation 4. The dynamic viscosities of the reference and equation 4 values intersect at a temperature of 300 degrees Celsius, where the error is lowest at 1.46% and maximum at 0 degrees and 10 degrees Celsius, respectively. The mean square error for equation 1 is 8.95E-04, while the average error rate is 8.42E04%. The temperature of 320 degrees Celsius, where both dynamic viscosity curves overlap, has the lowest error of 4.57%. The temperature of 20 degrees Celsius simultaneously records the largest error, 2.48 E05%.

Thermal Conductivity: Using reference values, the results of Equation 2 are analyzed for the thermal conductivity of R290 at the required pressure. The average error rate for this graph is 1.01E04%, and the mean square error is 2.33E08. Thermal conductivity values have been found to increase with temperature, but if the temperature hits 230 degrees Celsius, the increase is fairly abrupt. On the other hand, as temperature increases, the error curve flattens out. This indicates that the lowest error, which was recorded at a temperature of 300 degrees Celsius, was 1.88%, while the maximum error, which was recorded at a temperature of -20 degrees Celsius, was 3.56E04. This temperature point is where both curves meet.

R290 at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.91E-04	2.43E-04	8.95E-04	2.45E+08
Average Error %	7.72E03 %	5.54E03 %	8.42E04 %	1.01E04 %
Mini Error %	6.24 %	1.46 %	4.57 %	1.88 %
Max Error %	2.99E04 %	1.67E04 %	2.48E05 %	3.56E04 %

6.5.3 Dynamic Viscosity and Thermal Conductivity of R290 at 0.379 MPa

Dynamic Viscosity: For this pressure value, the graphs for all three equations are comparable. Values from the equations determine the dynamic viscosity curve for equations 3 and 4, which grows gradually up to 200 degrees Celsius before climbing rapidly to the highest temperature. The dynamic viscosity curve, on the other hand, grows steadily for the values specified in the equation, as evidenced by the graph produced by equation 1. On the other hand, the reference values' depiction of the dynamic viscosity curve shows a sudden ascent at a faster rate from 230 degrees Celsius. The average error is 3.30E03 % and the mean square error for the equation 3 curve is 6.18E-04. At a beginning temperature of 0 degrees Celsius, the error is reported as 1.33E04, whereas at a temperature of 250 degrees Celsius, the error is given as

2.98%. This is followed by a progressive increase in the error rate. For the graph of equation 4, the mean square error is 5.74E-04 and the average error is 2.48E03%. At 260 degrees Celsius, where the error is lowest (6.18%), and at 20 degrees Celsius, where the error is highest (8.31E03), the dynamic viscosities of the reference and equation 4 values coincide. The average error rate is 7.58E04%, and the mean square error for equation 1 is 9.28E-04. The lowest inaccuracy is 4.57% at 320 degrees Celsius where both dynamic viscosity curves overlap. The highest error, 2.48E05%, is recorded at a temperature of 20 and 30 degrees Celsius.

Thermal Conductivity: The findings of Equation 2 are examined for the thermal conductivity of R290 at the necessary pressure using reference values. This graph has a mean square error of 2.58E08 and an average error rate of 8.72E03%. Thermal conductivity values have been observed to rise with temperature, however, the rise is very abrupt once the temperature reaches 220 degrees Celsius. On the other hand, the error curve flattens out as the temperature rises. This shows that the minimum error, which was recorded at 300 degrees Celsius, was 1.88%, and the largest error, which was recorded at 0 degrees Celsius, was 3.34E04. The intersection of both curves occurs at this temperature.

R290 at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	6.18E-04	5.74E-04	9.28E-04	2.58E+08
Average Error %	3.30E03 %	2.48E03 %	7.58E04 %	8.72E03 %
Mini Error %	2.98 %	6.18 %	4.57 %	1.88 %
Max Error %	1.33E04 %	8.31E03 %	2.48E05 %	3.34E04 %

6.5.4 Dynamic Viscosity and Thermal Conductivity of R290 at 0.896 MPa

Dynamic Viscosity: The graphs for all three equations are comparable at this pressure value. The dynamic viscosity curve for equations 3 and 4 is determined by values from the equations. It increases gently up to 200 degrees Celsius before accelerating to the maximal temperature. On the other hand, the graph created by equation 1 shows that the dynamic viscosity curve increases steadily for the values indicated in the equation. The dynamic viscosity curve, however, is depicted by the reference values as abruptly rising at a quicker rate from 210 degrees Celsius. The mean square error for the equation 3 curve is 1.01E-03, while the average error is 8.78E02%. The error is stated as 3.91E03% at a starting temperature of 0 degrees Celsius and as 8.77% at a temperature of 170 degrees Celsius. The error rate then gradually goes up after that. The mean square error and average error for the graph of equation 4 are 9.82E-04 and 6.99E02%, respectively. The dynamic viscosities of the reference and equation 4 values coincide at 170 degrees Celsius, where the error is lowest (11.7%), and at 40 degrees Celsius, where it is largest (2.76E03%). The mean square error for equation 1 is 9.78E-04, while the average error rate is 6.07E04%. At 320 degrees Celsius, where both dynamic viscosity curves intersect, there is the least error (4.57%). At a temperature of 30 degrees Celsius, the largest error is seen, 2.48E05%.

Thermal Conductivity: The results of Equation 2 are used to test the thermal conductivity of R290 at the required pressure. The mean square error and average error rate for this graph are 2.81E08 and 6.64E03%, respectively. The temperature has been seen to increase thermal conductivity values, although the increase is fairly abrupt once the temperature hits 230 degrees Celsius. The error curve, on the other hand, flattens out as the temperature increases. This demonstrates that the biggest error was recorded at 30 degrees Celsius and was 3.02E04%, with the least error being reported at 300 degrees Celsius being 1.88%. When the temperature reaches this level, both curves intersect.

R290 at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.01E-03	9.82E-04	9.78E-04	2.81E+08
Average Error %	8.78E02 %	6.99E02 %	6.07E04 %	6.64E03 %
Mini Error %	8.77 %	11.7 %	4.57 %	1.88 %
Max Error %	3.91E03 %	2.76E03 %	2.48E05 %	3.02E04 %

6.5.5 Dynamic Viscosity and Thermal Conductivity of R290 at 3.17 MPa

Dynamic Viscosity: The error curve for Equations 3 and 4 displays significant irrationality. For equation 3, the temperature at which there is the least error, 2.44%, and the temperature at which there is the greatest mistake, 3.90E02%, is 250 degrees Celsius. Equation 3 has a mean square error of 7.96E-04 and an average error rate of 78.7%. The biggest error, 3.07E02%, is reported at a temperature of 90 degrees Celsius, while the least error, 6.18%, is recorded at a temperature of 250 degrees Celsius. The lines of dynamic viscosity for the reference values and equation values for both graphs intersect at 250 degrees Celsius. Equation 1 has a mean square error of 1.07E-03 and an average error rate of 2.31E04%. The least error (4.57%) is found at 320 degrees Celsius, where both dynamic viscosity curves overlap. The highest error is observed at a temperature of 90 degrees Celsius, or 1.87E05%.

Thermal Conductivity: To get R290's thermal conductivity at the necessary pressure, the solutions to Equation 2 are employed. This graph has a mean square error of 3.41E08 and an average error rate of 2.16E03%, respectively. Thermal conductivity levels have been observed to rise with temperature, albeit the increase is very rapid once the temperature reaches 230 degrees Celsius. On the other hand, when the temperature rises, the error curve flattens out. This reveals that the largest error , 2.15E04, was recorded at 90 degrees Celsius, while the smallest error, 1.88%, was recorded at 300 degrees Celsius. Both curves meet at this point in the temperature spectrum.

R290 at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	7.96E-04	7.41E-04	1.07E-03	3.41E+08
Average Error %	78.7 %	70.2 %	2.31E04 %	2.16E03 %
Mini Error %	2.44 %	6.18 %	4.57 %	1.88 %
Max Error %	3.90E02 %	3.07E02 %	1.87E05 %	2.15E04 %

6.5.6 Dynamic Viscosity and Thermal Conductivity of R290 for the entire pressure range

Dynamic Viscosity: The dynamic viscosity of the refrigerant R290 over the pressure range of 0.096 MPa to 3.17 MPa is statistically analyzed in this section. The results of equation 4 have the lowest mean square error (5.82E-04), whereas the results of equation 1 have the highest mean square error when the results of the three equations are compared for mean square error and error percentage values (8.85E-04). Equation 4 has the lowest average percentage error (1.03E04%), whereas equation 1 has the largest average percentage error (5.96E04%). Equation 3 has a mean square error of 6.97E04 and an average error of 1.03E04%.

Thermal Conductivity: This section statistically analyzes the thermal conductivity of the refrigerant R290 over the pressure range of 0.096 MPa to 3.17 MPa. For the entire pressure range, the mean square error is 2.67E08, with an average error of 8.21E03%.

6.5.7 Conclusion

For the refrigerant R290, all equations showed a tendency that the values tended to approach the reference values as the temperature increased, regardless of pressure values. Since the average error is the lowest at temperature of 130 degrees Celsius, even if all equations can be used to compute the dynamic viscosity regardless of pressure, the temperature range is undoubtedly constrained. As a consequence, equation 4 produced the best results, recording the smallest average error and offering dynamic viscosity values that were the most similar to those of the reference. Since the situation for thermal conductivity was identical to that of dynamic viscosity, this equation may be used starting at a temperature of 250 degrees Celsius. Therefore, for all pressure levels employed in the experiment, this equation for thermal conductivity is regarded as being accurate at higher temperature ranges. Because the existing equations are insufficient to determine the findings for these characteristics, it is determined that both the equations for dynamic viscosity and thermal conductivity need to be updated for this refrigerant. The error percentage supplied in any pressure value is too big to be taken into account, hence it can be concluded that neither equation can be utilized to determine dynamic viscosity. Similar circumstances apply to thermal conductivity, where equation 2 yields solutions with significant error margins for all pressure levels. In order to determine the dynamic viscosity and thermal conductivity of refrigerant R290 in a super-heated condition, new equations must be created.

6.6 R404A

The R404A refrigerant's dynamic viscosity and thermal conductivity are investigated independently for each of its five pressure ranges. The second worksheet checks the error generally over the full pressure range, from the first to the last value, to determine how much error each equation has throughout the entire pressure range and which equation is closest to the reference value.

6.6.1 Dynamic Viscosity and Thermal Conductivity of R404A at 0.096 MPa

Dynamic Viscosity: When the data for dynamic viscosity for refrigerant R404A are reviewed, all of the graphs show the same result, with dynamic viscosity increasing with increasing temperature. Individually, the graph of equation 3 shows a u-shaped curve for dynamic viscosity produced from equation values, suggesting that dynamic viscosity acquired from equation values drops until 60 degrees Celsius, then increases. The curves meet at higher temperatures above 220 degrees Celsius, and the lowest error rate of 0.0417% is reported at temperature 230 degrees Celsius. At the lowest temperature of -30 degrees Celsius, the largest inaccuracy is 85.2%. This graph's average error is 21%, while the mean square error is 1.22E-11. The graph for equation 4 shows an average error rate of 2.06% and a mean square error of 1.38E-13. The lines using both reference and equation values meet at several temperature points, resulting in the lowest error of 0.0147% at 130 degrees Celsius. The graph illustrates a V-shape in the error curve for equation 4, with it decreasing with increasing temperature until 130 degrees Celsius, where the lowest error of 0.0147% is recorded. The biggest error, 4.38%, is recorded at -30 degrees Celsius, the temperature scale's beginning point. This visual result has an average error rate of 2.06% and a mean square error of 1.38E-13. The average error of the results for equation 1 is 87.3%, and the mean square error is 2.18E-10. The lowest reported error is 59.2% at the lowest temperature, and the biggest error is 1.11E02% at the maximum temperature, 260 degrees Celsius.

Thermal Conductivity: For thermal conductivity, the intersection of the values obtained by equation 2 and reference at 150 degrees Celsius has the lowest error rate of 0.173%. This means that the error curve lowers until the temperature is reached, then increases until the end. As a result, the maximum error of 54.7% is created at the beginning temperature of -30 degrees Celsius. This curve has an average error of 18.4% and a mean square error of 1.47E-05.

R404A at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.22E-11	1.38E-13	2.18E-10	1.47E-05
Average Error %	21 %	2.06 %	87.3 %	18.4 %
Mini Error %	0.041 %	0.014 %	59.2 %	0.017 %
Max Error %	85.2 %	4.38 %	1.11E02 %	54.7 %

6.6.2 Dynamic Viscosity and Thermal Conductivity of R404A at 0.179 MPa

Dynamic Viscosity: The average error measured for equation 3 is 36.9%, and the mean square error is 4.28E-11. The graph shows that as temperature rises, not only the dynamic viscosity but also the error percentage grows. As a consequence, the lowest error of 9.31% is recorded at the starting point temperature of -20 degrees Celsius, and the maximum error is recorded at the highest temperature, 260 degrees. While the error rate for the findings shown by equation 4 is exactly the contrary, decreasing with increasing temperature. As a consequence, the lowest error is 44.2% at the highest temperature of 260 degrees Celsius and the biggest error is 49.8% at the lowest temperature. This graph's average error is 46.8%, while the mean square error is 5.36E-11. Because the findings of equation 1 are identical to those of equation 3, the lowest error for this graph is 61.6% at the lowest temperature and the maximum error is 1.11E02% at the highest temperature of 260 degrees Celsius. The average error percentage for equation 4 is 88.1%, with a mean square error of 2.24E-10.

Thermal Conductivity: The intersection of the values given by equation 2 and the reference at 150 degrees Celsius has the lowest error rate for thermal conductivity, at 0.218%. Accordingly, the error curve decreases until the temperature is attained before increasing again. As a result, at the starting temperature of -20 degrees Celsius, the highest error of 49.4% is produced. This curve has a mean square error of 1.40E-05 and an average error of 17%.

R404A at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	4.28E-11	5.36E-11	2.24E-10	1.40E-05
Average Error %	36.9 %	46.8 %	88.1 %	17 %
Mini Error %	9.31 %	44.2 %	61.6 %	0.218 %
Max Error %	47.1 %	49.8 %	1.11E02 %	49.4 %

6.6.3 Dynamic Viscosity and Thermal Conductivity of R404A at 0.379 MPa

Dynamic Viscosity: When examining the findings for all three graphs, it is seen that each error curve differs, showing that there is no relationship between any of the three graphs' outcomes. Looking at each result separately, the graph of result 8 shows that the dynamic viscosity curves generated from equation 3 and the reference curve at 30 Celsius temperature meet. This intersection results in the lowest error at the specified temperature, which is 0.9%. This causes the error curve, which is V-shaped, to drop until the temperature is specified, then climbs, with the maximum error being 25.7% at 260 degrees Celsius. The mean square error for this graph and its data is 1.08E-11, and the average error percentage is 16.4%. While the findings of equation 4's graph demonstrate that the error curve is flattening as temperature rises. As a result, the lowest error, 21.8%, is recorded at the greatest temperature, 260 degrees Celsius, and the highest error, 32.1%, is recorded at the lowest temperature, 0 degrees Celsius. The mean square error is 1.67E-11, while the average error for the full dynamic viscosity curve is 26%. The error line for the final graph, which represents the output of equation 1's calculations, grows as the temperature rises. As a result, at the lowest temperature, the lowest error is recorded at 66.2%, and at the highest temperature, the largest error is reported at 1.10E02%. The mean square error for this graph is 2.36E-10, and the average error is 89.4%.

Thermal Conductivity: The thermal conductivity value with the lowest error rate, 0.331%, is the intersection of the values from equation 2 and the reference at 150 degrees Celsius. As a result, the error curve reduces until the temperature is reached before increasing once more. As a result, the largest error of 39.6% is generated at the starting temperature of -20 degrees Celsius. This curve has a 14.5% average error and a mean square error of 1.26E-05.

R404A at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.08E-11	1.67E-11	2.36E-10	1.26E-05
Average Error %	16.4 %	26 %	89.4 %	14.5 %
Mini Error %	0.90 %	21.8 %	66.2 %	0.331 %
Max Error %	25.7 %	32.1 %	1.10E02 %	39.6 %

6.6.4 Dynamic Viscosity and Thermal Conductivity of R404A at 0.896 MPa

Dynamic Viscosity: The mean square error for equation 3 is 1.70E-11, while the average error is 22.8%. The graph demonstrates that as temperature increases, both the error percentage and the dynamic viscosity increase. As a result, at the beginning point temperature of 20 degrees Celsius, the error is recorded at 12.5%, and at the highest temperature of 260 degrees, the error is recorded at 28.5%. On the other hand, equation 4's results exhibit the exact opposite trend, with error rates falling as temperature rises. As a result, at the highest temperature of 260 degrees Celsius, the error is 25%, and at the lowest temperature of 20 degrees Celsius, the error is 40.9%. The mean square error of this graph is 2.49E-11, while the average error is 30.9%. The lowest error for this graph is 70.3% at the lowest temperature of 20 degrees Celsius and the biggest error is 1.07E02% at the highest temperature of 260 degrees Celsius since the results of equations 1 and 8 are equal. With a mean square error of 2.45E-10, equation 4 has an average error percentage of 89.5%.

Thermal Conductivity: The intersection of the numbers from equation 2 and the reference at 150 degrees Celsius produces the thermal conductivity value with the lowest error rate, 0.662%. As a result, the error curve decreases until the temperature is attained before growing again. As a result, the highest inaccuracy of 27.9% is produced at the beginning temperature of 20 degrees Celsius. This curve has an average error of 11.9% and a mean square error of 1.08E-05.

R404A at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.70E-11	2.49E-11	2.45E-10	1.08E-05
Average Error %	22.8 %	30.9 %	89.5 %	11.9 %
Mini Error %	12.5 %	25 %	70 %	0.662 %
Max Error %	28.5 %	40.9 %	1.08E02 %	27.9 %

6.6.5 Dynamic Viscosity and Thermal Conductivity of R404A at 3.17 MPa

Dynamic Viscosity: While equation 1's output produces a completely different graph, equations 3 and 4's outputs for the dynamic viscosity of the refrigerant R404A at a pressure value of 3.18 MPa show identical curves for both the dynamic viscosity and error percentage. For equation 3 findings, the lowest error of 0.935 % is noted at the temperature value of 90 degrees Celsius since the curves derived from values of dynamic viscosity of equation 3 and reference values appear to be crossing there. This also causes a V-shaped error curve to appear, with the curve reducing until the target temperature and then rising as the temperature rises. At an ending temperature of 260 degrees Celsius, the largest error of 28.1 % was observed. The mean square error for this curve is 1.73E-11, while the average error is 19.4 %. At a temperature of 130 degrees Celsius, for the results of equation 4 the curves of dynamic viscosity for equation and reference values overlap, giving the lowest error of 1.83 %. This is because equation 4's findings are identical to those of equation 3's. The beginning temperature point yields the largest error of 42.9 %, exhibiting a V-shaped error curve. The mean square error for the solutions to equation 4 is 1.82E-11, with an average error of 19.1 %. For equation 1, both the error curve and the dynamic viscosity curve show an increase in temperature for both values. As a result, the lowest error on the scale, at 70 degrees Celsius, is 46.8 %, while the highest error, at 260 degrees Celsius, the highest temperature on the scale, is 97.7 %. The mean square error calculated for these data is 2.42E-10, with an average error of 78.5 %.

Thermal Conductivity: The error curve for thermal conductivity for R404A at the mentioned pressure value seems to form a sinusoid curve indicating that the curve increases with temperature increase until 90 degrees Celsius and then reduces till the temperature value of 170 degrees Celsius and then increases afterward As a result, the largest error of 31.2% is recorded at the specified temperature is 260 degrees Celsius. Since the curve is a sinusoid curve, the lowest error of 0.416 % is recorded at a temperature of 170 degrees Celsius. The reported mean square error for this result is 6.44E-06, with an average error percentage of 6.53 %.

R404A at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.73E-11	1.82E-11	2.42E-10	6.44E-06
Average Error %	19.4 %	19.1 %	78.5 %	6.53 %
Mini Error %	0.935 %	1.83 %	46.8 %	0.416 %
Max Error %	28.1 %	42.9 %	97.7 %	13.6 %

6.6.6 Dynamic Viscosity and Thermal Conductivity of R404A for the entire pressure range

Dynamic Viscosity: It should be noted that equation 3's values for the dynamic viscosity of the refrigerant R404A throughout the whole pressure range in which the study was performed had a minimum average error percentage of 23.7% and a minimum mean square error of 2.04E-11. While equation 1's output has the largest error rate, with a mean square error of 2.32E-10 and an average error of 87%. The mean square error for equation 4 is 2.29E-11, while the average error is 25%.

Thermal Conductivity: The solutions to equation 2 for the total pressure for refrigerant 404A's thermal conductivity provide an average error percentage of 14.2% and a mean square error of 1.21E-05. The lowest and greatest errors are 0.173% and 54.7%, respectively.

6.6.7 Conclusion

Equation 3 provides the best average error between the equation and reference values for the dynamic viscosity based on findings for the refrigerant R404A over the pressure range of 0.096 MPa to 3.17 MPa. With the graph of 0.096 MPa pressure being the lone exception, the average error recorded is 23.7%, and all graphs show that the error percentage is lowest near the beginning of the temperature range. This leads to the conclusion that the error between the findings likewise grows as pressure and temperature rise. The equation's values appear to become closer and intersect with reference values at a higher temperature of 150 degrees Celsius, according to the thermal conductivity data, nevertheless. This shows that the equation values are producing results for all pressure values that are quite similar to reference values as the temperature rises. As a consequence, from a temperature range of 100 degrees Celsius to the endpoint temperature, this equation may be used to determine the thermal conductivity of refrigerant R404A. According to the examination of all five pressure values, equations 3 and 4 provide the best results for calculating the dynamic viscosity of the refrigerant R404A in the super-heated condition since their error percentage is much lower than that of equation 1's. To compute thermal conductivity, equation 2 similarly shows a narrow error percentage range for all pressure levels. As a result, equation 2 may be utilized to determine thermal conductivity and equation 3 to determine dynamic viscosity. These equations can be enhanced further in the future to get precise results.

6.7 R407C

The dynamic viscosity and thermal conductivity of the R407C refrigerant are examined separately for each of its five pressure levels. In order to assess how much error each equation has throughout the whole pressure range and which equation is closest to the reference value, the second worksheet examines the error generally over the entire pressure range, from the first to the final value.

6.7.1 Dynamic Viscosity and Thermal Conductivity of R407C at 0.096 MPa

Dynamic Viscosity: The results of dynamic viscosity for the refrigerant R407C at mentioned pressure value for equations 1 and 4 have similar graphic results, while the results given by equation 1 is completely opposite. For the equation 4, the error curve as well as dynamic viscosity curve increases with an increase in temperature indicating the lowest error of 5.68 % at beginning temperature of -30 degrees Celsius temperature, while the highest error of 12.7 % is recorded at the highest temperature of 260 degrees Celsius. The average error percentage for this curve is recorded as 9.78 % with the mean square error of 2.98E-12. Similar to equation 4, the findings of equation 1 demonstrate that the error curve and dynamic viscosity curve both rise with temperature, with the lowest error at the lowest temperature being 42.6% and the largest error at the highest temperature being 86.9%. The mean square error for this equation curve is 1.43E-10, and the average error percentage is 67.7%. The error curve, on the other hand, is inversely proportional to the dynamic viscosity curve for the solutions of equation 3, meaning that as temperature rises, the dynamic viscosity curve grows while the error curve decreases. As a consequence, at the greatest temperature of 260 degrees Celsius, the lowest error of 6.83% is noted. This curve's mean square error is 2.58E-11 and its average error percentage is 33.1%. While a starting point temperature of -30 degrees Celsius is where the biggest error, 1.05E02, is recorded. The dynamic viscosity of equation 3 results in a somewhat u-shaped curve.

Thermal Conductivity: The error curve is inversely proportional to the thermal conductivity curve for the refrigerant R407C at the specified pressure as determined by equation 2's findings for thermal conductivity. The endpoint point temperature of 260 degrees Celsius forms the lowest error at 4.68%, while the initial temperature of -30 degrees Celsius records the biggest error at 86.5%. This shows that the error curve is flattening out as the temperature rises. The mean square error for these results is 4.67E-05, with an average error of 38.1%.

R407C at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.58E-11	2.98E-12	1.43E-10	4.67E-05
Average Error %	33.1 %	9.79 %	67.7 %	38.1 %
Mini Error %	6.83 %	5.68 %	42.6 %	4.68 %
Max Error %	1.05E02 %	12.7 %	86.9 %	86.5 %

6.7.2 Dynamic Viscosity and Thermal Conductivity of R407C at 0.179 MPa

Dynamic Viscosity: While the solutions to equations 3 and 1 are somewhat similar for this pressure number, the solutions to equation 4 are entirely different. While the findings of equations 8 and 1 showed that the error curve grows with an increase in temperature, the error curve for equation 4 decreases with an increase in temperature. Due to this, equation 4 records the lowest error at 260 degrees Celsius, which is 39.5%, and the highest error, which is 44.5%, at -20 degrees Celsius. This shows that the dynamic viscosity values of equation 4 and reference values appear to be approaching each other as the temperature rises. The mean square error for this outcome is 4.48E-11, with an average error of 41.4%. At the lowest temperature of -20 degrees Celsius, the results from equations 3 and 1 have the lowest error of 0.339% and 45%. The biggest inaccuracy, 42.7% for equation 3 and 86.7% for equation 1, is observed at 260 degrees Celsius, the highest temperature. The error curve for equation 1 has a consistent increase over the course of the whole temperature range, but the error curve for equation 3 has a rapid increase in error. The mean square error for equation 3 is 3.45E-11, while the average error is 30.4%. While the mean square error for equation 1 is 1.47E-10 and the average error is 68.5%.

Thermal Conductivity: The results of equation 2 for thermal conductivity show that the error curve is inversely proportional to the thermal conductivity curve for the refrigerant R407C at the stated pressure. The temperature at the endpoint point, 260 degrees Celsius, has the lowest error at 4.74%, while the temperature at -20 degrees Celsius has the most error, 80.7 %. This demonstrates that when the temperature rises, the error curve flattens out. These findings have a mean square error of 4.58E-05, or a 36.3% average error.

R407C at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.45E-11	4.48E-11	1.47E-10	4.58E-05
Average Error %	30.4 %	41.4 %	68.5 %	36.3 %
Mini Error %	0.339 %	39.5 %	45 %	4.74 %
Max Error %	42.7 %	44.5 %	86.7 %	80.7 %

6.7.3 Dynamic Viscosity and Thermal Conductivity of R407C at 0.379 MPa

Dynamic Viscosity: For this pressure value, the graphs of the solutions to equations 3 and 4 show some similarities, however equation 1 yields a different solution. Even though the dynamic viscosity in all three graphs increases as the temperature rises, each graph's error curve is unique. The error curve for equation 1 shows that it reduces as temperature rises, with the lowest error being 49.4% at 0 degrees Celsius (the starting point) and the largest error being 86.2% at 260 degrees Celsius (the endpoint). The mean square error for this curve is 1.55E-10, while the average error percentage is 69.8%. In contrast, the error curve flattens out as temperature rises, with the lowest error of 15% recorded at the maximum temperature and the largest error of 24.6% recorded at the zero degree Celsius beginning temperature. The graph shows that the dynamic viscosity curves appear to get closer as temperature rises; the average error is 18.4%, the mean square error is 8.74E-12. At 70 degrees Celsius, where the dynamic viscosity curves of the reference value and equation 3 values cross, the equation 3 error curve forms a V shape, showing the lowest error of 0.491%. At the starting point temperature of 0 degrees Celsius, the maximum error of 21.5% is observed. The mean square error for this outcome is 5.72E-12, while the average error is 12%.

Thermal Conductivity: According to equation 2's results for thermal conductivity, the error curve for the refrigerant R407C at the specified pressure is inversely proportional to the thermal conductivity curve. The inaccuracy is lowest at 260 degrees Celsius, where it is 4.91%, and highest at zero degrees Celsius, when it is 69.9%. This depicts how the error curve flattens out as the temperature rises. These results have an average error of 32.9% and a mean square error of 4.37E-05.

R407C at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.72E-12	8.74E-12	1.55E-10	4.37E-05
Average Error %	12 %	18.4 %	69.8 %	32.9 %
Mini Error %	0.491 %	15 %	49.4 %	4.91 %
Max Error %	21.5 %	24.6 %	86.2 %	69.9 %

6.7.4 Dynamic Viscosity and Thermal Conductivity of R407C at 0.896 MPa

Dynamic Viscosity: For this pressure value, the answers to equations 3 and 1 are fairly comparable, however the solutions to equation 4 are completely different. While the error curve for equations 3 and 1 climbs as the temperature rises, equation 4's error curve actually reduces as the temperature rises. As a result, equation 4 shows the lowest error, 18.2%, at 260 degrees Celsius and the biggest error, 31.6%, at 30 degrees Celsius. This demonstrates how the reference values and dynamic viscosity values of equation 4 seem to be getting closer to one another as the temperature increases. This result has a mean square error of 1.47E-11, or an average error of 22.98%. The values from equations 3 and 1 have the lowest errors, 3.06%, and

55.2%, respectively, at the lowest temperature of 30 degrees Celsius. The largest error, 22% for equation 3 and 84.9% for equation 1 are found at the highest temperature, 260 degrees Celsius. Throughout the whole temperature range, the error curve for equation 1 shows a steady increase, but the error curve for equation 3 shows a sharp increase in error. Equation 3 has a mean square error of 9.17E-12 and an average error of 14.9%. While the average error and mean square error for equation 1 are both 71%.

Thermal Conductivity: The findings of equation 2 for thermal conductivity demonstrate that, for the refrigerant R407C at the specified pressure, the error curve is inversely proportional to the thermal conductivity curve. The error is lowest at 260 degrees Celsius, where the temperature is, and is highest at 30 degrees Celsius, where the error is highest, at 54%. This shows that the error curve flattens out as temperature increases. The average error for these results is 28.4%, with a mean square error of 4.03E-05.

R407C at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	9.17E-12	1.47E-11	1.66E-10	4.03E-05
Average Error %	14.9 %	22.9 %	71 %	28.4 %
Mini Error %	3.06 %	18.2 %	55.2 %	5.37 %
Max Error %	22 %	31.6 %	84.9 %	54 %

6.7.5 Dynamic Viscosity and Thermal Conductivity of R407C at 3.17 MPa

Dynamic Viscosity: However, the outputs of equations 3 and 4 for the dynamic viscosity of the refrigerant R407C at a pressure value of 3.18 MPa generate similar curves for the dynamic viscosity and error percentage, the output of equation 1 results in an entirely different graph. The curves generated from equation 3's dynamic viscosity values and reference values appear to intersect at a temperature of 100 degrees Celsius when the equation 3 results show the lowest error of 1.3%. Additionally, this results in the appearance of a V-shaped error curve, with the curve decreasing up to the target temperature and then rising as the temperature increases. The greatest error of 25.5% was noted at a starting temperature of 70 degrees Celsius. This curve has a mean square error of 5.14E-12 and an average error of 10.6%. The dynamic viscosity curves for equation 4's findings coincide at 150 degrees Celsius, resulting in the lowest error of 0.0895% and the best equation 4 results. This is due to the fact that equation 4's results are the same as equation 3's. The starting temperature point, which displays a V-shaped error curve, produces the greatest error of 43,1%. The average error for the answers to equation 4 is 13.2%, with a mean square error of 8.92E-12. The error curve and the dynamic viscosity curve for equation 1 both depict a rise in temperature for both values. As a result, the scale's inaccuracy ranges from 39.7% at 70 degrees Celsius to 77.9% at 260 degrees Celsius, the greatest temperature it can measure. With an average inaccuracy of 63.5%, the mean square error estimated for this data is 1.62E-10.

Thermal Conductivity: The findings show that the error curve in the graph is creating an inverse parabola for the thermal conductivity of refrigerant R407C at a pressure of 3.17 MPa. This states that the error increases as the temperature rises up to 120 degrees Celsius before decreasing. As a result, the temperature of 120 degrees Celsius has the biggest error, which is 31.2%. The lowest error of 7.99% forms at the greatest temperature of 260 degrees Celsius, despite the thermal conductivity curves appearing to become closer as temperature rises. The mean square error for this curve is 3.62E-05, while the average error is 21.6%.

R407C at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.14E-12	8.92E-12	1.62E-10	3.62E-05
Average Error %	10.6 %	13.2 %	63.5 %	21.6 %
Mini Error %	1.3 %	0.089 %	39.7 %	7.99 %
Max Error %	25.5 %	43.1 %	77.9 %	31.2 %

6.7.6 Dynamic Viscosity and Thermal Conductivity of R407C for the entire pressure range

Dynamic Viscosity: The dynamic viscosity of the refrigerant R407C according to equation 4 was calculated to have a minimum average error percentage of 21.3% and a minimum mean square error of 1.66E-11 for the whole pressure range in which the investigation was conducted. With a mean square error of 1.53E-10 and an average error of 68.3%, equation 1's result has the highest error rate. Equation 3 has a mean square error of 1.73E-11 and an average error of 21.3%.

Thermal Conductivity: The answers to equation 2 provide an average error percentage of 32.2% and a mean square error of 4.31E-05 for the total pressure for the thermal conductivity of refrigerant 407C. The smallest and largest mistakes are, respectively, 4.68% and 86.5%.

6.7.7 Conclusion

According to the statistical study for the refrigerant R407C, the average error of equations 3 and 4 over the whole pressure range of 0.096 MPa to 3.17 MPa is only slightly different, being 21.3% and 21.6%, respectively. However, comparing the numbers and graphs for the two equations reveals quite different outcomes. Equation 4 provides a low error for high temperature values whereas the equation provides a low error for low temperature values. Therefore, each of these equations may be utilized independently to get the dynamic viscosity of R407C. Thus, it can be said that equation 3 may be used to determine dynamic viscosity from a starting range temperature of up to 100 degrees, whereas equation 4 can be used to determine from a temperature of 120 degrees Celsius. Looking at all the graphic results, it can be seen that the error curve is descending with an increase in temperature of all the pressure values graph, with an average error of 32.3% for the thermal conductivity findings for the full pressure range. This suggests that instead of using the starting point of the super-heated zone, the thermal conductivity may be calculated using this equation at higher temperatures beginning at 130 degrees Celsius. Equation 4 can be used to calculate dynamic viscosity and can be further improved because the results from equation 3 show a wide error range for different pressure values, whereas equation 2 needed to be improved to lower the error percentage range when calculating thermal conductivity for refrigerant R407C in the super-heated state.

6.8 R410A

The dynamic viscosity and thermal conductivity of the R410A refrigerant are examined separately for each of its five pressure levels. In order to assess how much error each equation has throughout the whole pressure range and which equation is closest to the reference value, the second worksheet examines the error generally over the entire pressure range, from the first to the final value.

6.8.1 Dynamic Viscosity and Thermal Conductivity of R410A at 0.151 MPa

Dynamic Viscosity: For each equation, the results displaying dynamic viscosity for refrigerant R410A at pressure 0.151 MPa have distinct graphics. Using the solutions to equation 3, it can be seen that the dynamic viscosity curve for equation values is somewhat U-shaped and indicates that it increases after reaching 50 degrees Celsius, while the curve produced from the reference value increases as the temperature rises. At a temperature of 40 degrees Celsius, where both of these curves cross, the lowest error of 1.48% is seen at a starting temperature of -30 degrees Celsius, the largest error of 41% was discovered. The error curve is V-shaped, and when the temperature rises over 40 degrees, the error percentage starts to rise as well. The mean square error for this curve is 5.53E-12, while the average error is 14.3%. Although equation 4's findings show that the dynamic viscosity curve rises for both values, the error curve falls as temperature rises. As a consequence, the beginning point temperature has the maximum error of 27.2% and the lowest error of 22.9% at the highest temperature of 150 degrees Celsius. This curve has a mean square error of 1.34E-11 and an average error percentage of 24.7%. On the other hand, the solutions to equation 1 show the error percentage curve and the fact that dynamic viscosity rises as pressure rises. The mean square error for this curve is 7.05E-12, while the average error is 14.4%. Due to the nature of the error curve, the starting temperature has the lowest error (2.60%), and the endpoint temperature (150 degrees Celsius) has the largest error (24.8%).

Thermal Conductivity: The graph showing the solutions to equation 2 for the refrigerant R410A's thermal conductivity at a pressure of 0.151 MPa demonstrates that the error and thermal conductivity curves climb with increasing temperature. As a result, the ending temperature of 150 degrees Celsius has the biggest error, at 34.5%, while the starting temperature of -30 degrees Celsius has the lowest error, at 4.58%. The mean square error between the two thermal conductivity curves is 1.87E-05, and the average error percentage is 19.2%.

R410A at 0.151 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.53E-12	1.34E-11	7.05E-12	1.87E-05
Average Error %	14.3 %	24.7 %	14.4 %	1.92 %
Mini Error %	1.48 %	22.9 %	2.60 %	4.58 %
Max Error %	41 %	27.2 %	24.8 %	34.5 %

6.8.2 Dynamic Viscosity and Thermal Conductivity of R410A at 0.344 MPa

Dynamic Viscosity: The graphs of equations 3 and 4 show somewhat similar results for the dynamic viscosity at a pressure of 0.344 MPa, with the dynamic viscosity curve increasing and the error curve having a slight V-shape toward the end of the temperature range in equation 4 and toward the beginning of the temperature range in equation 3. While the error curve and the dynamic viscosity curve in equation 1 both rise as the temperature rises. The curves for the equation 3 values and the reference values strangely cross at this temperature point, with the lowest error for equation 3 being 0.026% at 0 degrees Celsius. After that, the error curve steepens as the temperature rises, and as a result, the maximum error of 28.9% is measured at 150 degrees Celsius. The mean square error between two dynamic viscosities is 1.09E-11, and the average error percentage is 17.3%. The results of equation 4 show that the temperature of 130 degrees Celsius, where both dynamic viscosity curves overlap, has the lowest error of 0.0327%. At the starting temperature of -10 degrees Celsius, the largest error of 7.91% is noted. The mean square error for this outcome is 2.33E-13, and the average error percentage is 2.88%. As opposed to this, equation 1's answers display the error percentage curve and the fact that dynamic viscosity increases with temperature. This curve's average error is 15.6%, with a mean square error of 7.76E-12. The beginning temperature has the smallest error (5.38%), while the endpoint temperature (150 degrees Celsius) has the biggest error (24.6%) due to the structure of the error curve.

Thermal Conductivity: The error and thermal conductivity curves grow with rising temperature, as shown by the graph plotting the answers to equation 2 for the refrigerant R410A's thermal conductivity at a pressure of 0.344 MPa. As a consequence, the 150 degrees Celsius ending temperature has the most error (34.5%) while the -10 degree Celsius starting temperature has the smallest error (8.07%). The average error percentage is 21%, and the mean square error between the two thermal conductivity curves is 2.11E-05.

R410A at 0.344 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.09E-11	2.33E-13	7.76E-12	2.11E-05
Average Error %	17.3 %	2.88 %	15.6 %	21 %
Mini Error %	0.026 %	0.0327 %	5.38 %	8.07 %
Max Error %	28.9 %	7.91 %	24.6 %	34.5 %

6.8.3 Dynamic Viscosity and Thermal Conductivity of R410A at 0.896 MPa

Dynamic Viscosity: The findings showing the dynamic viscosity for refrigerant R410A at pressure 0.896 MPa for each equation have unique visuals. The dynamic viscosity curve for equation values and the curve created from the reference value both show an increase as the temperature rises, as can be shown using the solutions to equation 3. The smallest error, 0.504%, is seen at a temperature of 80 degrees Celsius, where both of these curves intersect, while the biggest error, 13%, was found at a starting temperature of 10 degrees Celsius. When the temperature exceeds 80 degrees, the error percentage also begins to increase. The error curve is V-shaped. The average error is 5.53%, while the mean square error for this curve is 9.40E-12. The dynamic viscosity curve is seen to increase for both values according to equation 4, yet the error curve decreases as temperature increases. As a consequence, the greatest error at the starting point temperature of 10 degrees Celsius is 26.7%, and the minimum error is 12.8% at the maximum temperature of 150 degrees Celsius. The average error percentage for this curve is 18%, with a mean square error of 7.83E-12. As opposed to this, equation 1's answers display the error percentage curve and the fact that dynamic viscosity increases with pressure. This curve has an average error of 16.1% and a mean square error of 8.22E-12. The beginning temperature has the smallest error (7.43%) and the endpoint temperature (150 degrees Celsius) has the biggest error (24.1%), according to the shape of the error curve.

Thermal Conductivity: The graph illustrating equation 2's answers for the thermal conductivity of the refrigerant R410A at a pressure of 0.896 MPa shows that the error and thermal conductivity curves rise with rising temperature. Due to this, the starting temperature of 10 degrees Celsius has the lowest inaccuracy, with a 1.47% mistake, while the ending temperature of 150 degrees Celsius has the worst error, at 34.5%. The mean square error and average error percentage for the two thermal conductivity curves are 2.48E-05 and 23.6%, respectively.

R410A at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	9.40E-13	7.83E-12	8.22E-12	2.48E-05
Average Error %	5.53 %	18 %	16.1 %	23.6 %
Mini Error %	0.50 %	12.8 %	7.43 %	14.7 %
Max Error %	13 %	26.7 %	24 %	34.5 %

6.8.4 Dynamic Viscosity and Thermal Conductivity of R410A at 2.206 MPa

Dynamic Viscosity: The error percentage curve for the graphs showing the solutions to equations 3 and 4 decreases as the temperature rises, but the error percentage curve for the graphs showing the solutions to equation 1 increases as the temperature rises. For equation 4's findings, the maximum error of 35% is recorded at the starting point, which has the lowest temperature of 40 degrees Celsius, and the lowest error of 7.97% is recorded at the highest temperature of 150 degrees Celsius since the error curve is decreasing with rising temperature. The results of equation 4 show an average error of 18.1% between the two dynamic viscosity curves, with a mean square error of 3.84E-12. The dynamic viscosity curves from equation 3 and the reference values appear to overlap for the equation 3 results from 90 to 140 degrees Celsius. As a result, the temperature at which the lowest error of 0.496% is observed is 100 degrees Celsius. At a starting temperature of 40 degrees Celsius, the maximum error of 9.51% is observed. The mean square error for this outcome is 2.58E-13, while the average error is 2.16%. In contrast, the solutions to equation 1 show the error percentage curve and the fact that dynamic viscosity rises as the temperature rises. The mean square error of this curve is 7.76E-12, with an average error of 15.1%. Due to the shape of the error curve, the error at the starting temperature of 40 degrees Celsius is the least (7.43%), while the error at the endpoint of 150 degrees Celsius is the most (21.7%).

Thermal Conductivity: The curves meet at higher temperature values for the results shown by calculations between equation 2 and reference values thermal conductivity. As a consequence, at 140 degrees Celsius, the error is recorded at 0.227%, whereas at 70 degrees Celsius, the error is reported at 12%. The error percentage curve is sinusoid-shaped, with a mean square error of 2.35E-06 and an average error percentage of 7.11%.

R410A at 2.20 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.58E-13	9.84E-12	7.76E-12	2.35E-06
Average Error %	2.16 %	18.1 %	15.1 %	7.11 %
Mini Error %	0.496 %	7.97 %	7.35 %	0.227 %
Max Error %	9.51 %	35 %	21.7 %	12 %

6.8.5 Dynamic Viscosity and Thermal Conductivity of R410A at 3.88 MPa

Dynamic Viscosity: For the dynamic viscosity at a pressure of 3.88 MPa, the graphs of equations 3 and 4 show results that are somewhat similar. The dynamic viscosity curve rises, and the error curve has a slight V-shape toward the end of the temperature range in equation 4 and toward the beginning of the temperature range in equation 3. While equation 1's dynamic viscosity curve and error curve both increase as the temperature increases. At this temperature, the curves for equation 3 values and reference values overlap, with the lowest equation 3 error at 80 degrees Celsius being 0.026%. The highest error of 21.9% is then observed at 140 degrees

Celsius, after which the error curve steepens as the temperature increases. The average error percentage is 13.3%, and the mean square error between two dynamic viscosities is 7.91E-12. According to equation 4, the temperature of 110 degrees Celsius, where the overlap of both dynamic viscosity curves occurs, has the lowest error, which is 1.43%. The highest error of 32.1% is recorded at the starting temperature of 70 degrees Celsius. This result has a mean square error of 7.22E-13 and an average error percentage of 11.7%. In contrast, the solutions to equation 1 show the error percentage curve and the dynamic viscosity rises as the temperature rises. The curves for both dynamic viscosity cross at the starting point temperature of 70 degrees Celsius, giving the lowest error of 0.839%. While the endpoint temperature of 140 degrees Celsius shows the largest error of 15.9%. The graph's average error is 9.87%, with the mean square error being 4.26E-12.

Thermal Conductivity: In the graph exhibiting results of thermal conductivity for equation 2, the reference curve is shown formed in U-shaped suggesting that it drops with an increase in temperature until 90 degrees, and then it increases. On the other hand, the curve derived from the values in equation 2 rises as the temperature does. The lowest error, 0.151%, is produced as a result, and it occurs at a temperature of 130 degrees Celsius. However, at the initial temperature of 70 degrees Celsius, the maximum error of 10.9% is created. The mean square error between these two curves is 1.10E-06, and the average error percentage is 2.51%.

R410A at 3.88 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	7.91E-12	7.22E-12	4.26E-12	1.10E-06
Average Error %	13.3 %	11.7 %	9.87 %	2.51 %
Mini Error %	0.065 %	1.43 %	0.839 %	0.151 %
Max Error %	21.9 %	32.1 %	15.9 %	10.9 %

6.8.6 Dynamic Viscosity and Thermal Conductivity of R410A for the entire pressure range

Dynamic Viscosity: The findings of equation 3 were determined to have a minimum average error percentage of 11% and a minimum mean square error of 5.23E-12 over the whole pressure range in which the inquiry was done for the dynamic viscosity of the refrigerant R410A. The answer of equation 4 is the one with the highest error rate, with a mean square error of 7.79E-12 and an average error of 15.5%. The average error in Equation 1 is 14.7%, and the mean square error is 7.27E-12.

Thermal Conductivity: For the whole pressure range of 0.151 MPa to 3.88 MPa for the thermal conductivity of refrigerant 410A, the solutions to equation 2 yield an average error percentage of 16.6% and a mean square error of 1.58E-05. The lowest and greatest errors are 0.151% and 34.5%, respectively.

6.8.7 Conclusion

After reviewing the findings for the dynamic viscosity of the refrigerant R410A, it is apparent that, while equation 3 has the lowest average error—11%—the average errors of the other equations—equations 9 and 1—are both 15.5% and 14.7%, respectively. The graphs of the solutions to this equation for each degree of pressure show the contrast. While the error curve in equation 4 graphs decreases as temperature rises, the error curve in equation 1 graphs rises as temperature rises, and the error curve in equation 3 graphs decreases up to a specific temperature before increasing. As a result, equation 1 may be used to determine dynamic viscosity at lower temperatures, whereas equations 3 and 4 can be utilized at higher temperatures. An average error of 16.1% is noted for the thermal conductivity throughout the full pressure range, and close examination reveals that the error curve climbs as temperature rises. The implication is that this equation may be utilized for both lower pressure values at lower temperatures up to 60 degrees Celsius and greater pressure values at higher temperatures. Given the low error percentage of the results, it can be inferred from this study that equations 3 for dynamic viscosity and equation 2 for thermal conductivity may be utilized to determine the dynamic viscosity and thermal conductivity for refrigerant R410A at a super-heated state. To acquire accurate answers in the future and reduce the obtained error percentage, these equations can be improved.

6.9 R507C

The R507C refrigerant's dynamic viscosity and thermal conductivity are investigated independently for each of its five pressure levels. The second worksheet checks the error generally throughout the full pressure range, from the first to the final value, to determine how much error each equation has throughout the entire pressure range and which equation is closest to the reference value.

6.9.1 Dynamic Viscosity and Thermal Conductivity of R507C at 0.096 MPa

Dynamic Viscosity: For the refrigerant R507C at 0.096 MPa pressure, the dynamic viscosity recorded by equations 3, 4, and 1 reveals radically different results in terms of error percentage between equation values and reference values. For equation 3, the curve generated by the equation values for the dynamic viscosity is somewhat parabolic, whereas the reference value produces a straight line that is inclined and rises with temperature. These curves cross at higher temperatures ranging from 190 to 220 degrees Celsius, and as a consequence, the lowest error of 0.139% is reported at 200 degrees. At the lowest temperature of -30 degrees Celsius, the largest error of 81.6% is observed. This illustrates that the error curve lowers with increasing temperature and then slightly rises over 200 degrees Celsius. These two curves have an average error of 19.3% and a mean square error of 1.08E-11. The findings of equation 4 are nearly identical to those of equation 3. As a consequence, at the lowest temperature of -30 degrees Celsius, the largest error of 6.24% is observed. The curves of dynamic viscosity derived from equation 4 values and reference values cross at temperatures ranging from 170 to 220 degrees Celsius. At 200 degrees Celsius, this results in the lowest error of 0.155%. This curve has an average error of 2.68% and a mean square error of 1.64E-13. The error percentage curve decreases until the temperature reaches 200 degrees Celsius, then increases, forming a tiny V-shape at the end. In contrast, the solutions to equation 1 show the error percentage curve, and the dynamic viscosity increases with increasing temperature. This results in the lowest error of 63.2% being reported at -30 degrees Celsius and the largest error of 1.17E02% being recorded at 260 degrees Celsius. The average error for this curve is 92 % and the mean square error is 2.45E-10.

Thermal Conductivity: The reference value and equation value curves for the thermal conductivity of refrigerant R507C at a pressure of 0.096 MPa increase with temperature and cross at a temperature of 150 degrees Celsius. This yields the lowest inaccuracy, 0.319%, ever noted for the temperature in question. While the -30 degrees Celsius beginning point temperature records the largest error, which is 53.3%. This shows that the error curve climbs as temperature increases, generating a V-shape after the error curve decreases with temperature up to 150 degrees Celsius. The mean square error is 1.45E-05, while the average error percentage for this curve is 18.1%.

R507C at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.08E-11	1.64E-13	2.45E-10	1.46E-05
Average Error %	19.3 %	2.68 %	92 %	18.1 %
Mini Error %	0.139 %	0.155 %	63.2 %	0.319 %
Max Error %	81.6 %	6.24 %	11.7 %	53.3 %

6.9.2 Dynamic Viscosity and Thermal Conductivity of R507C at 0.179 MPa

Dynamic Viscosity: The results for the dynamic viscosity of the refrigerant R507C at pressures of 0.179 MPa and 0.096 MPa are quite close. For equation 3, the reference values curve is a straight line that increases with temperature, however, the dynamic viscosity curve created by equation 3 values is in a U-shape. On the other hand, when the temperature rises, the error curve flattens out. The lowest error of 3.85% is obtained at 260 degrees Celsius temperature because the values of dynamic viscosity for equation 3 and reference are practically identical at higher temperatures. While the lowest temperature of -20 degrees Celsius records the biggest error of 77.9%. The mean square error for this curve is 1.42E-11, while the average error is 23.9%. On the other hand, equation 4 has a smaller temperature range of -20 degrees to 30 degrees Celsius where the curves for dynamic viscosity reference values and equation 4 values cross, leading to the lowest error of 0.161% being observed at the temperature of 0 degrees Celsius. The error curve rises as temperature rises to start at 0 degrees Celsius, with the maximum error of 9.49% occurring at 260 degrees Celsius. The mean square error for this curve is 9.86E-13, while the average error is 4.57%. While the solutions to equation 1 show that both the error curve and the dynamic viscosity curve rise as the temperature rises. The mean square error for this curve is 2.51E-10, while the average error is 92.8%. The endpoint temperature of 260 degrees Celsius, which is the highest temperature on the scale, has the maximum error of 1.16E02%, while the lowest error of 65.6% is recorded at the temperature of -20 degrees Celsius.

Thermal Conductivity: The reference value and equation value curves for the refrigerant R507C's thermal conductivity at 0.179 MPa of pressure rise with temperature and cross at 150 degrees Celsius. This results in the lowest error ever recorded for the temperature in question, 0.276%. While the biggest error, which is 48.1%, is recorded at the temperature of -30 degrees Celsius. This demonstrates that the error curve rises with temperature and then falls with temperature up to 150 degrees Celsius, producing a V-shape. The average error percentage for this curve is 16.7%, and the mean square error is 1.40E-05.

R507C at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.42E-11	9.86E-13	2.51E-10	1.40E-05
Average Error %	23.9 %	4.57 %	92.8 %	16.7 %
Mini Error %	3.85 %	0.161 %	65.6 %	0.276 %
Max Error %	77.9 %	9.49 %	1.16E02 %	48.1 %

6.9.3 Dynamic Viscosity and Thermal Conductivity of R507C at 0.379 MPa

Dynamic Viscosity: The dynamic viscosity for the values obtained from equations rises with the rise in temperature for this pressure value, which is shared by the graphs of equations 3, 4, and 1. The main distinction, though, is in how each graph's error percentage curve is constructed. The dynamic viscosity curves for equation values and reference values cross at a temperature of 60 degrees Celsius, according to the graph and findings of equation 3. As a consequence, the specified temperature point has the lowest error, 0.789%. From 0 to 60 degrees Celsius, the error percentage curve forms a V shape and then starts to rise, with the largest error of 19.6% being recorded at the end temperature of 260 degrees Celsius. This curve has a mean square error of 5.92E-12 and an average error of 12.5%. The error curve for equation 4 is decreasing as temperature rises, with the lowest error of 15.4% being recorded at the highest temperature and the largest error of 25.9% being noted at the lowest. The mean square error value for this curve is 9.67E-12, while the average error is 19.9%. In contrast to the graph of equation 4, the error curve for equation 1 increases as the temperature rises. Thus, at 260 degrees Celsius, the largest error of 1.16E02% is produced, while at 0 degrees Celsius, the lowest error of 70.3% is produced. The mean square error is 2.65E-10, and the average error between the dynamic viscosity curve and equation 4 is 94.3%.

Thermal Conductivity: At 0.379 MPa of pressure, the reference value and equation value curves for the thermal conductivity of the refrigerant R507C grow with temperature and cross at 150 degrees Celsius. This yields an error of 0.187%, the smallest ever for the temperature in question. While the temperature of 0 degrees Celsius records the largest error, which is 38.9%. This indicates that the error curve has a V-shaped relationship with temperature, rising with temperature up to 150 degrees Celsius before falling. The mean square error is 1.27E-05, while the average error percentage for this curve is 14.3%.

R507C at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.92E-12	9.67E-12	2.65E-10	1.27E-05
Average Error %	12.5 %	19.9 %	94.3 %	14.3 %
Mini Error %	0.789 %	15.4 %	70.3 %	0.187 %
Max Error %	19.6 %	25.9 %	1.16E02 %	38.9 %

6.9.4 Dynamic Viscosity and Thermal Conductivity of R507C at 0.896 MPa

Dynamic Viscosity: The graphs of equation 3 and 1 for refrigerant R507C at pressure of 0.896 MPa are comparable in regards to structure, however the graph generated by equation 4 values are entirely different. The dynamic viscosities curves and the error percentage curve both flatten out as pressure increases, with the maximum error, 33.7%, occurring at the lowest temperature, 20 degrees Celsius, and the lowest error, 15.8%, occurring at the highest temperature, 260 degrees Celsius. This demonstrates how the dynamic viscosity curve and the error percentage curve are negatively related. The mean square error for the solutions to equation 4 is 1.31E-11, with an average error percentage of 22.1%. The graph showing the solutions to equation 3 shows that the dynamic viscosity curves cross at the lowest temperature of 20 degrees Celsius, where the lowest error of 1.82% is also observed. Then, when temperature rises, this curve, which resembles a dynamic viscosity curve, climbs and records the maximum error, 19.7%, at the end point temperature of 260 degrees Celsius. The answers of equation 3 have an average error percentage of 14.4%, and the value of the means square error is 7.14E-12. The error percentage curve of equation 1 likewise climbs with an increase in temperature, suggesting their similarity, much like the outcomes of equation 3 do. As a result, the biggest error, 1.14E02%, is recorded at the highest endpoint temperature, while the lowest error, 74.4%, is recorded at the lowest starting point temperature. The mean square error is 2.75E-10, while the average error percentage for this curve is 95.1%.

Thermal Conductivity: The reference value and equation value curves for the thermal conductivity of the refrigerant R507C rise with temperature and cross at 150 degrees Celsius at 0.896 MPa of pressure. This results in a 0.155% error, the least ever for the temperature in question. The temperature of 0 degrees Celsius has the greatest error (27.4%). This implies that the error curve has a V-shaped relationship with temperature, climbing up to 150 degrees

Celsius before declining. The mean square error for this curve is 1.10E-05, while the average error percentage is 11.2%.

R507C at 0.895 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	7.14E-12	1.31E-11	2.75E-10	1.10E-05
Average Error %	14 %	22.1 %	95.1 %	11.2 %
Mini Error %	1.92 %	15.8 %	74.4 %	0.155 %
Max Error %	19.7 %	33.7 %	1.14E02 %	27.4 %

6.9.5 Dynamic Viscosity and Thermal Conductivity of R507C at 3.171 MPa

Dynamic Viscosity: The dynamic viscosity recorded by equations 3, 4, and 1 for the refrigerant R507C at 3.171 MPa pressure yields significantly different results in terms of error percentage between equation values and reference values. For equation 3, the curve formed by the equation values for dynamic viscosity rises with temperature, but the reference value curve decreases and subsequently rises. These curves intersect at higher temperatures ranging from 220 to 260 degrees Celsius, resulting in the lowest error of 0.0592% at 240 degrees. The highest error of 39.2% is seen at the lowest temperature of 70 degrees Celsius. This shows how the error curve decreases with increasing temperature. These two curves have a mean square error of 5.32E-12 and an average error of 8.84%. Equation 4 yields results that are virtually identical to equation 3. As a result, the highest error of 54% is seen at the lowest temperature of 70 degrees Celsius. At 240 degrees Celsius, the dynamic viscosity curves generated from equation 4 values and reference values intersect. This results in the lowest error of 0.0392% at 240 degrees Celsius. This curve has a 16% average error and a 1.43E-11 mean square error. The error percentage curve declines until the temperature go up to 230 degrees Celsius, at which point it slightly climbs, making a little V-shape at the end. The solutions to equation 1, on the other hand, show the error percentage curve, and the dynamic viscosity increases with increasing temperature. This results in the lowest inaccuracy of 51.1% at 70 degrees Celsius and the biggest error of 1.03E02% at 260 degrees Celsius. This curve has an average error of 83.2% and a mean square error of 2.74E-10.

Thermal Conductivity: The sinusoid curve is the result of the error percentage curve for the thermal conductivity values supplied by equation 2 for refrigerant R507C at a pressure of 3.171 MPa. This demonstrates that the difference between the equation values and reference values grows with an increase in temperature until 100 degrees Celsius, and subsequently, it reduces until the temperature of 160 degrees Celsius and rises again afterward. At the exact point of the temperature of 160 degrees Celsius, the lowest error of 0.689% is observed while the maximum error of 14.2% is reported at the temperature of 260 degrees Celsius. The lowest error is reported at 160 degrees Celsius because the thermal conductivity curves from equation values and reference values overlap. The mean square error is 6.96E-06 and the average error between these curves is 6.74%.

R507C at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.33E-12	1.43E-11	2.74E-10	6.96E-06
Average Error %	8.84 %	16 %	83.2 %	6.74 %
Mini Error %	0.0592 %	0.0395 %	51.1 %	0.689 %
Max Error %	39.2 %	54 %	1.03E02 %	14.2 %

6.9.6 Dynamic Viscosity and Thermal Conductivity of R507C for the entire pressure range

Dynamic Viscosity: The results of equation 4 were determined to have a minimum average error percentage of 12.5% and a minimum mean square error of 6.94E-12 for the whole pressure range in which the dynamic viscosity of the refrigerant R507C was investigated. The solution to equation 1 has the greatest mistake rate, with a mean square error of 2.60E-10 and an average error rate of 91.7%. In Equation 3, the average error is 16.2%, and the mean square error is 9.00E-12.

Thermal Conductivity: The answers to equation 2 produce an average error percentage of 14% and a mean square error of 1.18E-05 for the whole pressure range of 0.096 MPa to 3.171 MPa for the thermal conductivity of refrigerant R507C. The minimum and maximum errors are 0.155% and 53.3%, respectively.

6.9.7 Conclusion

The best results are obtained for the refrigerant R507C using equation 4, which has an average error of 12.5% for the pressure range of 0.096 MPa to 3.17 MPa. The error curve for equation 4 results decreases with increasing temperature for all pressure values except for 0.179 MPa, showing that higher temperatures will bring dynamic viscosity values closer to reference values. This equation may be applied throughout the whole temperature range at any pressure to determine the dynamic viscosity of R507C. Even at the lowest temperature, the maximum error of less than 20% is obtained for all pressure values. By looking at the figures, it appears that the error curve is decreasing until the temperature of 150 degrees Celsius before rising once more for thermal conductivity, with equation 2 producing an average error of 14% for the full pressure range. This leads to the conclusion that this equation may be used to calculate thermal conductivity for any pressure and a temperature range of 100 to 260 degrees Celsius. It can be concluded that equation 4 for dynamic viscosity and equation 2 for thermal conductivity may be used to determine respective characteristics for refrigerant R507C, and they can be improved further to reduce error percentage.

6.10 R513A

The dynamic viscosity and thermal conductivity of the R513A refrigerant are examined separately for each of its five pressure levels. In order to establish how much error each equation has throughout the whole pressure range and which equation is closest to the reference value, the second worksheet examines the error generally across the entire pressure range, from the first to the final value.

6.10.1 Dynamic Viscosity and Thermal Conductivity of R513A at 0.096 MPa

Dynamic Viscosity: The dynamic viscosity for each graph of equations 3, 4, and 1 for the refrigerant R513A at the specified pressure value of 0.096 MPa increases as temperature rises. The major difference is the error percentage curve which is different for each graph. When applied to equation 3, the dynamic viscosity of the equation's values forms a curve that somewhat resembles a U shape and intersects with the curve of the reference value's dynamic viscosity at a temperature of 110 degrees Celsius. At this temperature, the lowest error is seen (0.707%). The biggest error, 52.8%, is reported at the beginning point temperature of -20 degrees Celsius due to the structure of the reference value curve**.** For equation 3, the mean square error between two dynamic viscosity curves is 6.31E-12, and the average error is 16.1%. In the graph that shows the solutions to equation 4, the error curve is dropping as temperature rises, but the dynamic viscosity curves are rising as temperature rises. As a result, at the greatest temperature of 150 degrees Celsius, the lowest error is recorded at 11.5%, while at the lowest temperature of -20 degrees Celsius, the largest error is recorded at 15.4%. The mean square error for this curve is 3.17E-12, while the average error is 13.1%. The solutions to equation 1 are in direct opposition to those of equation 4, showing that both the error curve and the dynamic viscosity curves rise as temperature rises. The mean square error for this outcome is 2.04E-10, while the average error is 99%. The end point with the greatest temperature records the largest error of 1.16E02, while the starting point with the lowest error of 79.3% records the lowest error.

Thermal Conductivity: At a high temperature of 140 degrees Celsius, the thermal conductivity curves of equation 2 and reference values cross, giving the lowest error of 0.546%. While the lowest temperature on the scale, -20 degrees Celsius, has the biggest error of 50.1%. This suggests that the error curve is dropping with rise in temperature. This result's mean square error is 9.70E-06 while the average error is 19.7%.

R513A at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	6.31E-12	3.17E-12	2.04E-10	9.70E-06
Average Error %	16.1 %	13.1 %	99 %	19.7 %
Mini Error %	0.707 %	11.5 %	79.3 %	0.546 %
Max Error %	52.8 %	15.4 %	1.16E02 %	50.1 %

6.10.2 Dynamic Viscosity and Thermal Conductivity of R513A at 0.179 MPa

Dynamic Viscosity: For the refrigerant R513A at the required pressure value of 0.179 MPa, the dynamic viscosity for each graph of equations 3, 4, and 1 grows as the temperature rises. The error percentage curve, which varies for each graph, is the main distinction. When applied to equation 3, the dynamic viscosity of the equation's values rises gradually with temperature, intersecting with the reference value's curve at a temperature of 150 degrees Celsius. The smallest error is seen at this temperature (0.214%). Due to the design of the reference value curve, the largest error, 43.6%, is recorded at the starting point temperature of 0 degrees Celsius**.** The average error for equation 3 is 16.4%, and the mean square error between two dynamic viscosity curves is 6.50E-12. The dynamic viscosity curves are growing as temperature rises while the error curve is decreasing in the graph that displays the answers to equation 4. As a consequence, at 150 degrees Celsius, the highest temperature, the lowest error is recorded at 5.39%, while at 0 degrees Celsius, the highest error is recorded at 10.7%. This curve's average error is 7.56%, and its mean square error is 1.09E-12. Equation 1's answers stand in stark contrast to equation 4's, demonstrating that as temperature increases, so do both the error curve and the dynamic viscosity curves. This result has a mean square error of 2.20E-10 and an average error of 1.01E02%. The maximum mistake, 1.16E02, is recorded at the endpoint with the highest temperature, while the smallest error, 84.5%, is recorded at the beginning point.

Thermal Conductivity: The thermal conductivity curves of equation 2 and reference values intersect at a high temperature of 140 degrees Celsius, yielding the lowest error of 0.578%. The largest error on the scale is 39.5 % at the lowest temperature, 0 degrees Celsius. This indicates that the error curve is flattening with temperature increase. The average error for this result is 16.2%, while the mean square error is 7.92E-06.

R513A at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	6.50E-12	1.09E-12	2.20E-10	7.92E-06
Average Error %	16.4 %	7.56 %	1.01E02 %	16.2 %
Mini Error %	0.214 %	5.39 %	84.5 %	0.578 %
Max Error %	43.6 %	10.7 %	1.16E02 %	39.5 %

6.10.3 Dynamic Viscosity and Thermal Conductivity of R513A at 0.379 MPa

Dynamic Viscosity: The graphs of equations 3 and 1 are identical for the dynamic viscosity of the refrigerant R513A at the pressure of 0.379 MPa, however equation 4 displays an entirely different graph. When each graph was taken into account, it was seen that the error curve in the graph of equations 3 and 1 increased as the temperature increased, but the error curve in the graph of equation 4 decreased as the temperature increased. As a result, at the starting temperature of 10 degrees Celsius, which also marks the intersection of the reference and equation values for dynamic viscosity, equation 3 showed the lowest error of 1.47%. At the greatest temperature of 150 degrees Celsius, the largest error of 23% is noted. For equation 3, the mean square error between two dynamic viscosity values is 13.5%, and the mean square error is 5.75E-12. Similar to the outcomes of equation 3, the results of equation 1 show that the lowest error, 86.7%, is recorded at 10 degrees Celsius and the biggest error, 1.15E02, is recorded at 150 degrees Celsius. The mean square error for equation 1 is 2.28E-10, while the average error for this computation is 1.02E02%. In the graph that shows the solutions to equation 4, the dynamic viscosity curves increase as temperature increases while the error curve decreases. As a result, the lowest error of 27.4 % is recorded at the maximum temperature, 150 degrees Celsius, while the biggest error is recorded at 10 degrees Celsius, 33.9%. The mean square error of this curve is 1.83E-11, with an average error of 29.9%.

Thermal Conductivity: At a high temperature of 140 degrees Celsius, where the thermal conductivity curves of equation 2 and reference values overlap, the error is the smallest (0.669%). At the lowest temperature, 10 degrees Celsius, the scale's maximum error is 34.3 %. This shows that as temperature rises, the error curve flattens. The mean square error for this finding is 6.97E-06, while the average error is 14.5%.

R513A at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.75E-12	1.83E-11	2.28E-10	6.97E-06
Average Error %	13.5 %	29.9 %	1.02E02 %	14.5 %
Mini Error %	1.47 %	27.4 %	86.7 %	0.669 %
Max Error %	23 %	33.9 %	1.15E02 %	34.2 %

6.10.4 Dynamic Viscosity and Thermal Conductivity of R513A at 0.896 MPa

Dynamic Viscosity: For the dynamic viscosity of the refrigerant R513A at the pressure of 0.896 MPa, equations 3 and 1 show identical graphs; equation 4, however, shows a completely different graph. When each graph was taken into consideration, it became clear that the error curve in the graph of equation 3 lowers up to a temperature of 70 degrees Celsius and then increases with temperature, but the error curve in the graph of equation 1 reduced as the temperature grew. As a result, equation 3 had the lowest error of 0.115% at a temperature of 70 degrees Celsius, which also coincides with the intersection of the reference and equation values for dynamic viscosity. The maximum error of 6.64% is found at the highest temperature of 150 degrees Celsius. The mean square error for equation 3 is 3.55E-13 and is 2.91% for two dynamic viscosity values. Equation 1's results are similar to those of equation 3 in that the lowest error, 91.9%, is noted at 40 degrees Celsius and the largest error, 1.13E02, is noted at 150 degrees Celsius. Equation 1's mean square error is 2.51E-10, whereas this calculation's average error is 1.03E02%. The dynamic viscosity curves in the graph, which displays the answers to equation 4, rise as temperature rises while the error curve falls. As a consequence, the highest mistake, 26%, is recorded at 40 degrees Celsius, while the smallest error, 12.5%, is recorded at the maximum temperature, 150 degrees Celsius. This curve has a mean square error of 7.12E-12 and an average error of 17.8%.

Thermal Conductivity: The error is minimal (0.449%) at a high temperature of 150 degrees Celsius, when the thermal conductivity curves of equation 2 and reference values coincide. The scale's maximum error is 21.1% at 40 degrees Celsius, which is the lowest temperature. This demonstrates how the error curve flattens as temperature increases. This result has a mean square error of 4.30E-06 and an average error of 9.99%.

R513A at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.55E-13	7.12E-12	2.51E-10	4.30E-06
Average Error %	2.91 %	17.8 %	1.03E02 %	9.99 %
Mini Error %	0.115 %	12.5 %	91.9 %	0.449 %
Max Error %	6.64 %	26 %	1.13E02 %	21.1 %

6.10.5 Dynamic Viscosity and Thermal Conductivity of R513A at 2.96 MPa

Dynamic Viscosity: The graphs produced by equations 3 and 4's findings show that the dynamic viscosity curves from equation values and reference values overlap at particular temperature values and as a consequence yield the lowest error for the dynamic viscosity for refrigerant R513A at a pressure of 2.96 MPa. At a temperature of 100 degrees, equation 3 records the lowest error of 3.9%, while at a temperature of 120 degrees Celsius, equation 4 records the lowest error of 0.408%. This suggests that a V-shaped curve is forming towards the beginning of the temperature range for the graph of equation 3 and near the end of the temperature range for the graph of equation 4. At an endpoint temperature of 140 degrees Celsius, the graph 8 equation's results show the largest error of 21.4%. At the beginning temperature of 90 degrees Celsius, the result of graph 4 shows the biggest error, which is 26.8%. The findings of equation 3 show an average error percentage of 13.1% and a mean square error of 7.12E-12, whereas equation 4 shows an average error percentage of 10.3% and a mean square error of 5.17E-12. The dynamic viscosity curves and the error curve for equation 1's findings both rise as the temperature rises. As a consequence, the mean square error is 2.31E-10 and the mean error percentage is 84.8%. The endpoint temperature recorded the maximum error of 87.7%, and the starting point temperature recorded the lowest error of 81.7%.

Thermal Conductivity: The graph for the refrigerant R513A's thermal conductivity at 2.96 MPa pressure produced by equation 2 is entirely different from that for earlier pressure readings. At 90 degrees Celsius, which is the lowest temperature, the error percentage is 1.92%, and at 140 degrees Celsius, which is the highest temperature, the error percentage is 8.72%. The mean square error for these results is 3.18 E-06, while the average error is 6.99%.

R513A at 2.96 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	7.12E-12	5.17E-12	2.31E-10	3.18E-06
Average Error %	13.1 %	10.3 %	84.8 %	6.99 %
Mini Error %	3.9 %	0.408 %	81.7 %	1.92 %
Max Error %	21.4 %	26.8 %	87.7 %	8.72 %

6.10.6 Dynamic Viscosity and Thermal Conductivity of R507C for the entire pressure range

Dynamic Viscosity: For the whole pressure range in which the dynamic viscosity of the refrigerant R513A was examined, the results of equation 3 were found to have a minimum mean square error of 5.24E-12 and a minimum average error percentage of 12.9%. With a mean square error of 2.24E-10 and an average error rate of 99.5%, the solution to equation 1 has the highest mistake rate. The mean square error in Equation 4 is 6.95E-12, while the average error is 16.1%.

Thermal Conductivity: For the whole pressure range of 0.096 MPa to 2.96 MPa, the solutions to equation 2 result in an average error percentage of 14.8% and a mean square error of 7.11E-06 for the thermal conductivity of refrigerant R513A. The minimal and greatest errors are, respectively, 0.449% and 50.1%.

6.10.7 Conclusion

Equation 3 produced the best results for the statistical analysis of the refrigerant R513A, with an average error of 12.9% throughout the whole pressure range. Looking at the graphic findings, each pressure value has unique graphic results, demonstrating that while equation 3 is utilized to determine dynamic viscosity for lower temperatures at higher pressure values, it is appropriate to find dynamic viscosity for higher temperatures at specific lower pressure levels. For the thermal conductivity, equation 2 produces an average error of 14.8%, and for all pressure levels, the error curve flattens out as temperature rises. This suggests that, regardless of pressure, equation 2 may be used to determine thermal conductivity at greater temperatures. Equation 3 may be used to compute and may be further modified in the future to get results with a low error percentage when considering the findings for dynamic viscosity for refrigerant R513A. While equation 2's error range is rather modest for all pressure levels when it comes to thermal conductivity, it may still be utilized to determine the refrigerant R513A's thermal conductivity because the error percentage is so low. Similar to the situation of dynamic viscosity, equation 2 can be improved upon in the future to lower the error rate when calculating thermal conductivity.

6.11 R717

For each of its five pressure levels, the R717 refrigerant's dynamic viscosity and thermal conductivity are tested independently. The second worksheet checks the error generally throughout the full pressure range, from the first to the final value, in order to determine how much error each equation has across the entire pressure range and which equation is closest to the reference value.

6.11.1 Dynamic Viscosity and Thermal Conductivity of R717 at 0.096 MPa

Dynamic Viscosity: Different error curves are shown for each graph after the statistical analysis for refrigerant 0.096 MPa for refrigerant R717. For the findings shown by the equation 3 graph, the dynamic viscosity reference values curve exhibits a sharp increase as the temperature rises, but the equation 3 values curve exhibits an overall steady increase. Both of these curves cross at a temperature of 20 degrees Celsius, giving the lowest inaccuracy of 0.301%. While the At the highest temperature, 140 degrees Celsius, the largest error, 67.8%, is seen. The mean square error is 3.91E-11 and the average error percentage for both of these curves is 20.9%. The results of equation 4 show that the dynamic viscosity curves do not overlap, and as a consequence, the endpoint temperature of 140 degrees Celsius exhibits the maximum error of 70% and the lowest error of 31.1%, respectively. The mean square error for these two curves is 5.02E-11, while the average error is 36.9%. The error curve for the values from equation 1 is significantly different since it increases with temperature up to 80 degrees Celsius before decreasing till 120 degrees Celsius and then increasing again. Due to this behavior, the lowest error, which is measured at 120 degrees Celsius, is 4.17%, and the maximum error, which is measured at 140 degrees Celsius, is 42.8%. These data have an average error of 18.2%, and the mean square error is 1.47E-11.

Thermal Conductivity: Both thermal conductivities are comparable in behavior and form for the refrigerant R717 at a pressure of 0.096 MPa, however the error curve exhibits distinct behavior at various temperature ranges. Prior to decreasing for the endpoint temperature, it initially rises with temperature till 90 degrees Celsius, then drops to 100 degrees Celsius before increasing once more until the temperature of 130 degrees. At a temperature of 140 degrees Celsius, the error is reported as being 17.5%, whereas at a temperature of 130 degrees Celsius, the error is recorded as being 1.05E02. The mean square error for these results is 2.90E-03, while the average error is 48.5%..

R717 at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.91E-11	5.02E-11	1.47E-11	2.90E-03
Average Error %	20.9 %	36.9 %	18.2 %	48.5 %
Mini Error %	0.30 %	31.1 %	4.17 %	17.5 %
Max Error %	67.8 %	70 %	42.8 %	1.05E02 %

6.11.2 Dynamic Viscosity and Thermal Conductivity of R717 at 0.179 MPa

Dynamic Viscosity: Following the statistical analysis for refrigerant R717 at pressure of 0.179 MPa, several error curves are displayed for each graph. According to the results displayed by the equation 3 graph, although the equation 3 values curve shows an overall steady increase as the temperature rises, the dynamic viscosity reference values curve demonstrates a sudden increase. The lowest error is 0.6% when both of these curves cross at a temperature of 40 degrees Celsius. The biggest error, 65.4%, is seen at the maximum temperature, 140 degrees Celsius. The average error percentage for both of these curves is 19%, and the mean square error is 3.68E-11. Because the dynamic viscosity curves do not overlap, the endpoint temperature of 140 degrees Celsius displays the highest maximum error of 67.8% and the lowest minimum error of 26.3%, according to the findings of equation 4. These two curves have an average error of 32.8% and a mean square error of 4.66E-11. Since it grows with temperature up to 80 degrees Celsius before reducing till 120 degrees Celsius and then increasing again, the error curve for the values from equation 1 is noticeably different. The largest error, which is recorded at 140 degrees Celsius, is 42.8%, and the minimum error, which is measured at 120 degrees Celsius, is 4.17% as a result of this behavior. The mean square error for this data is 1.56E-11, with an average error of 18.8%.

Thermal Conductivity: At a pressure of 0.179 MPa, both thermal conductivities for the refrigerant R717 behave and take on similar shapes, however, the error curve behaves differently depending on the temperature range. It first rises with a temperature up to 100 degrees Celsius, then lowers to 110 degrees Celsius before rising from a temperature of 120 degrees Celsius at the endpoint. The biggest error, 58.7%, was recorded at a temperature of 140 degrees Celsius, while the lowest error, 32.9%, was reported at a temperature of 120 degrees Celsius. These data have a mean square error of 8.51E-03 and an average error of 44.1%.

R717 at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.68E-11	4.66E-11	1.56E-11	8.51E-03
Average Error %	19 %	32.8 %	18.8 %	44.1 %
Mini Error %	0.6 %	26.3 %	4.17 %	32.9 %
Max Error %	65.4 %	67.8 %	42.8 %	58.7 %

6.11.3 Dynamic Viscosity and Thermal Conductivity of R717 at 0.379 MPa

Dynamic Viscosity: The graphs of the solutions to equations 3, 4, and 1 are quite similar for the dynamic viscosity of refrigerant R717 at a pressure of 0.379 MPa. For equation 3, the error curve begins to grow at 140 degrees Celsius after initially decreasing with an increase in temperature. As a consequence, the temperature in question has the lowest error, 18.8%. At the zero-degree Celsius starting point, the largest error of 1.66E02 is observed. The mean square error for the solutions to equation 3 is 1.98E-10, while the average error is 99.8%. The error curve for equation 4's findings increases with temperature up to 60 degrees Celsius, then decreases to 130 degrees Celsius before increasing again. This causes the lowest error, 12.9%, to be reported at 130 degrees Celsius and the biggest error, 71.6%, to be recorded at 60 degrees Celsius. The mean square error for the dynamic viscosity findings from equation 4 is 1.16E-10, with an average error of 58.6%. The error curve for the numbers from equation 1 is notably different since it increases with temperature up to 70 degrees Celsius before decreasing to 120 degrees Celsius and then rising once again. As a result of this behavior, the maximum error, measured at 140 degrees Celsius, is 67.6%, while the smallest error, measured at 120 degrees Celsius, is 4.17%. This data has a mean square error of 1.09E-10 or an average error of 22.3%.

Thermal Conductivity: Both of the R717 refrigerant's thermal conductivities act similarly at a pressure of 0.379 MPa, while the error curve exhibits distinct behavior depending on the temperature range. It first rises with a temperature of up to 100 Celsius degrees then falls to a temperature of 130 Celsius degrees before rising once more. While the lowest mistake, 18%, was reported at a temperature of 130 degrees Celsius, the largest error, 63.5%, was observed at 150 degrees Celsius. These data have a 44.9% average error and a mean square error of 1.64E-01.

R717 at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.98E-10	1.16E-10	1.09E-10	1.64E-01
Average Error %	99.8 %	58.6 %	22.3 %	44.9 %
Mini Error %	18.8 %	12.9 %	4.17 %	18 %
Max Error %	1.66E02 %	71.6 %	67.6 %	63.5 %

6.11.4 Dynamic Viscosity and Thermal Conductivity of R717 at 0.896 MPa

Dynamic Viscosity: For equations 3, 4, and 1, the dynamic viscosity values for the refrigerant R717 at a pressure of 0.8.96 MPa are shown in the corresponding graphics. The intersection of two dynamic viscosity curves at a temperature of 140 Celsius yields the best results for equation 3, with a minimum error of 1.22%. The largest error is measured at 30 degrees Celsius, where it is 1.84E02%. The mean square error for the solutions to equation 3 is 2.95E-10, and the average error percentage between these two dynamic viscosity curves is 1.21E02%. Up until a temperature of 130 degrees, the error curve is falling; beyond that, it is growing. For the results of equation 4, the error curve climbs up to a temperature of 70 degrees Celsius before falling until a temperature of 140 degrees Celsius, at which point it records the lowest error of 5.79%, and then it rises once again. This results in the largest error, 1.09E02%, being measured between 60 and 70 degrees Celsius. At a temperature of 70 degrees Celsius, where the dynamic viscosity curves cross, the error percentage is the lowest. The mean square error of dynamic viscosity curves is 1.73E019, and the average error percentage is 84.3%. The junction of the reference values and equation 1 values curves is at a temperature of 120 degrees Celsius, where the results shown by equation 1 have the lowest error of 4.17%. At the greatest temperature of 140 degrees Celsius, the largest error of 67.6% is noted. The mean square error between these two curves is 1.34E-10, and the average error percentage is 23.8%.

Thermal Conductivity: At a pressure of 0.896 MPa, both thermal conductivities of the R717 refrigerant behave identically, however the error curve behaves differently depending on the temperature range. When it first rises, the temperature reaches up to 110 Celsius degrees. It then drops until the temperature reaches 130 Celsius degrees, after which it rises once more. The biggest error, 63.5%, was recorded at a temperature of 150 degrees Celsius, while the smallest error, 18%, was recorded at a temperature of 130 degrees Celsius. The mean square error for this data is 2.02E-01, with an average error of 46.3%.

R717 at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.95E-10	1.73E-10	1.34E-10	2.02E-01
Average Error %	1.21E02 %	84.3 %	23.8 %	46.3 %
Mini Error %	1.22 %	5.79 %	4.17 %	18 %
Max Error %	1.84E02 %	1.09E02 %	67.6 %	63.5 %

6.11.5 Dynamic Viscosity and Thermal Conductivity of R717 at 3.17 MPa

Dynamic Viscosity: The accompanying figures display the dynamic viscosity values for the refrigerant R717 at a pressure of 0.3.17 MPa for equations 3, 4, and 1. The intersection of the dynamic viscosity curves at a temperature of 80 Celsius yields equation 3 values and has the lowest error of 2.54% ever measured. The largest error of 56.3% occurs at a temperature of 140 degrees Celsius. The mean square error between these two dynamic viscosity curves is 4.72E-11, and the average error percentage is 17%. The intersection of two dynamic viscosity curves, which yields the solutions of equation 4, occurs at a temperature of 120 degrees Celsius and has the lowest error, 2.04%. At a maximum error of 140 degrees Celsius, the largest error of 43.3% is noted. The error curve for this result has an average error percentage of 15% and a mean square error of 2.61E-11, and it increases up to a temperature of 90 degrees Celsius before decreasing to 120 degrees and then climbing beyond that. While the error curve for the equation's findings rises after 120 degrees Celsius and then starts to fall from the starting point temperature. The dynamic viscosity curves cross at 120 degrees Celsius when the error between them is at its lowest point of 4.17%. At a temperature of 140 degrees Celsius, the largest error, 42.8%, is noted. The biggest error % has been seen at the highest temperature in all three equation graphs, following a similar trend. The mean square error between the two dynamic viscosity curves is 2.78E-11, and the average error percentage is 20%.

Thermal Conductivity: Both of the R717 refrigerant's thermal conductivities act identically at 3.17 MPa, while the error curve exhibits various behaviors depending on the temperature range. The temperature can be as high as 110 Celsius degrees when it initially rises. The temperature then declines until it hits 130 Celsius, at which point it starts to climb again. At a temperature of 140 degrees Celsius, the highest mistake was recorded at 61.1%, while at a temperature of 130 degrees Celsius, the smallest error was reported at 18%. This data has a mean square error of 1.24E-02, or a 46% average error.

R717 at 3.17 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	4.72E-11	2.61E-11	2.78E-11	1.24E-02
Average Error %	17 %	15 %	20 %	46 %
Mini Error %	2.54 %	2.04 %	4.17 %	18 %
Max Error %	56.3 %	43.3 %	42.8 %	61.1 %

6.11.6 Dynamic Viscosity and Thermal Conductivity of R717 for the entire pressure range

Dynamic Viscosity: The findings of equation 1 were found to have a minimum mean square error of 6.02E-11 and a minimum average error percentage of 20.5% throughout the whole pressure range in which the dynamic viscosity of the refrigerant R717 was studied. The solution of equation 3 has the greatest average error rate, with a mean square error of 1.23E-10 and a mean error rate of 56.7%. Equation 4 has a mean square error of 6.902E-11 and an average error of 47.2%.

Thermal Conductivity: The answers to equation 2 give the thermal conductivity of refrigerant R717 with a mean square error of 7.92E-02 and an average error percentage of 46% throughout the whole pressure range of 0.096 MPa to 3.17 MPa. The lowest and highest error rates are 17.5% and 1.05E02%, respectively.

6.11.7 Conclusion

Regardless of pressure settings, all equations for the refrigerant R717 indicated a trend for the values to move closer to the reference values as the temperature rose. Even while all formulae may be used to calculate the dynamic viscosity independent of pressure, the temperature range is obviously limited because the average error is the lowest between 20 and 50 degrees Celsius. As a result, equation 1 had the best results, recording the minimum average error of 20.5% over the full pressure range and providing dynamic viscosity values that were the closest to the reference values. This equation may be applied to start at a temperature of 20 degrees Celsius as the conditions for thermal conductivity and dynamic viscosity was the same. As a result, this equation for thermal conductivity is accepted as being correct for higher temperature ranges for all pressure levels used in the experiment. Reviewing the findings, it is clear that for refrigerant R717 at all pressure levels for both dynamic viscosity and thermal conductivity, the error range is fairly large. As a result, existing equations need to be improved or new equations need to be developed in order to determine the thermal conductivity and dynamic viscosity of refrigerant R717 in super-heated state.

6.12 R744

For each of its five pressure levels, the R744 refrigerant's dynamic viscosity and thermal conductivity are tested independently. The second worksheet checks the error generally throughout the full pressure range, from the first to the final value, in order to determine how much error each equation has across the entire pressure range and which equation is closest to the reference value.

6.12.1 Dynamic Viscosity and Thermal Conductivity of R744 at 0.86 MPa

Dynamic Viscosity: The findings for the dynamic viscosity of the refrigerant R744 at a pressure of 0.86 MPa are presented in the corresponding graphs produced by equations 3, 4, and 1. At a temperature of 30 degrees Celsius, the dynamic viscosity curves from the reference and equations values overlap, producing the lowest error of 0.61% for the equation 3 findings. Equation 3 yields a dynamic viscosity curve that is constantly decreasing up to a temperature of 40 degrees Celsius and then steadily rising. Throughout the temperature range, the reference value's curve is increasing. The temperature of 300 degrees Celsius, which is the greatest temperature, records the biggest error of 31.1%. This demonstrates that the error curve has a V-shape. The mean square error is 2.60E-11, and the average error between two dynamic viscosity measurements is 20.2%. On the other hand, when temperature rises, the dynamic viscosity curves for equation 4 findings and reference values appear to approach one another, and at higher temperatures, they appear to cross. Due to this, the lowest error, 0.763%, is measured at 300 degrees Celsius, the maximum temperature. The maximum error, 10.3%, is observed at the starting point temperature of -30 degrees Celsius since the error decreases as temperature rises. The solutions from equation 4 have mean square errors of 4.34E-13 and an average error of 3.49% between two dynamic viscosity curves. Similar findings from equation 1 demonstrate that the error curve is flattening down while the dynamic viscosity curves are rising with a rise in temperature. As a result, the beginning point temperature, which is the lowest, produces the maximum error of 41.8% and the lowest error of 24.3% at the highest temperature of 300 degrees Celsius. The mean square error for equation 1's output is 3.80E-11 and the average error is 31.5%.

Thermal Conductivity: The curves from equation values and reference values appear to meet at a higher temperature for the results of equation 2 calculations for the thermal conductivity of refrigerant R744 art pressure of 0.86 MPa. This shows that the error between two numbers decreases as the temperature rises. The lowest error of 0.0973% is found when two thermal conductivity curves overlap at a temperature of 290 degrees Celsius. While -30 degrees Celsius produces the biggest error, which is 35.9%. The mean square error between any two thermal conductivity measurements is 9.19E-06, and the average error is 13.3%.

R744 at 0.861 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.60E-11	4.34E-13	3.80E-11	9.19E-06
Average Error %	20.2 %	3.49 %	31.5 %	13.3 %
Mini Error %	0.61 %	0.763 %	24.3 %	0.0973 %
Max Error %	31.1 %	10.3 %	41.8 %	35.9 %

6.12.2 Dynamic Viscosity and Thermal Conductivity of R744 at 2.41 MPa

Dynamic Viscosity: The related graphs created by equations 3, 4, and 1 show the results for the dynamic viscosity of the refrigerant R744 at a pressure of 2.41 MPa. The dynamic viscosity curve appears to be rising with temperature rise, which is the sole similarity between both plots. The lowest error of 4.34% is noted for equation 3 outcomes at a starting temperature of 0 degrees Celsius. The error curve is growing as temperature rises, and the largest error of 37.3% is observed at the highest temperature of 300 degrees Celsius. The mean square error is 4.35E-11, and the average error between two dynamic viscosity measurements is 23.8%. According to equation 4's results, the mean square error is 6.63E-13, and the average error between two dynamic viscosity values is 37%. According to these results, the dynamic viscosity curves from equation 4 and the reference values appear to cross at 50 degrees Celsius and then at higher temperatures between 260 and 300 degrees Celsius. As a result, the error curve rises until a temperature of 100 degrees Celsius before falling again. This process repeats again until a temperature of 50 degrees Celsius. As a consequence, the temperature at 50 degrees Celsius records the lowest error of 0.70%, and the temperature at 0 degrees Celsius records the biggest error of 12%. The dynamic viscosity curve for the equation 1 results is rising as temperature rises, whereas the error curve is decreasing. The mean square error between two dynamic viscosity values is 5.24E-11, and the average error percentage is 33.2%. Due to the nature of the error curve, temperatures between 290 and 300 degrees Celsius have the lowest errors (30.6%) and zero degrees Celsius have the largest errors (40.5%).

Thermal Conductivity: The thermal conductivity curves for refrigerant R744 at a pressure of 2.41 MPa are parallel to one another, rise with temperature, and get smaller as the error curve gets smaller. As a result, the temperature of 300 degrees Celsius has the lowest error of 7.81% while the temperature of 0 degrees Celsius has the largest error of 21.8%. The mean square error between the two thermal conductivity curves is 9.29E-06, and the average error percentage is 11.8%.

R744 at 2.41 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	4.35E-11	6.63E-13	5.24E-11	9.29E-06
Average Error %	23.8 %	3.7 %	33.2 %	11.8 %
Mini Error %	4.34 %	0.7 %	30.6 %	7.81 %
Max Error %	37.3 %	12 %	40.5 %	21.8 %

6.12.3 Dynamic Viscosity and Thermal Conductivity of R744 at 4.48 MPa

Dynamic Viscosity: The dynamic viscosity values graphs for equations 3, 4, and 1 for the refrigerant R744 at a pressure of 4.48 MPa all show an increase with temperature, with the error curve acting as the primary difference. The graph showing the results from equation 3 has an inverted parabola-shaped error curve that assumes a V-shape approaching the extremes of the temperature range. This causes the error curve to rise from 10 degrees to 80 degrees Celsius temperature before falling to 240 degrees and then climbing again. As a result, the starting temperature of 10 degrees Celsius produces the lowest error of 0.14% while the starting temperature of 80 degrees Celsius produces the maximum error of 16.5%. For equation 3, the mean square error between two dynamic viscosity curves is 4.26E-12, and the average error is 8.88%. The dynamic viscosity curves intersect at 110 degrees Celsius, giving equation 4 results with the lowest error of 0.598%, and they are near to crossing at higher temperature levels. The error curve is decreasing with temperature until 110 degrees Celsius, increasing to 140 degrees Celsius, and then declining. The largest error, 37.1%, is recorded at the beginning temperature of 10 degrees Celsius. The mean square error for equation 4's findings is 3.38E-12, while the average error is 6.76%. The error curve is decreasing whereas the dynamic viscosity curve for equation 1 shows a rise as temperature increases. The average error percentage and mean square error between two dynamic viscosity values are 5.40E-11 and 33.8%, respectively. The temperature 290 degrees Celsius has the lowest error (30.4%), while the temperature of 10 degrees Celsius has the worst errors (43.8%).

Thermal Conductivity: The error curve from equation 2's results for the thermal conductivity of refrigerant R744 at a pressure of 4.48 MPa increases with temperature up to 60 degrees Celsius before decreasing till 140 degrees Celsius and then increasing again. As a result, the temperature at which the error is largest, at 9.8%, is 60 degrees Celsius, and the temperature at which the error is lowest, at 2.61%, is 10 degrees Celsius at the beginning point. The answers of equation 2 have a mean error of 6.82% and a mean square error of 4.03E-06.

R744 at 4.48 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	4.26E-12	3.38E-12	5.40E-11	4.03E-06
Average Error %	8.88 %	6.76 %	33.8 %	6.82 %
Mini Error %	0.14 %	0.598 %	30.4 %	2.61 %
Max Error %	16.5 %	37.1 %	43.8 %	9.8 %

6.12.4 Dynamic Viscosity and Thermal Conductivity of R744 at 5.86 MPa

Dynamic Viscosity: For the refrigerant R744 at a pressure of 4.48 MPa, the dynamic viscosity values graphs for equations 3, 4, and 1 all indicate an increase with temperature, with the error curve serving as the main difference. According to equation 3's output, the biggest error is recorded at a beginning temperature of 30 degrees Celsius (20.1%), while the lowest error is seen at a temperature of 290 degrees Celsius (0.0423%). This shows that the error curve is lowering as the temperature rises. Looking at the graph, the error curve initially decreases till 70 degrees Celsius, then rises to 150 degrees Celsius before dropping once more. The mean square error for equation 3's results is 1.25E-12, while the average error is 4.25%. While equation 4's findings show that at 170 degrees Celsius, the dynamic viscosity curves from the reference and equation 4 values overlap, resulting in the lowest error of 0.279% ever observed. At the temperature of the beginning point, which is 30 degrees Celsius, the maximum error of 46.2% is noted. This indicates that the error curve decreases as temperature rises up to 170 degrees Celsius before rising again. The mean square error for the solutions of equation 4 is 8.16E-12, while the average error between two dynamic viscosity curves is 10%. While the dynamic viscosity curve for equation 1 indicates a rise as temperature rises, the error curve is dropping. The mean square error and average error percentage between the two dynamic viscosity values are, respectively, 4.78E-11 and 32.1%. The accuracy ranges from the lowest at 290 degrees Celsius (23.8%) to the highest at 30 degrees Celsius (45.8%).

Thermal Conductivity: The curves from reference values and equation values for the thermal conductivity findings of equation 2 cross at 40 degrees Celsius and 210 degrees Celsius. This causes the error curve to decrease from 30 degrees to 40 degrees Celsius, increase till 80 degrees Celsius, then decrease once again to 210 degrees Celsius, increases afterwards, and create a sinusoid curve. As a result, at a temperature of 30 degrees Celsius, the maximum error of 6.92% forms and the lowest error of 0.154 % forms at 210 degrees Celsius. The mean square error for the solutions to equation 2 is 1.02E-6, and the average error percentage is 3.02%.

R744 at 5.86 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.25E-12	8.16E-12	4.78E-11	1.02E-06
Average Error %	4.25 %	10 %	32.1 %	3.02 %
Mini Error %	0.0423 %	0.279 %	23.8 %	0.154 %
Max Error %	20.1 %	46.2 %	45.8 %	6.92 %

6.12.5 Dynamic Viscosity and Thermal Conductivity of R744 at 7.37 MPa

Dynamic Viscosity: In terms of the dynamic viscosity results, equation 3's findings show that the dynamic viscosity curves cross at a temperature of 60 degrees Celsius, with the lowest error recorded at 2.68%. While the temperature scale's lowest point, 30 degrees Celsius, records the biggest error being 90.2%. This demonstrates that the error curve decreases as temperature rises up to 60 degrees Celsius before rising again. The mean square error for equation 3's output is 7.85E-11, while the average error is 19.5%. The intersection of the dynamic viscosity curves in equation 4's findings occurs at a higher temperature, 250 degrees Celsius, and results in the lowest error, 0.23%. The temperature of 30 degrees Celsius has the biggest error, 95.7%. The mean square error for the solutions to equation 1 is 8.58E-11, and the average error percentage is 15.9%. The dynamic viscosity curves for equation 1's results do not cross, and the error curve likewise gets smaller as temperature rises. As a consequence, the lowest error, recorded at the temperature of 300 degrees Celsius, is 23.9%, while the biggest error, recorded at the temperature of 30 degrees Celsius, is 79.1%.

Thermal Conductivity: At 60 degrees Celsius and 200 degrees Celsius, the curves from the reference values and equation values for the thermal conductivity results of equation 2 intersect. This results in a sinusoid curve, with the error curve decreasing from 30 degrees to 60 degrees Celsius, increasing to 90 degrees Celsius, decreasing once more to 200 degrees Celsius, and increasing again. As a consequence, the highest mistake of 21.2% arises at a temperature of 30 degrees Celsius, while the lowest error of 0.08% forms at a temperature of 200 degrees Celsius. The average error percentage for the solutions to equation 2 is 3.25%, and the mean square error is 1.24E-5.

R744 at 7.33 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	7.85E-11	8.58E-11	1.03E-10	1.24E-05
Average Error %	19.5 %	15.9 %	34.9 %	3.25 %
Mini Error %	2.68 %	0.23 %	23.9 %	0.08 %
Max Error %	90.2 %	95.7 %	79.1 %	21.2 %

6.12.6 Dynamic Viscosity and Thermal Conductivity of R744 for the entire pressure range

Dynamic Viscosity: Throughout the whole pressure range in which the dynamic viscosity of the refrigerant R744 was examined, the results of equation 4 were determined to have a minimum mean square error of 1.85E-11 and a minimum average error percentage of 7.7%. With a mean square error of 5.80E-11 and a mean error rate of 33.1%, the solution to equation 1 has the highest average error rate. The average error in Equation 3 is 15.7%, with a mean square error of 3.08E-11.

Thermal Conductivity: With a mean square error of 7.36E-06 and an average error percentage of 7.99% for the whole pressure range of 0.86 MPa to 7.37 MPa, the solutions to equation 2 provide the thermal conductivity of refrigerant R744. The error rates range from 0.08% to 35.9%, respectively.

6.12.7 Conclusion

Equation 4 produces the best results for the refrigerant R744 over a pressure range of 0.86 MPa to 7.37 MPa, with an average error of 7.7%. At all five pressure values of 0.86 MPa, 2.41 MPa, 4.48 MPa, 5.86 MPa, and 7.37 MPa, the error curve for all graphs of equation 4 is decreasing with an increase in temperature, showing that this equation is useful to find dynamic viscosity at higher temperature ranges starting from 50 degrees Celsius. However, a comparable example is found for the solutions of equations 3 and 1, leading to the conclusion that they may both be applied to the same situation. The average error in equation 3 is 15.7%, and the initial temperature is similarly 50 Celsius. in order to conduct heat. Equation 2 shows that the overall average error is 7.88%, and the graph shows that the error curve flattens out as the temperature rises. Because the mistake at the starting point is not very large and the equation still produces values that are near to the reference values, it may be utilized across the full range. In conclusion, equation 4 may be used to determine the dynamic viscosity of R744 at all pressure levels in the super-heated state, and equation 2 can be improved to determine thermal conductivity.

6.13 1234yf

For each of its five pressure levels, the 1234yf refrigerant's dynamic viscosity and thermal conductivity are tested independently. The second worksheet checks the error generally throughout the full pressure range, from the first to the final value, in order to determine how much error each equation has across the entire pressure range and which equation is closest to the reference value.

6.13.1 Dynamic Viscosity and Thermal Conductivity of 1234yf at 0.096 MPa

Dynamic Viscosity: The graphs of equations 3, 4, and 1 are entirely different for the dynamic viscosity of refrigerant 1234yf at a pressure of 0.096 MPa. The lowest error of 0.48% is shown for equation 3 at the intersection of dynamic viscosity curves from equation 3 values and reference values at the temperature of 70 degrees Celsius. While the starting point temperature of -20 degrees Celsius shows the largest error of 44.8%. The mean square error between the two dynamic viscosity measurements is 5.44E-12, and the average error percentage is 14.3%. The error curve for equation 4's findings somewhat decreases as temperature rises up to 40 degrees Celsius, then rises to 90 degrees Celsius and then gradually decreases. This irregularity causes the lowest error, 16.6%, to be reported at 200 degrees Celsius and the maximum error, 19.9%, to be recorded at -30 degrees Celsius as the starting point. The average error percentage for equation 4 is 18.6%, and the mean square of the values' divergence from the reference values is 7.84E-12. The dynamic viscosity curves and the error curve for equation 1's findings both rise as the temperature rises. Due to this, the temperature at -30 degrees Celsius has the lowest error of 78.5% while the temperature at 200 degrees Celsius has the largest error of 1.20E02%. The mean square error between the two dynamic viscosity curves is 2.53E-10, while the average error is 99.4%.

Thermal Conductivity: The results of equation 2 show that the two thermal conductivity curves cross at a temperature of 110 degrees Celsius, and as a consequence, this location exhibits the lowest error of 0.569% between them for the thermal conductivity of refrigerant 1234yf at a pressure of 0.096 MPa. The graph shows that the error percentage curve is decreasing up to a temperature of 110 degrees Celsius before increasing and taking the shape of a V. As a consequence, at a starting temperature of -30 degrees Celsius, the maximum error of 41.7% is shown. The mean square error is 8E-06, and the average error between the thermal conductivity curves of equation 2 and reference values is 15%.

1234yf at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.44E-12	7.84E-12	2.53E-10	8.00E-06
Average Error %	14.3 %	18.6 %	99.4 %	15 %
Mini Error %	0.48 %	16.6 %	78.5 %	0.569 %
Max Error %	44.8 %	19.9 %	1.2E02 %	41.7 %

6.13.2 Dynamic Viscosity and Thermal Conductivity of 1234yf at 0.179 MPa

Dynamic Viscosity: The graphs of equations 3, 4, and 1 results for dynamic viscosity at a pressure of 0.179 MPa indicate no similarities in the error curve, however the dynamic viscosity curves are rising as the temperature rises. The error curve and the dynamic viscosity curves for the solution of equation 1 are growing as the temperature rises. As a consequence, the lowest error, which is generated at 0 degrees Celsius for the starting temperature, is 83.9%, while the largest error, which is demonstrated at 200 degrees Celsius for the end temperature, is 1.66E02%. The mean square error is 3.06E-10, while the average error between the two dynamic viscosity curves is 1.12E02%. The intersection of dynamic viscosity curves at a starting point temperature of 10 degrees Celsius yields the lowest error, 2.09%, for the equation 3 results. While the maximum error of 25.8% is produced at 110 degrees Celsius in temperature. This shows that the error curve decreases from 0 degrees to 10 degrees Celsius temperature before increasing till 110 degrees Celsius temperature and then decreasing after that. The mean square error is 9.36E-12, and the average discrepancy between the dynamic viscosity findings from equation 3 and reference values is 18.4%. The error curve for equation 4's findings is lowered from 0 degrees Celsius to 170 degrees Celsius, where the lowest error of 0.936% is placed, and then it climbs from there. At a temperature of 0 degrees Celsius, this causes the largest error to occur, at 15.2%. The mean square error between two dynamic viscosity measurements is 2.48E-12, with an average error of 10.3%.

Thermal Conductivity: According to equation 2, the two thermal conductivity curves intersect at a temperature of 110 degrees Celsius, and as a result, the thermal conductivity of refrigerant 1234yf at a pressure of 0.179 MPa displays the lowest error at this point, which is 0.303%. The graph demonstrates that the error percentage curve decreases until a temperature of 110 degrees Celsius, at which point it begins to rise and assume a V-shaped form. As a result, the highest error of 32% is demonstrated at a starting temperature of 0 degrees Celsius. The average discrepancy between the thermal conductivity curves of equation 2 and reference values is 16.5%, and the mean square error is 1.84E-05.

1234yf at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	9.36E-12	2.48E-12	3.06E-10	1.84E-05
Average Error %	18.4 %	10.3 %	1.12E02 %	16.5 %
Mini Error %	2.09 %	0.936 %	83.9 %	0.3 %
Max Error %	25.8 %	15.2 %	1.66E02 %	32 %

6.13.3 Dynamic Viscosity and Thermal Conductivity of 1234yf at 0.379 MPa

Dynamic Viscosity: The error curves for equations 1 and 3 for the dynamic viscosity findings are comparable, whereas the error curve for equation 4 for the dynamic viscosity results is entirely different from the other two. The error curve decreases with temperature whereas the dynamic viscosity curves grow with temperature and are parallel to one another. As a result, the starting temperature of 10 degrees Celsius exhibits the maximum error of 16% while the ending temperature of 200 degrees Celsius exhibits the lowest error of 7.43%. In equation 4, the mean square error and the average between two parallel dynamic viscosity lines are 10.9% and 2.73E-12, respectively. The curves of dynamic viscosity from the equation 3 results and the reference results cross at a temperature of 10 degrees Celsius, exhibiting the lowest error of 0.36%. The error curve shows a rise as temperature rises since the largest error of 28% is created at the highest temperature of 200 degrees Celsius. As a consequence, the mean square error for equation 3 is 1.18E-11, and the lowest error percentage between two dynamic viscosity curves is 18%. The values of equation 1, which are remarkably similar to those of equation 3, have an average error percentage of 1.02E02% and a mean square error of 2.78E-10. There is no intersection between the dynamic viscosity curves. The beginning point temperature has the lowest error of 86.2% while the endpoint temperature has the largest error of 1.19E02%.

Thermal Conductivity: Equation 2 states that the two thermal conductivity curves cross at 110 degrees Celsius. As a consequence, the refrigerant 1234yf's thermal conductivity at this pressure, 0.379 MPa, has the lowest error at this point, 0.284%. The graph shows that the error % curve rises and takes on a V-shaped structure when the temperature approaches 110 degrees Celsius. As a consequence, at a starting temperature of 10 degrees Celsius, the greatest error of 27% is shown. The mean square error is 7.27E-06 and the average difference between the thermal conductivity curves of equation 2 and reference values is 11.5%.

1234yf at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	1.18E-11	2.73E-12	2.78E-10	7.27E-06
Average Error %	18 %	10.9 %	1.02E02 %	11.5 %
Mini Error %	0.36 %	7.43 %	86.2 %	0.284 %
Max Error %	28 %	16 %	1.19E02 %	27 %

6.13.4 Dynamic Viscosity and Thermal Conductivity of 1234yf at 0.896 MPa

Dynamic Viscosity: For the dynamic viscosity results for the refrigerant 1234yf at a pressure of 0.896 MPa, the error curves for equations 1 and 3 are comparable, however the error curve for equation 4 is wholly different from the other two. The dynamic viscosity curves expand with temperature and intersect at high temperatures of 200 degrees Celsius, when the lowest error of 1.84% is recorded, but the error curve of equation 4 results declines with temperature. As a result, the 40 degree Celsius beginning temperature has a maximum error of 17.9%. The average of the two dynamic viscosity lines and the mean square error in equation 4 are 7.3% and 1.60E-12, respectively. At a temperature of 40 degrees Celsius, where the dynamic viscosity curves from equation 3 results and the reference results are closest, they have the lowest error of 6%. Since the maximum mistake of 17.8% is produced at the highest temperature of 200 degrees Celsius, the error curve indicates a climb as temperature increases. As a result, equation 3's mean square error is 4.97E-12, and 12% is the lowest error rate between the two dynamic viscosity curves. The values of equation 1, which are quite comparable to those of equation 3, have a mean square error of 2.98E-10 and an average error percentage of 1.01E02%. The dynamic viscosity curves do not meet at any point. The temperature at the starting point, 40 degrees Celsius, has the lowest error at 89.5%, while the temperature at the finish, 200 degrees Celsius, has the highest error at 1.14E02%.

Thermal Conductivity: The two thermal conductivity curves, according to Equation 2, intersect at 110 and 120 degrees Celsius. As a result, comparing two thermal conductivity curves, the refrigerant 1234yf's thermal conductivity at this pressure, 0.896 MPa, has the lowest error, 1.06%, at a temperature of 120 degrees Celsius. The graph demonstrates that the error percentage curve decreases from 40 degrees to 110 degrees Celsius and increases with temperature from 120 degrees Celsius on up, producing a V-shape. As a result, the largest error of 16.1% is demonstrated at a starting temperature of 40 degrees Celsius. The average difference between the thermal conductivity curves of equation 2 and reference values is 8.69%, and the mean square error is 5.95E-06.

1234yf at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	4.97E-12	1.60E-12	2.98E-10	5.95E-06
Average Error %	12 %	7.3 %	1.01E02 %	8.69 %
Mini Error %	6 %	1.84 %	89.5 %	1.06 %
Max Error %	17.8 %	17.9 %	1.14E02 %	16.1 %

6.13.5 Dynamic Viscosity and Thermal Conductivity of 1234yf at 2.102 MPa

Dynamic Viscosity: The findings of equations 3 and 4 provide comparable graphs for the dynamic viscosity results of refrigerant 1234yf at the pressure of 2.102 MPa. The results from equation 3 and reference values dynamic viscosity are creating the lowest error of 0.476% at a temperature of 100 degrees Celsius, while the dynamic viscosity curves are crossing at a temperature of 110 degrees Celsius and producing the lowest error of 0.429%. The error curves for both graphs have a V-shape, which shows that the temperature is dropping until it reaches its lowest error % before increasing once more. At a starting point temperature of 80 degrees Celsius, the largest error for equation 3 results is generated at 10.5%, and for equation 4 results, the highest error is formed at an endpoint temperature of 200 degrees Celsius at 23.9%. When comparing two dynamic viscosity curves, the mean square error for equation 3 is 2.14E-12 and the average error is 7.02%. Between two dynamic viscosity curves, the results of equation 4 show an average error of 13.2% and a mean square error of 8.41E-12. A mean square error of 3.04E-10 and an average error rate of 92.8% characterize the values of equation 1. The curves for dynamic viscosity never come together. In comparison to the temperature at the finish line, which is 200 degrees Celsius, the error at the starting point, 80 degrees Celsius, is the lowest at 77.5% and the greatest at 1.05E02%.

Thermal Conductivity: According to Equation 2, the two thermal conductivity curves intersect at 130 degrees Celsius. As a result, the thermal conductivity of the refrigerant 1234yf at this pressure, 2.10 MPa, has the lowest error at this point, 0.79%. When the temperature reaches 110 degrees Celsius, the error percentage curve climbs and takes on a V-shaped structure, as seen in the graph. As a result, the largest error of 12.7% is seen at the endpoint temperature of 200 degrees Celsius. The average square error is 4.18E-06, while the average difference between equation 2's thermal conductivity curves and reference values is 6.35%.

1234yf at 2.10 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	2.14E-12	8.41E-12	3.04E-10	4.18E-06
Average Error %	7.02 %	13.2 %	92.8 %	6.35 %
Mini Error %	0.476 %	0.429 %	77.5 %	0.79 %
Max Error %	10.5 %	23.9 %	1.05E02 %	12.7 %

6.13.6 Dynamic Viscosity and Thermal Conductivity of 1234yf for the entire pressure range

Dynamic Viscosity: The findings of equation 4 were determined to have a minimum mean square error of 4.50E-12 and a minimum average error percentage of 12.3% for the whole pressure range in which the dynamic viscosity of the refrigerant 1234yf was studied. The solution to equation 1 has the greatest average error rate, with a mean square error of 2.85E-11 and a mean error rate of 1.02E02%. In Equation 3, the average error is 14.6%, with a mean square error of 7.128E-12.

Thermal Conductivity: The answers to equation 2 yield the thermal conductivity of refrigerant 1234yf with a mean square error of 9.27E-06 and an average error percentage of 12.3% over the whole pressure range of 0.096 MPa to 2.102 MPa. The error rates range between 0.284% and 41.7%.

6.13.7 Conclusion

For the statistical study of the refrigerant 1234yf, Equation 4 yielded the best results, with an average error of 12.3% throughout the whole pressure range. By examining the graphic findings, it can be shown that while equation 3 is used to calculate dynamic viscosity for higher temperatures at particular lower pressure levels, it is appropriate to find dynamic viscosity for lower temperatures at higher pressure values. For all pressure levels, equation 2 yields an average error of 12.3% for the thermal conductivity. For the temperature range of 100 to 150 degrees Celsius, the error curve flattens and then rises once more. This implies that equation 2 may be used to calculate thermal conductivity at these temperatures, independent of pressure, and that there may be some error at other temperatures, though the average error for them is less than 20%. This research leads to the conclusion that equation 2 can be used to compute thermal conductivity and equation 3 can be used to calculate the dynamic viscosity for refrigerant 1234yf. These equations can be improved in the future to lower the error percentage and produce accurate results.

6.14 1234ze

For each of its five pressure levels, the 1234ze refrigerant's dynamic viscosity and thermal conductivity are tested independently. The second worksheet checks the error generally throughout the full pressure range, from the first to the final value, in order to determine how much error each equation has across the entire pressure range and which equation is closest to the reference value.

6.14.1 Dynamic Viscosity and Thermal Conductivity of 1234ze at 0.096 MPa

Dynamic Viscosity: The error curves and dynamic viscosity curves for refrigerant 1234ze at a pressure of 0.096 MPa are comparable in the graphs of results produced by equations 3, 4, and 1. The error curve decreases till a given temperature is reached, whereas the dynamic viscosity curve from equations increases in a straight line. For equations 3 and 1, the dynamic viscosity curves intersect at a temperature of 110 degrees Celsius, yielding the lowest errors of 9.14% and 21.1%, respectively, whereas graph 4 shows the dynamic viscosity curves intersecting at a temperature of 120 degrees Celsius, yielding the lowest error of 14.3%. The position of the largest mistake observed differs between these plots. The largest error of 1.72E02% is reported for equation 3 results at -10 degrees Celsius, whereas the highest error of 1.44E02% is recorded for equation 4 results at temperatures of 20 degrees and 30 degrees Celsius. At a temperature of 50 degrees Celsius, the largest error of 92.8% is observed for equation 1. The average error between dynamic viscosity curves for equation 3 results is 98%, with a mean square error of 3.07E-09, whereas the average error for equation 4 results is 1.13E02, with a mean square error of 2.75E-09. The average error for equation 1 results is 75.9%, and the mean square error is 2.81E-09. For all of the equation's visual findings, the error curve becomes a V-shape near the conclusion of the temperature range.

Thermal Conductivity: For the findings of equation 2 for the thermal conductivity of refrigerant 1234ze at a pressure of 0.096 MPa, the error curve decreases as temperature increases, while thermal conductivity increases. The mean square error between these two thermal conductivity curves is 5.29E-02, while the average error is 8.36E02%. The greatest temperature of 140 degrees Celsius produces the lowest inaccuracy of 1.56%, while the lowest temperature of -10 degrees Celsius produces the largest error of 1.27E03%.

1234ze at 0.096 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.07E-09	2.75E-09	2.81E-09	5.29E-02
Average Error %	98 %	1.13E02 %	75.9 %	8.36 E02 %
Mini Error %	9.14 %	14.3 %	21.1 %	1.56 %
Max Error %	1.72E02 %	1.44E02 %	92.8 %	1.27E03 %

6.14.2 Dynamic Viscosity and Thermal Conductivity of 1234ze at 0.179 MPa

Dynamic Viscosity: The graphs of equations 3 and 4 show a similar error curve for the dynamic viscosity findings at 0.179 MPa, demonstrating that it decreases with rising temperature before increasing again. The dynamic viscosity curves from reference values and equation values overlap at particular temperatures, which is shared by all three graphs. For equation 3, the curve decreases at a temperature of 70 degrees Celsius, where the dynamic viscosity curve intersects, and the lowest inaccuracy of 2.29% is observed. At the greatest temperature of 130 degrees Celsius, the largest inaccuracy of 84.1% is observed. For equation 3 findings, the average error between two dynamic viscosity curves is 26.2%, and the mean square error is 6.34E-10. For the results of equation 4, the error curve decreases until the temperature of 100 degrees Celsius is reached, at which point the intersection of dynamic viscosity curves yields the lowest error of 1.08%. At a temperature of 130 degrees Celsius, the largest error of 78.2% is reported. Between these two curves, the mean square error is 5.33E-10, and the average error is 29.2%. At a temperature of 50 degrees Celsius, equation 1 has the greatest error of 92.8%. The intersection for equation 1 occurs at 110 degrees Celsius, with the lowest error of 21.1% reported. For equation 1 findings, the average error is 74.3%, and the mean square error is 4.58E-10.

Thermal Conductivity: The error curve reduces as temperature increases, but thermal conductivity increases, according to the results of equation 2 for the thermal conductivity of refrigerant 1234ze at a pressure of 0.179 MPa. The average error between these two thermal conductivity curves is 4.64E02%, with a mean square error of 1.20E-02. The greatest temperature, 130 degrees Celsius, results in the lowest error of 8.8%, while the lowest temperature, 10 degrees Celsius, results in the largest error of 6.68E02%.

1234ze at 0.179 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	6.34E-10	5.33E-10	4.58E-10	1.20E-02
Average Error %	26.2 %	29.2 %	74.3 %	4.64E02 %
Mini Error %	2.29 %	1.08 %	21.1 %	8.8 %
Max Error %	84.1 %	78.2 %	92.8 %	6.68E02 %

6.14.3 Dynamic Viscosity and Thermal Conductivity of 1234ze at 0.379 MPa

Dynamic Viscosity: The error curve for the dynamic viscosity results at 0.379 MPa is comparable on the graphs of equations 3 and 1, indicating that it lowers with increasing temperature before increasing once more. At specific temperatures, the dynamic viscosity curves from reference values and equation values overlap, which is true for all three graphs. The dynamic viscosity curve crosses at a temperature of 110 degrees Celsius in equation 3, when the curve starts to decline, and here is where the lowest error of 11% is shown. The maximum error of 89.4% is seen at the highest temperature of 140 degrees Celsius. The mean square error for equation 3 results is 3.86E-09, and the average error between two dynamic viscosity curves is 57.4%. The error curve for equation 4's output falls until a temperature of 50 degrees Celsius is achieved, which results in the lowest error of 14.7%. The greatest error, 93.4%, is recorded at a temperature of 140 degrees Celsius. The mean square error between these two curves is 4.30E-09, while the average error is 35.6%. Equation 1 has a 92.8% error at

50 degrees Celsius, which is the highest error. Equation 1's intersection occurs at 110 degrees Celsius, and the lowest observed error is 21.1%. The mean square error for equation 1's results is 3.44E-09, while the average error is 74.1%.

Thermal Conductivity: According to the findings of equation 2 for the thermal conductivity of refrigerant 1234ze at a pressure of 0.379 MPa, the error curve decreases as temperature rises while thermal conductivity rises. These two thermal conductivity curves have an average inaccuracy of 7.47 E02%, with a mean square error of 6.04 E-02. The lowest mistake, 1.56%, is produced by the highest temperature, 140 degrees Celsius, while the largest error, 1.15E03%, is produced by the lowest temperature, 20 degrees Celsius.

1234ze at 0.379 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	3.86E-09	4.30E-09	3.44E-09	6.04E-02
Average Error %	57.4 %	35.6 %	74.1 %	7.47E02 %
Mini Error %	11 %	14.7 %	21.1 %	1.56 %
Max Error %	89.4 %	93.4 %	92.8 %	1.15E03 %

6.14.4 Dynamic Viscosity and Thermal Conductivity of 1234ze at 0.896 MPa

Dynamic Viscosity: The answers from equations 4 and 1 for dynamic viscosity at 0.896 MPa are comparable. While the solutions of equation 3 differ, the error curve rises as the temperature rises. The dynamic viscosity curves cross at a temperature of 50 degrees Celsius, where the lowest error of 7.6% is also the beginning temperature. At a temperature of 130 degrees Celsius, the maximum error of 85.3% is observed. The solutions to equation 3 have a mean square error of 9.51E-10. The intersection for equation 4's outcomes occurs at a temperature of 110 Celsius, when the lowest error of 7.13% is noted. At a temperature of 130 degrees Celsius, the maximum error of 73.3% is observed. The mean square error between dynamic viscosity curves is 6,69E-10, with an average error of 37.8%. The intersection occurs at a temperature of 110 degrees Celsius, which results in the lowest error for equation 1's values of 21.1%. At a temperature of 50 degrees Celsius, the largest error, of 92.8%, is observed. The answers of equation 1 have a mean square error of 6.08E-10, and the average error rate between two dynamic viscosities is 67.4%.

Thermal Conductivity: The results of equation 2 show that the error curve reduces as temperature increases while thermal conductivity increases for refrigerant 1234ze at a pressure of 0.896 MPa. The mean square error for these two thermal conductivity curves is 1.39E-02, with an average error of 3.86E02%. The temperature with the lowest error, 8.8%, is 130 degrees Celsius, while the temperature with the worst error, 5.87E02%, is 50 degrees Celsius.

1234ze at 0.896 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	9.51E-10	6.69E-10	6.08E-10	1.39E-02
Average Error %	32.8 %	37.8 %	67.4 %	3.86E02 %
Mini Error %	7.60 %	7.13 %	21.1 %	8.8 %
Max Error %	85.3 %	73.3 %	92.8 %	5.87E02 %

6.14.5 Dynamic Viscosity and Thermal Conductivity of 1234ze at 2.93 MPa

Dynamic Viscosity: The graphs of equations 3 and 4 provide findings for the dynamic viscosity of refrigerant 1234ze at a pressure of 2.93 MPa that are comparable. The lowest error and maximum error in these two equations are both found at the same temperature. The temperature of 130 degrees Celsius yields the lowest error, which is 33.8 percent for equation 3 and 42% for equation 4. While the largest error is found at a temperature of 120 degrees Celsius, it is 66.9% for equation 3 results and 71.7% for equation 4 results. This shows that the error curve for equations 3 and 4 results rises up to a temperature of 120 degrees Celsius before falling. The average error between dynamic viscosity curves for equation 3 results is 55.8%, and the mean square error is 8.08E-10. The average error percentage for equation 3 results is 47.6%, and the mean square error is 5.88E-10. The error curve of the equation is entirely the contrary; it decreases up to a temperature of 110 degrees Celsius before rising as the temperature rises. As a consequence, the temperature at 110 degrees Celsius has the lowest error (21.1%) while the temperature at 130 degrees Celsius has the biggest error (65.3%). The solutions of equation 1 have an average error of 43% between two dynamic viscosity curves, and a mean square error of 1.16E-09.

Thermal Conductivity: The error curve for the results of equation 2 for the refrigerant 1234ze's thermal conductivity at a pressure of 02.93 MPa falls as temperature rises while thermal conductivity rises. The average inaccuracy is 1.85E02%, while the mean square error between these two thermal conductivity curves is 1.76E-02. The lowest error is 8.8% at the highest temperature of 130 degrees Celsius, while the maximum error is 4.27E02% at the lowest temperature of 100 degrees Celsius.

1234ze at 2.93 MPa	Dynamic Viscosity			Thermal Conductivity
Equations	3	4	1	2
MSE	5.88E-10	8.08E-10	1.16E-09	1.76E-02
Average Error %	4.76E+01	5.58E+01	4.30E+01	1.85E+02
Mini Error %	3.38E+01	4.20E+01	2.11E+01	8.80E+00
Max Error %	6.69E+01	7.17E+01	6.53E+01	4.27E+02

6.14.6 Dynamic Viscosity and Thermal Conductivity of 1234ze for the entire pressure range

Dynamic Viscosity: The results of refrigerant 1234ze for dynamic viscosity for the complete pressure range of 0.096 MPa to 2.93 MPa show that equation 1 has the lowest mean square of 1.92E-09 and equation 3 has the lowest average error percentage of 57.1%. Equation 3 has the greatest average error percentage of 71.3% and equation 1 the highest mean square error of 2.15E-09, respectively. On the other hand, equation 4 has a mean square error of 2.11E-09 and an average error percentage of 58.3%.

Thermal Conductivity: With a mean square error of 3.61E-02 and an average error percentage of 6.06E02% across the whole pressure range of 0.096 MPa to 2.93 MPa, the solutions to equation 2 provide the thermal conductivity of refrigerant 1234ze. The error rates vary from 1.56 to 1.27E03 percent.

6.14.7 Conclusion

According to the statistical study, the average error for all equations for the final refrigerant 1234ze is fairly significant, with equation 3 having the lowest error at 57.1%. Regardless of pressure settings, every equation demonstrated a trend for the values to move closer to the reference values as the temperature rose. Even while all equations may be used to calculate the dynamic viscosity independent of pressure, the temperature range is obviously limited since the average error is the lowest between 100 and 130 degrees Celsius. Equation 2 for thermal conductivity displays a curve that is comparable to the reference curve in terms of calculation values, with the difference being the difference in the values' errors. Over the whole pressure range of 0.096 MPa to 2.93 MPa, the average error is rather substantial. When examining each graph separately, it can be seen that the error curve shrinks as the temperature rises; as a result, this equation can only be used to determine thermal conductivity at temperatures over 120 degrees Celsius. All the equations have substantial error percentages for both dynamic viscosity and thermal conductivity, as can be shown by looking at end results and overall results from all pressure values. As a consequence, it is determined that none of these equations apply to refrigerant 1234ze, and new equations for determining dynamic viscosity and thermal conductivity are required. These new equations may be created by making improvements to the ones that were employed here.

7. Hypotheses and Conclusion

Following a detailed statistical examination of the mentioned refrigerants, several very intriguing findings were discovered. While some equations had relatively significant error rates for particular pressure levels, several explanations were identical to the reference values with the least degree of error. The statistical analysis for thermal conductivity was carried out using equation 2, whereas the dynamic viscosity study was carried out using equations 1, 3, and 4.

Equations 3 and 4 were regarded as the main equations to compute the dynamic viscosity for the majority of the refrigerants. Equation 1 was producing results that were quite close to the values used as a benchmark for the refrigerants R152a and R717. This leads to the conclusion that, of the 14 refrigerants chosen, equation 1 is utilized to provide results that are similar to the reference results for just two of them, with the remainder being determined by equations 3 or 4. The average error produced by these equations for all pressure values is also in the vicinity of 10% to 20%, more or less. This shows that even while these equations provide answers that are quite near to the reference values, there is still room for improvement to get close values with a lower error percentage. As a consequence, equations 3 and 4 can be considered and developed further, whereas equation 1 required to be either rejected or adjusted due to the significant error percentage shown by its results.

With the exception of R290 and 1234ze refrigerants, for which this equation yields a rather large error percentage, practically all refrigerants, equation 2 provides answers for thermal conductivity that are pretty similar. It is necessary to create a new equation for these two refrigerants. Finding an equation that was more based on thermodynamics or a heat transfer mechanism than a chemical one was the main issue throughout the examination of the literature and search for thermal conductivity equations. For statistical analysis, just one equation was employed because of this. Therefore, although equation 2 is undoubtedly useful for determining thermal conductivity for practically all refrigerants, it must be improved upon in order to determine the correct value.

This analysis can be summed up by saying that equations 3 and 4 are typically appropriate for calculating dynamic viscosity because they have fewer deviations from the reference values given and provide values that are nearly identical to reference values across all pressure ranges, as opposed to equation 1, which provides constant values across pressure ranges with high mean values and deviations compared to reference values, increasing the likelihood of error. Because it usually always yields results that are close to those of the reference, with lower variations and comparable mean values across all refrigerants, equation 2 is the one that may be used to compute thermal conductivity. Future developments for these equations should allow for the exact measurement of thermal conductivity and dynamic viscosity for super-heated refrigerants.

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