A SIMPLIFICATION OF READING THERMODYNAMIC PROPERTIES USING MICROSOFT EXCEL

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ID Number : MA08065

Date :

Dedicated to my parents

Adam Bin Abdullah

Noor HasidaBinti Din

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ABSTRACT

Thermodynamic properties calculator is an engineering tool built by MS Excel add-in which is crucial used due to calculate thermodynamics properties of water, air and superheated vapor. The main purpose of this project is to develop an excel file that can simply obtain thermodynamic properties without manually reading from thermodynamic properties table. The project scopes werefluids that will be used as a reference were water, superheated vapor and air, thermodynamic properties such as enthalpy, entropy, specific heat, thermal conductivity, specific volume, relative pressure ratio, specific volume ratio and internal energy were the main properties that need to be referred. All the properties were based on thermodynamic properties table and result validation. Formulas that suitable to the formula of interface created using excel file were identified and studied.All unknown for the common formula that used to do interpolation manually were listed out and identified its function. Then, formula for each unknown created using excel formula and lastly all the formulas created for each unknown were combined according to the common formula used for manual interpolation. The new formula created using excel formulas was tested and evaluated. The value of properties from the interface created was compared to the value of properties from manual interpolation using calculator in order to check the validation of the data. In the nutshell, interface of a simplest way to read thermodynamics properties table using excel software was successfully created and was checked by data validation. In order to improve this project, the function of changing the units of thermodynamics properties to other standard, for example into American Standard, should be developed and the software should also be able to run on other operating systems such as MAC for Apple and LINUX for Linus Torvalds so that people using other operating systems will have the benefits of using the software.

ABSTRAK

Termodinamik Kalkulator adalah salah satu alat kejuruteraan penting yang dibina oleh MS Excel add-in yang digunakan untuk mengira sifat termodinamik air, udara dan panas lampau wap. Tujuan utama projek ini adalah untuk menyediakan satu sistem menggunakan fail excel yang boleh mendapatkan sifat-sifat termodinamik dengan cara yang mudah tanpa membaca daripada jadual termodinamik secara manual. Skop projek ini adalah cecair yang akan digunakan sebagai rujukan adalah air, udara, wap panas lampau dan sifat-sifat termodinamik seperti entalpi, entropi, haba tentu, kekonduksian terma, isipadu tentu, nisbah tekanan relatif, nisbah isipadu tentu dan tenaga dalaman yang perlu dirujuk. Semua sifat termodinamik yang dirujuk adalah berdasarkan jadual termodinamik dan pengesahan data dikaji. Semua formula yang sesuai untuk formula sistem yang dicipta menggunakan fail excel dikenal pasti dan dikaji. Semua nilai yang tidak diketahui untuk formula yang biasa digunakan secara manual disenaraikan dan dinyatakan fungsinya. Formula untuk setiap nilai tidak diketahui dicipta menggunakan fail excel dan akhir sekali semua formula itu digabungkan dengan berpandukan formula umum yang digunakan untuk interpolasi manual. Formula baru yang dicipta menggunakan formula excel diuji dan dinilai. Nilai daripada sistem yang dicipta di bandingkan dengan nilai daripada interpolasi manual menggunakan kalkulator untuk memastikan pengesahan data. Kesimpulannya, sistem mudah untuk membaca jadual termodinamik dicipta dengan jayanya dan disemak dengan pengesahan data. Untuk memajukan lagi sistem ini, Fungsi menukar unit termodinamik sifat kepada standard yang lain, contohnya ke American Standard, perlu dibangunkan dan perisian ini juga boleh berfungsi di dalam sistem operasi lain seperti MAC untuk Apple dan LINUX untuk Linus Torvalds supaya orang yang menggunakan sistem operasi lain akan mempunyai manfaat menggunakan perisian ini.

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LIST OF SYMBOLS

Cp	Specific Heat
f	Saturated Liquid
fg	Evaporator
g	Saturated Vapor
h	Enthalpy
k	Thermal Conductivity
$Psat$	Saturation Pressure
T	Temperature
s	Entropy

LIST OF ABBREVIATIONS

ASTM	American society for testing and materials
FYP	Final Year Project
HTML	Hyper Text Markup Language
MAC	Macintosh
IAPS	International Association for the Properties of Steam
IAPWS	International Association for the Properties of Water and Steam
ICPS	International Conference on the Properties of Steam
NBS	National Bureau of Standards
NIST	National Institute of Standards and Technology
Soft	Software
UMP	University Malaysia Pahang
U.S.A	United States of America
VBA	Visual Basic for Application
VISICALC	Visible Calculator
XML	Extensible Markup Language

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Reading thermodynamic properties from the properties table is very confusing especially when time is insufficient. Sometimes, an addition of time is needed when the value of parameter is not in the table, and it needs interpolation. By using the interpolation tecnique,the calculation are prone to human error. The aim of this project is to give the simplest way and exact values for users in solving their problems which involve thermodynamic properties table by using excel. Computer calculation of thermodynamic properties is an efficient replacement for text property tables, which are still use in thermodynamic instruction. Computerized property calculations are used routinely in engineering application.

In this project, an excel file will be created where the thermodynamic properties can be easily obtained simply by filling in the value of temperature in a certain cells. The thermodynamic properties will appear automatically in the designated cells as a result. Less time will be needed toread the thermodynamic properties table and no interpolation is needed as it done by computer.This project described here as an interface thermodynamic calculation based on data and computational procedures. The program was design to provide easy-to-use thermodynamic properties tables within excel, which is widely available on personal and office computer.

A simple transition from the interface to cell formulas provide a wide range application from simple calculations of a single state to detail of thermodynamic properties table using cell formulas. Formulas in excel such as LOOKUP, MATCH, SEARCH, FIND, INDEX, DROPDOWNLIST and many other will be utillized to obtain the properties in the process. The thermodynamic properties is based on thermodynamic properties table. Samples of calculations will help in validating result from excel file with manual calculation.

1.2 PROBLEM STATEMENT

In this modern era, technology plays a vital role in decision making, communicating, and referring in a short time. Manual calculation can cause human error in side of calculation such as parallax error, key in the wrong value during calculation, and it also will takes long time to get the result.Furthermore, it will cause a difficulty to read the thermodynamics table and to do the interpolation manually when it comes to a rushing situation. Thus, this interpolation of thermodynamic properties table using excel file save a lot of time and hopefully the calculation will result error free.

1.3 PROJECT OBJECTIVE

The main objective of this project is to develop an excel file to simply obtain thermodynamic properties without manually reading from thermodynamic properties table.

1.4 SCOPE OF THE PROJECT

The scopes of this project are limited to:

a) Fluids that will be used as a reference are water, superheated vapor and air.
b) Thermodynamic properties such as enthalpy, entropy, specific heat, thermal conductivity, specific volume, relative pressure ratio, specific volume ratio and internal energy are the main properties that are to be referred.
c) All the properties are based on thermodynamic properties table.
d) Result validation.

CHAPTER 2

LITEATURE REVIEW

2.1 INTRODUCTION

In this chapter it will discuss about the history of Microsoft Excel and also history of Thermodynamic Properties Table such aschronology of Excel and Thermodynamic Properties Table and the author of both of them.

2.2 HISTORY OF EXCEL

2.2.1 Spreadsheet

A simple definition of spreadsheet is a document that stores data in a grid of vertical columns andhorizontal rows. Columns are typically labeled with letters (a, b, c, etc) while rows are labeled using numbers (1, 2, 3, etc.). Individual row/column locations, such as A1 or B2, are referred to as cells. Each cell can each store a unique instance of data. Information can be stored in a more structured way than using plain text by enteringthe data into a single spreadsheet. The row/column structure also allows the data to be analyzed using formulas and calculations.Spreadsheets are in widespread use throughout the world for engineering design.

Spreadsheets are more streamlined than databases and are particularly useful for processing numbers. This is why spreadsheets are commonly used in scientific, financial and engineering applications.Although there has been some interest in the accuracy of business and financial spreadsheets, it seems to have escaped the disciplines that have traditionally been applied to engineering design and to computer programming. (Panko, 1998) For a range of engineering calculations, there are now a number of specialized texts on spreadsheets written for engineers and specialized applications of spreadsheets are being developed and reported.(Morison,2000)

Furthermore, spreadsheet application is one of the computer programs that allow users in creating and manipulating spreadsheets electronically. In the spreadsheet applications, each value sits in each cell. The type of data can be defined in each cell and how different cells depend on one another. Formulasmean the relationships between cells, and the names of the cells are called labels.Once the cells have been defined and the formulas for connecting them together created, the data can be entered. Then, the selected values can be modified to see how all the other values change accordingly. This enables you to study the various what-if scenarios.

In addition, a spreadsheet can be used to store bank account data, including balance and interest information. A column that stored by the account balances of several clients can be easily summed to produce the total value of all the clients' balances. These amounts can then be multiplied by the interest rate from another cell to see the value of the accounts will be in a year. Once the formula has been created, by modifying the value of interest only, the rate cell will also change the projected value of all the accounts. They are alson widely used by others to support decision making, including use by professionals and all levels of management up to, and including, very senior management.(Cragg,1993)

There are many softwares that use spreadsheet such as MATLAB, MICROSOFT ACCESS, MICROSOFT EXCEL and others. All the softwares mention before have their own advantages and disadvantages.

SOFTWARE	DEFINITION	ADVANTAGES	DISADVANTAGES
Matlab	MATLAB is an interative system whosw basic data element is an array that does not require dimensioning.	It is an interpreted language for numerical computation which allows one to perform numerical calculations, and visualize the results without the need for complicated and time consuming programming.	It is an interpreted language and therefore can execute more slowly than compiled languages.
Microsoft Access	Microsoft Access is a database software program that makes manipulating data manageable for users of many skill levels.	Microsoft made it easy for just about anyone to learn how to work with databases by replacing some of the complicated work with easy-to-use templates.	Access is more useful for individual departments or small and medium business sectors and also has difficulty dealing with databases larger than 2GB in size.
Microsoft Excel	Microsoft Excel can best described as a full-featured spreadsheet for Windows from Microsoft which is a component of its Office product group for business applications.	Microsoft Excel is easy to understand, create column names, enter your data, create formulas, and you're on your way.	When you develop your application into one file it can be huge and will make your program execution very slow.

Table 2.1: Spreadsheet softwares

Source: CCNY Software Training Center.

2.2.2 Chronology of Excel

Chronology of Excel begins with Visible Calculator followed by Lotus 1-2-3 and lastly it comes to Microsoft Excel itself.

2.2.3 Visible Calculator

Figure 2.1: Visible Calculator

Source: Creative Computing, VisiCalc '79

In 1961, the development of computerized spreadsheets in business accounting applicationswas pioneered by Professor Richard Mattessich. Bricklinhad programmed the first working prototype of his conceptininteger basicin 1978with his brilliant idea. The purpose of this program was to help users input and manipulate a matrix of five columns and20 rows. Bricklin calls Frankstonthe "co-creator" of the electronic spreadsheet to improve and expand the program because the first version was not very powerful. After a while, Frankston had improved the program by created the production code withfaster speed, better arithmetic, and scrolling. (Dan Bricklin, 1984)

Daniel Bricklin, a master student in business administration at Harvard Business School came up with the idea for an interactive visible calculatorin 1978. Bob Frankston joined him to help in writing the programme for his new electronic spreadsheet. The idea behind VisiCalc was developed by Dan Bricklin, and the actual programming was performed by his friend, Bob Frankston. Bricklin and Bob Frankston then invented and created the software program VisiCalc together and at last both of them started their own company, Software Arts Inc., to develop their product. The name"VisiCalc" is a compressed form from "visible calculator" and it was the first "killer" application for personal computers at that time. (Dan Bricklin, 1984)

VisiCalc introduced a new level in application softwarecompared to the early microprocessor computers had been quickly supportedby BASIC and a few games. It was considered a fourth generation software program. Companies invested time and money in doing financial projections with manually calculated spreadsheets faced a problem such as recalculating every single cell in the sheet is needed if a single number in a cell is change. By using VisiCalc, you could change any cell, and the entire sheet would be automatically recalculated. (Dan Bricklin, 1984)

2.2.4 Lotus 1-2-3

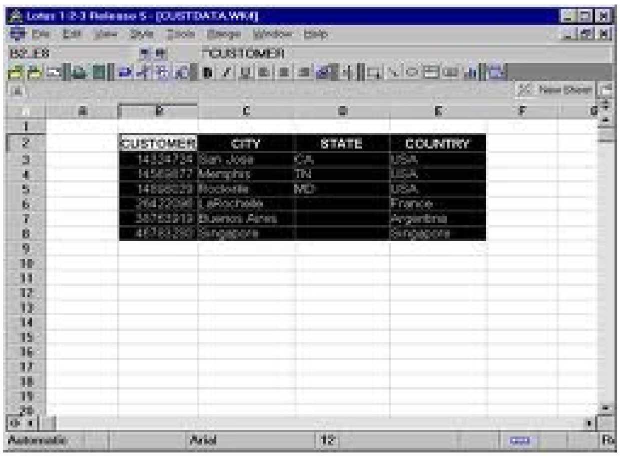

Figure 2.2: Lotus 1-2-3

Source: Lotus 1-2-3 version 1.0

Lotus 1-2-3 was developed by Mitch Kapoor and it is a new industryspreadsheet standard. Lotus' first product was presentation software for the Apple II known as Lotus Executive Briefing System.The name of Lotus 1-2-3 referred to the three ways the product could be used, as a spreadsheet, graphics package, and database manager. This Lotus 1-2-3 software made it easier to use spreadsheets and it added integrated charting, plotting anddatabase capabilities. It was established spreadsheet software as a major datapresentation package as well as a complex calculation tool. It was also the firstspreadsheet vendor to introduce cell ranges, naming cells, and spreadsheet macros. (Henderson,1983)

Lotus 1-2-3 will eventually be converted to other microcomputers that use the Intel 8086 or 8088 microprocessorand soon will be available for the IBM Personal Computer (PC). The initial version of 1-2-3 have 128K bytes of memory,an IBM PC with two disk drives, and either a monochrome or a color display. If the computer has both monochrome and color display, it can give the view of spreadsheet on the monochrome monitor and graphs on the color monitor at the same time. If there only the monochrome video display, it cannot give the view the graphs but can only print them out. It is different if there only the color video display, it provide two alternate ways between viewing the spreadsheet and the graph. (Henderson, 1983)

2.2.5 Microsoft Excel

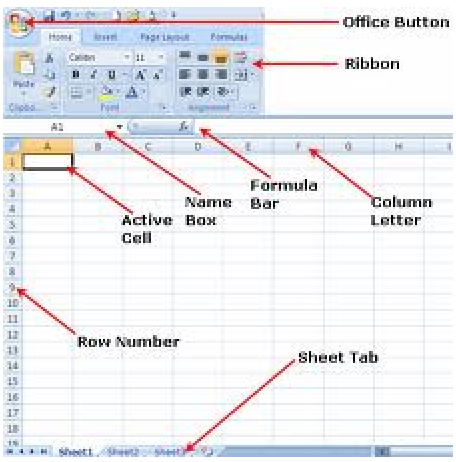

Figure 2.3: Microsoft Excel

Source: Microsoft Excel 97 developer's handbook

The next and latest the milestone was Microsoft Excel spreadsheet. In 1984-1985, Excel was originally written for the 512K Apple Macintosh. Excel was one of the first spreadsheets that use a graphical interface with pull down menus and a click capability using a mouse pointing device. The Excel spreadsheet with a graphical user interface was easier for most people to use compared to the command line interface of PC-DOS spreadsheet products. Many people bought Apple Macintoshes so that they could try and use Excel spreadsheet program that created by Bill Gates. In the past few decades, Excel has grown rapidly and offers so many different features and applications for users. From their earliest, simple spreadsheets to the wonderful program nowadays, there have been many changes improvement in the overall format of the program. But being honestly and truthly, the essence of the software is still the same. In fact, Excel of today still uses the same program, called VisiCalc, which displays the cells of the sheet, organized into neat columns and rows just like in the very first version. This program almost the same like before that also allows users to input information into the cells, such as numbers, and reference them to other cells in the spreadsheet. (Power,2010)

Microsoft Excel was actually the first spreadsheet program that allowed users to change up the overall look of the spreadsheet, such as the font, width, length and cell appearance. It was also the first program to give users an intelligent cell computation, which meant that users could total a number of cells together in one specific cell with a simple formula. This made the program different from the previous version and invaluable to users, especially in the financial industry.Microsoft Excel was developed and manufactured by Microsoft Corporation that allows the users in organizing, formatting, and calculating data with formulas using a spreadsheet system divided by columns and rows. It usually comes with the bundle of Microsoft Office and is compatible with other applications that offered in the suite of products like Power Point. In 1987, Microsoft documents show the launch of Excel 2.0 for MS-DOS version 3.0. When Microsoft was launched the Windows operating system in 1987, Excel was one of the first application products that released for it. Overall, Microsoft has done transformation over the years to become one of the leading spreadsheet software programs in the world and have millions of users rely on this in both their business and personal lives to keep organized. (Power, 2010)

Version	Released	Comments
1	1985	In 1984-1985, Excel was originally written for the 512K Apple Macintosh.
2	1987	The first Windows version included a run-time version of Windows.
3	1990	Improvement of new features like toolbars, drawing capabilities, outlining, add-in support, 3D charts, and many more.
4	1992	Improvementwhich included lots of usability features.
5	1993	A major upgradewhich included multi-sheet workbooks and it can support for Visual Basic For Application (VBA) program.
7	1995	Feature-wise which is very similar to Excel Version 5 and it is the first major 32-bit version of Excel.
8	1997	A major improvement with a new interface for VBA developers, UserForms, data validation, and many more.
9	1999	It can use HTML as a native file format, "self-repair" capability, enhanced clipboard, pivot charts, modeless user forms.
10	2001	It has a many new features in this version. The most significant feature is it has the ability to recover your work when Excel get crashes.
11	2003	This version consist of many new features. The most significant feature is it improved support for XML.
12	2007	A lot of improvements and upgrades have been done. It allows users enjoy fewer mouse clicks and better efficiency.
14	2010	Builds on Excel 2007 and is due to arrive in the first half of 2010. New features include sparkline graphics, pivot table slicers, an updated Solver, and a 64-bit version.

Table 2.2: Versions of Microsoft Excel

Source: J-Walk & Associates, Inc.

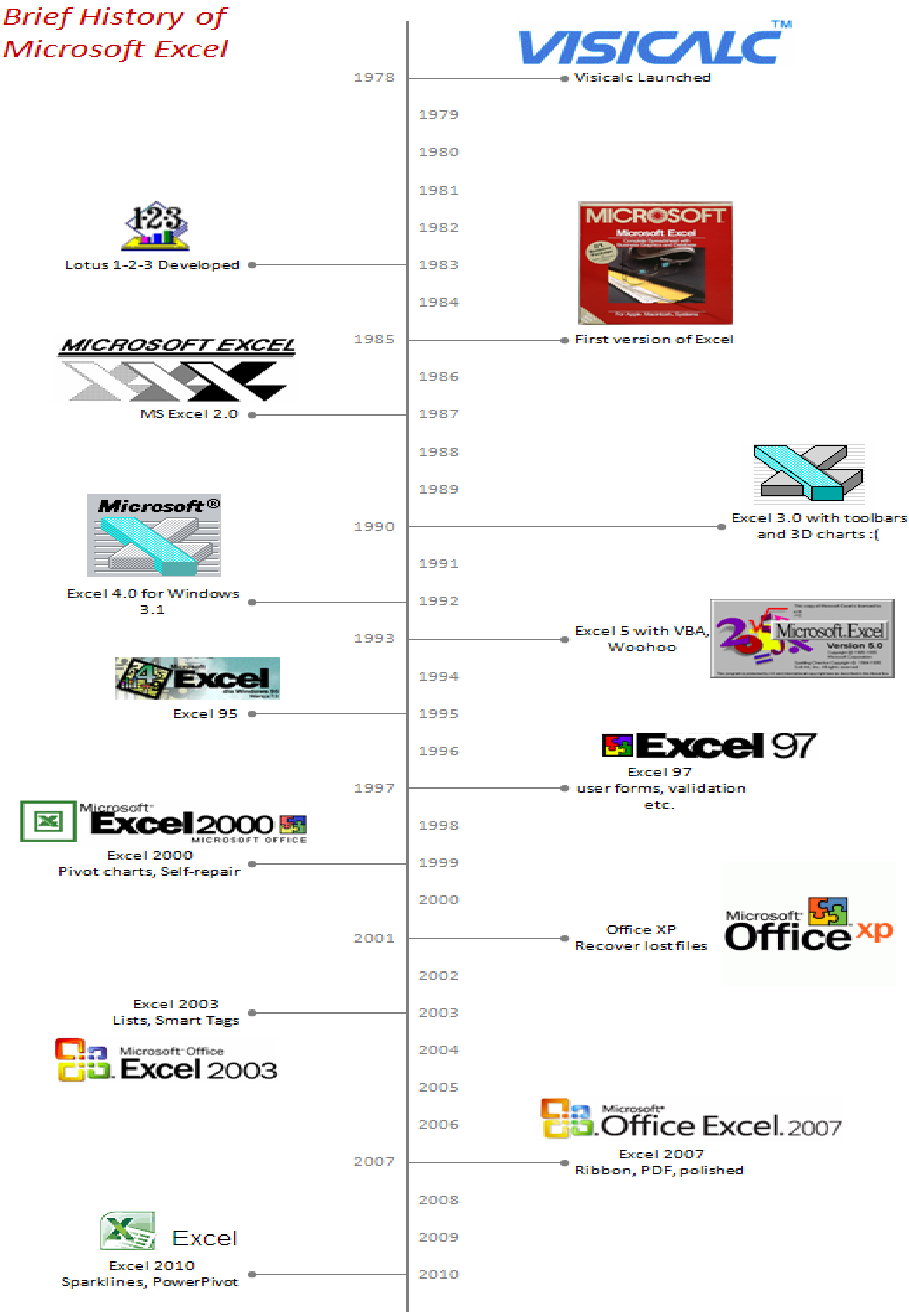

Figure 2.4: Chronology of Excel

Source: J-Walk & Associates, Inc.

2.3 HISTORY OF THERMODYNAMIC PROPERTIES TABLE

In the early part of this century, data were presented in the form of thermodynamic charts and tables. Since steam emerged as the working fluid in mechanical and electric power generation, the data taking, collecting, graphing and formulating of properties of water and steam has been an ongoing effort. Traditionally, the needs of the power engineers for property values of water and steam were called as Skeleton Tables. Thesewere tables of pressure, enthalpy and volume for the saturated vapor and liquid and ofspecific enthalpy and specific volume on a coarse grid of temperature-pressure points in theone-phase regions, sufficiently closely spaced that only linear interpolations are adequate (Sato, 1991)

An agreement was reached on the first International Skeleton Steam Tables in 1934. A substantial effort to expand and improve the experimental data base for steam was already under way, most notably by Osborne and coworkers at NBS, the National Bureau of Standards, presently NIST, the National Institute of Standards and Technology, in the U.S.A.A collection of data and tables for thermodynamic properties of water and steam was part of a comprehensive study by Dorsey in 1940. The acquisition, evaluation and correlation of steam properties gained new impetus in several countries after the Second World War. The International Skeleton Tables of the Thermodynamic Properties of Water Substance, 1963, were adopted at the Sixth International Conference on the Properties of Steam (ICPS) in New York, 1963. (Sato, 1991)

International Association for the Properties of Steam (IAPS) was established as a standing organization for the international cooperation on the properties of steam shortly after the 1968 Conference. The task of collecting and updating the experimental data on thermodynamic properties of ordinary water and steam is the beginning of IAPS. The purpose of this task was because there were many new high-quality experimental data had been obtained in much wider ranges of temperature and pressure since 1963. There have been many efforts done to extend and improve the formulation in order to obtain more precise formulations in more limited regions and to produce the more accurate Skeleton Tables that are currently accepted by IAPWS since 1984. (Sato, 1991)

International Association for the Properties of Water and Steam (IAPWS) adopted a new formulation called ‘‘The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use’’ in 1995 (IAPWS-95 formulation or IAPWS-95) for short. This work provides information on the selected experimental data of the thermodynamic properties of water used to develop the new formulation, but information is also given on newer data.(Wagner, 2002)Thisformulation is the current international standard for thermodynamicproperties of water, and is implemented in NIST Standard Reference Database 10. These properties are tabulated along the vapor-liquid saturation curve as a function of temperature and pressure. (Harvey, 1995)

The formulation provided in this release is recommended for industrial use, and is called “IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam”,(IAPWS-IF97). The IAPWS-IF97 replaces the previous industrial formulation "The 1967 IFC-Formulation for Industrial Use" (IFC-67). (Dr. R. Fernandez-Prini,1997)It is a set of equations that designed to give accuracy on the thermodynamic properties of liquid and gas with short computing times. The equations have been fitted to properties calculated from IAPWS-95 and it covers a smaller range of states than IAPWS-95 and this smaller range is divided into sub-regions in order to achieve fast computing times.For particular region, some of these regions have backward equations with different independent variables from the basic equation. (Watanabe, 2004)

2.4 EXISTING SOFTWARE FOR THERMODYNAMIC PROPERTIES TABLE

There is lots of software for thermodynamic properties table in the market. All these software have its own criteria. Software that will be shared are ChemicaLogicSteamTab Companion and Steam97.

2.4.1 ChemicaLogicSteamTab Companion

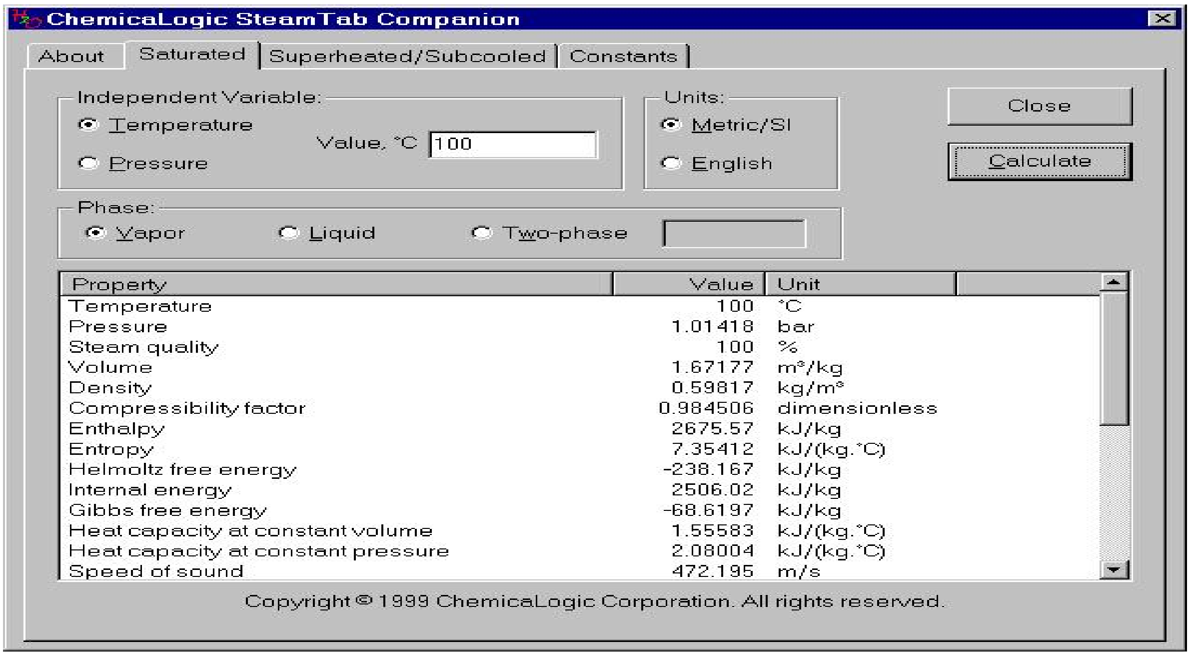

Figure 2.5: ChemicaLogicSteamTab Companion

Source: ChemicaLogic Corporation

ChemicaLogicSteamTab Companion is developed by ChemicaLogic Corporation. The source of this software is based on International standard IAPWS-95 formulation called ‘‘The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use’’. Properties that are used in this sofware are water and steam.

2.4.2 Steam 97

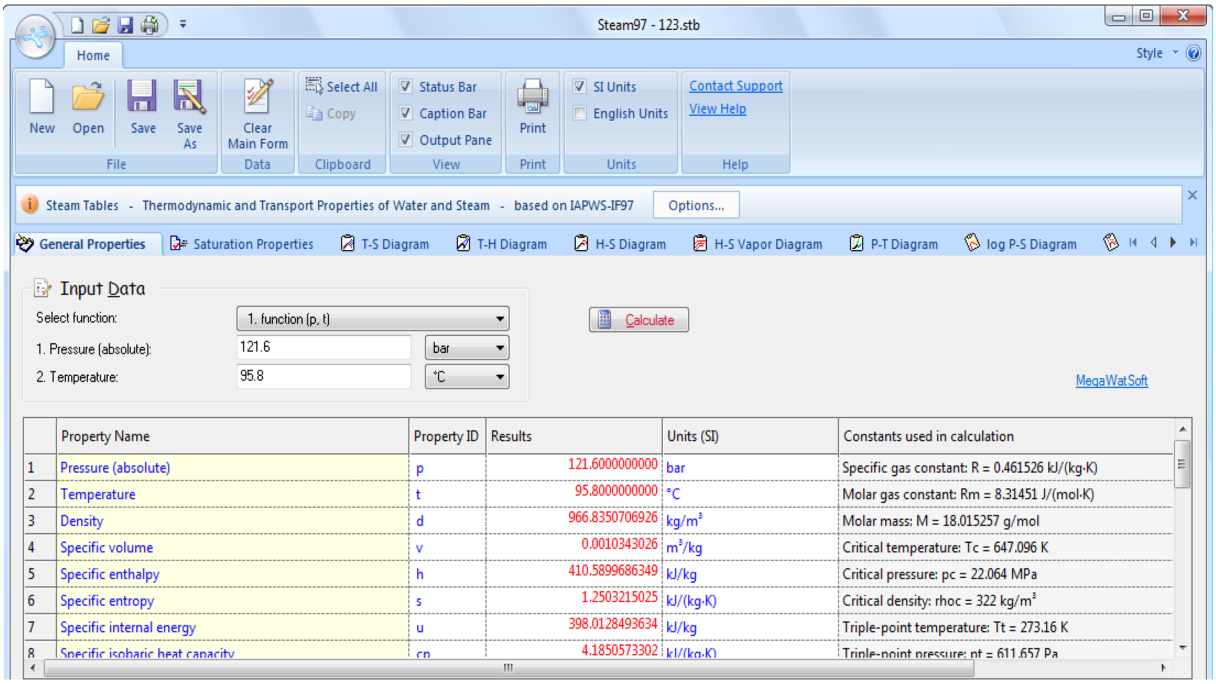

Figure 2.6: Steam97

Source: Mega WatSoft Inc.

Steam 97 is developed by Mega WatSoft Inc. the source of this software is based on Industrial Formulation for Steam tables, called *"IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97)*. Property that is used is only steam.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter introduces the method of creating interpolation formula of Thermodynamics Properties Table by using Excel File. It shows step by step process that will be done during this project. This project is being done to find a simplification of reading Thermodynamics Properties Table using Microsoft Excel. During the experiment, we will do two different Excel Files that the first one is we will do the Excel File of Thermodynamics Properties Table that using the exact match type formula which mean no interpolation needed just to get the value that exactly in the table. The second iswe will do the Excel File of Thermodynamics Properties Table that using the greater or less than match type formula in order to do the interpolation process to get the value that is not in the table. The flow chart in Figure 3.1 shows the overall flow of project in step by step process.

3.2 FLOW CHART

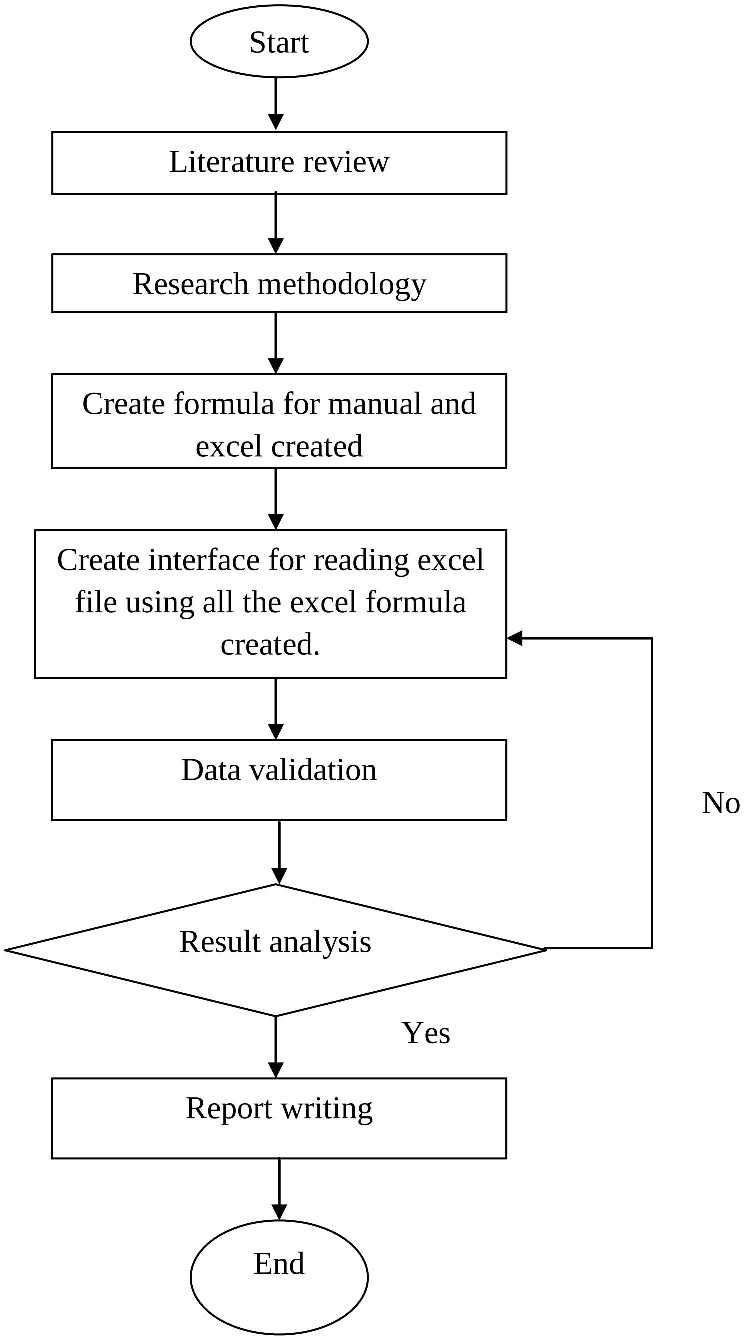

Figure 3.1: Flow Chart

This flow chart shows all the processes done in completing my final year project. I used this flow chat as a guide and reference to make sure my work completed in orderly.

3.3 Research methodology

3.3.1 Index Formula

Index formula is a formula in Excel that allows an extracting of the information in a cell by providing a larger location and pair of co-ordinates which mean row and column. It will return the value that is in the cell at the intersection of the row and column that have been specified. The full formula is “INDEX (array,row_num,column_num)” and the simplest translation of the formula is INDEX (range of the table referred, the row number of the table that the data is in, the column number of the table that the data is in). Figure 3.2 shows the example of index formula used in the excel software.

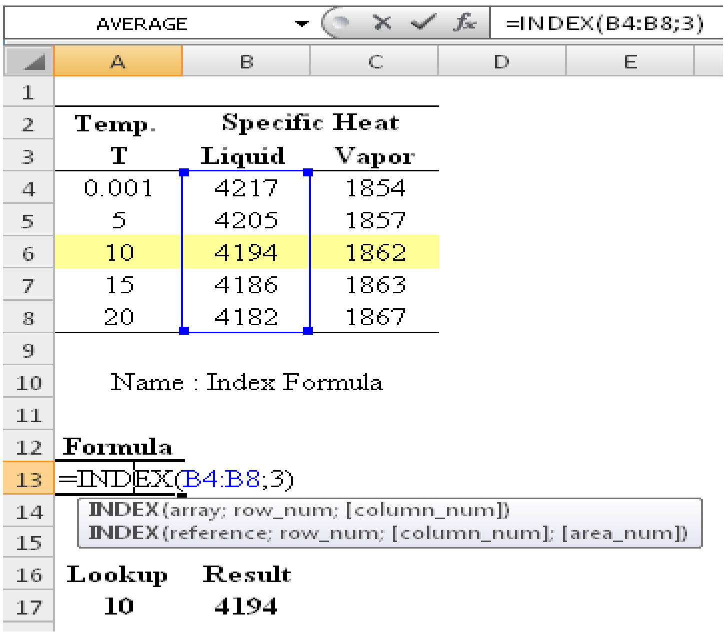

Figure 3.2: Index Example

3.3.2 Match Formula

In Excel, Match formula searches for a value in an array and returns the relative position of that item. The formula for Match is MATCH (lookup_value, lookup_array, match_type). Value is the value which we are trying to find in the array. It can be any number or a string. Array means a range of cells that contains the value that you are trying to match against. Match_type is optional parameter that specifies the type of match function will perform and operate. Figure 3.3 shows the match type and figure 3.4 shows the example of match formula used in the excel software.

Match Type	Explaination
1 Default)	The MATCH function will finds the largest value that is less than or equal to lookup_value. The array must be sorted in ascending order.
	If the match_type parameter is omitted, the Match function assumes as Match_type of 1.
0	The Match function will find the first value that is exactly equal to lookup_value. The array can be in any order.
-1	The Match function will find the smallest value that is greater than or equal to lookup_value. The array must be placed in descending order.

Figure 3.3: Match Types

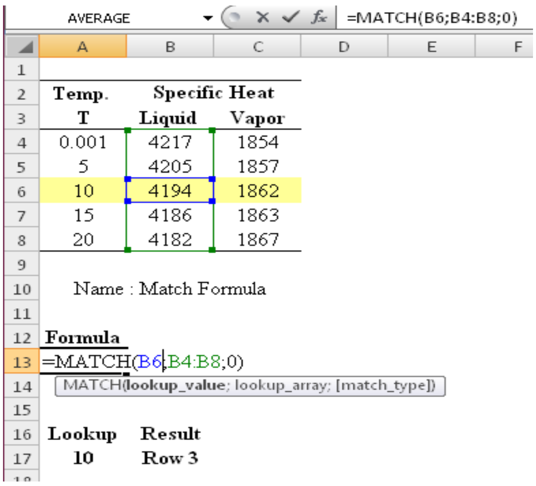

Figure 3.4: Match Example

3.3.3 Indirect

In Excel, Indirect function returns the reference specified by a text string. References are immediately evaluated to display their contents. INDIRECT is used when you want to change the reference to a cell within a formula without changing the formula itself.The formula for Indirect is INDIRECT(ref_text,a1). Ref_text is a reference to a cell that contains an A1-style reference, an R1C1-style reference, a name defined as a reference, or a reference to a cell as a text string. If this argument is TRUE, or omitted, the ref_text is A1 style. If the argument is FALSE, the ref_text is R1C1 style. If ref_text is not a valid cell reference, INDIRECT returns the #REF! error value.Figure 3.5 shows the example of indirect formula used in the excel software.

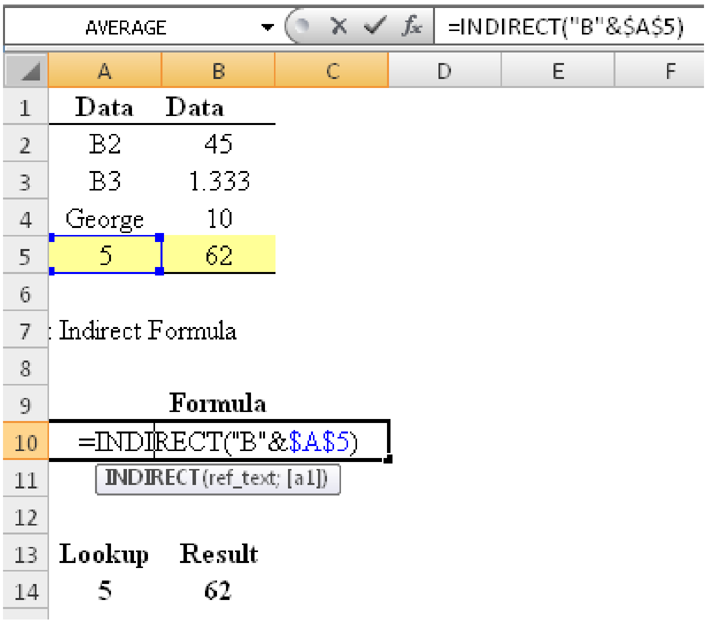

Figure 3.5: Indirect Example

3.3.4 Dropdown List

A drop down list gives you a set number of entries to choose from when entering data. To make data entry easier, or to limit entries to certain items that you define, you can create a drop-down list of valid entries that is compiled from cells elsewhere in the workbook. When you create a drop-down list for a cell, it displays an arrow in that cell. To enter information in that cell, click the arrow, and then click the entry that you want. Not only can this speed up data entry, but it can also prevent people from misspelling entries or even from entering the wrong data altogether.Figure 3.6 shows the example of dropdown list formula used in the excel software.

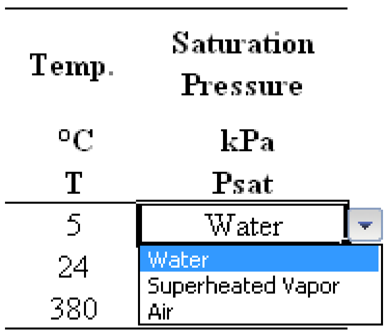

Figure 3.6: Drop down list Example

3.4 Interfaces

There are three different interfaces to be created which are water, air and superheated vapor. The method of creating interfaces of water and air are same but different in table referred because table of water properties is referred for water interface and for air interface, table of air properties will be referred. The method in creating interface of superheated vapor is same but table of superheated vapor properties will be referred and it needs twice interpolation.

3.5 Method of Finding Properties Values

There are two methods of finding properties values from the Thermodynamic Properties Table. First, directly refer to the table and we can get the result because the value of temperature given is listed in the table. Second, interpolation is needed because the value of temperature given is not listed in the table.

3.5.1 Value of Temperature Given Listed In the Table

Given Temperature: 10°C

Formula created using Excel formula:

=INDEX(INDIRECT(B5&"!A4:L79");MATCH(A5;INDIRECT(B5&"!A4:A79");0);3)

Table 3.1 shows interface of the exact value for water table at 10 °C of temperature.

Table 3.1: Interface of Exact Value At 10°C For Water Table

Temp.	Saturation Pressure	Enthalpy			Enthalpy			Specific Heat		Thermal Conductivity	
°C	kPa	kJ/kg			kJ/kg			Cp, J/kg.K		k, W/m.K	
T	Psat	Sat. liquid,h_f	Evaporator ,h_{fg}	Sat. vapor,h_g	Sat. liquid,S_f	Evaporator ,S_{fg}	Sat. vapor,S_g	Liquid	Vapor	Liquid	Vapor
10	DaTa	42.022	2477.2	2519.2	0.1511	8.7488	8.8999	4194	1862	0.58	0.018

After the formula has been created using Excel formula, Formula Evaluation is needed in order to know whether the formula we have cerated is right or wrong. It is also important as a guide for us if we have created wrong formula. By this formula evaluation, we can know where and what value that we have inserted it wrongly into the formula.

Figure 3.7 shows formula evaluation for the value listed in table of water at 10 °C.

Formula Evaluation	Explanation
Evaluation: = INDEX(INDIRECT(C5&"!A4:L79");MATCH(B5;INDIRECT(C5&"!A... = *DaTa*	C5 is a cell that referred to Data of water which located in the range of A4:L79 cells in water worksheet.
Evaluation: = INDEX(DaTa!$A$4:$L$79;MATCH(B5;INDIRECT(C5&"!A4:A79"... = *10*	B5 is a cell that referred to the value been selected or given which in this example T=10°C.
Evaluation: = INDEX(DaTa!$A$4:$L$79;MATCH(10;INDIRECT("DaTa!A4:A79");0);3)	INDIRECT function is referring to water worksheet in the range of A4:A79 cells which 10°C is located.
Evaluation: = INDEX(DaTa!$A$4:$L$79;MATCH(10;DaTa!$A$4:$A$79;0);3)	MATCH function is referring to the exact value that is equal to the value selected because we have set the MATCH type as 0.
Evaluation: = INDEX(DaTa!$A$4:$L$79;3;3)	INDEX Function refers to row number 3 and column number 3 which the value that we want to find is located.
Evaluation: = *42.022*	Lastly, after completing the formula correctly, the answer will appear as the value of enthalpy at saturated liquid for T=10°C is equal to 42.022.

Figure 3.7: Formula Evaluation for the Value Listed In Table

3.5.2 Value of Temperature Given Not Listed In Table

In completing interpolation method using excel, we need to do interpolation method manually first. After that, we need to translate the formula created manually into excel file using excel formula. For example, given temperature are24°C and we want to find value of enthalpy at saturated liquid for water.

3.5.3 Manual Interpolation Method

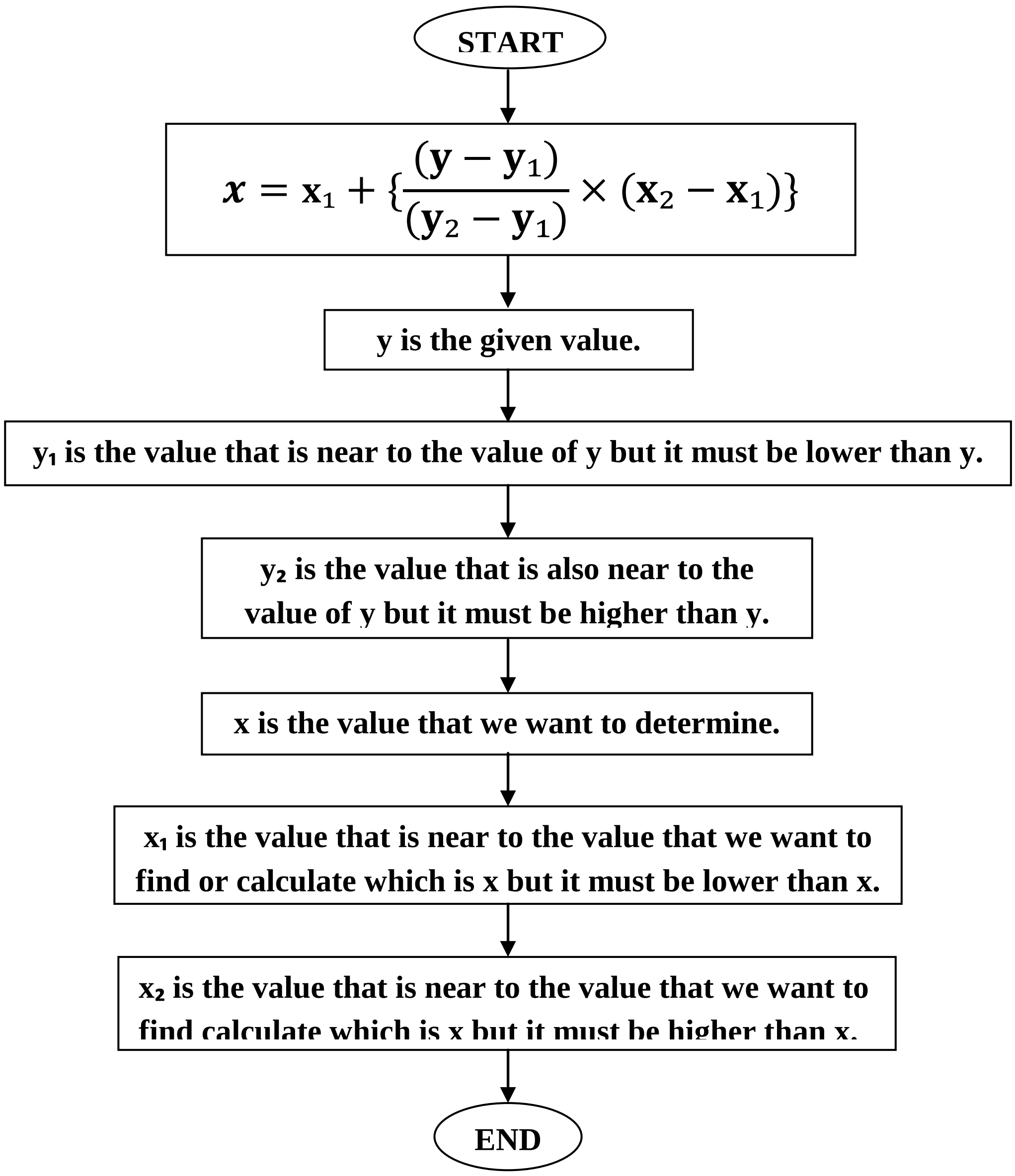

Figure 3.8: Process flow chart of creating the interpolation formula

3.5.4 Interpolation Using Excel Formula Method

Given Temperature: 24°C

Formula created using Excel formula:

IFERROR(INDEX(INDIRECT(B8&"!A4:L79");MATCH(A8;INDIRECT(B8&"!A4:A79");1);4)+(A8-INDEX(INDIRECT(B8&"!A4:L79");MATCH(A8;INDIRECT(B8&"!A4:A79");1);1))/(INDEX(INDIRECT(B8&"!A4:L79");1+MATCH(A8;INDIRECT(B8&"!A4:A79");1);1)-INDEX(INDIRECT(B8&"!A4:L79");MATCH(A8;INDIRECT(B8&"!A4:A79");1);1))*(INDEX(INDIRECT(B8&"!A4:L79");1+MATCH(A8;INDIRECT(B8&"!A4:A79");1);4)-INDEX(INDIRECT(B8&"!A4:L79");MATCH(A8;INDIRECT(B8&"!A4:A79");1);4));"out of range")

Table 3.2 shows interface of the interpolation value for water table at 24 °C of temperature.

Table 3.2: Interface of Interpolation Value At 24°C For Water Table

Temp.	Saturation Pressure	Enthalpy			Enthalpy			Specific Heat		Thermal Conductivity	
°C	kPa	kJ/kg			kJ/kg			Cp, J/kg.K		k, W/m.K	
T	Psat	Sat. liquid,hf	Evaporator ,hfg	Sat. vapor,hg	Sat. liquid,Sf	Evaporator ,Sfg	Sat. vapor,Sg	Liquid	Vapor	Liquid	Vapor
24	DaTa	100.647	2444.06	2544.68	0.35306	8.22552	8.57858	4180.4	1869.4	0.6052	0.01852

After the formula has been created using Excel formula, Formula Evaluation is needed in order to know whether the formula we have cerated is right or wrong. It is also important as a guide for us if we have created wrong formula. By this formula evaluation, we can know where and what value that we have inserted it wrongly into the formula.

Figure 3.9 shows formula evaluation for the value not listed in table of water at 24°C.

Formula EvaluatioFFn	Explanation
Evaluation: = IFERROR(INDEX(INDIRECT(C5&"!A4:L79");MATCH(B5;INDIRE… = DaTa	C5 is a cell that referred to Data of water which located in the range of A4:L79 cells in water worksheet.
Evaluation: = IFERROR(INDEX(DaTa!$A$4:$L$79;MATCH(B5;INDIRECT(C5&… = 24	B5 is a cell that referred to the value been selected or given which name as y For this example T=24°C.
Evaluation: = IFERROR(83.915+(B5-INDEX(INDIRECT(C5&"!A4:L79");MATC…	83.915 referred to the value of x1 which is the value of enthalpy at saturated liquid.
Evaluation: = IFERROR(83.915+(24-20)/(INDEX(INDIRECT(C5&"!A4:L79"	20 referred to the value of y1 which is the value of temperature.
Evaluation: = IFERROR(83.915+4/(25-INDEX(INDIRECT(C5&"!A4:L79");	25 referred to the value of y2 which is the value of temperature.
Evaluation: = IFERROR(83.915+0.8*(104.83-INDEX(INDIRECT(C5&"!A4:L79"	104.83 referred to the value of x2 which is the value of enthalpy at saturated liquid.
Evaluation: = 100.647	Lastly, after combining all the known values and completing the formula, the answer of the interpolation method will appear as the value of enthalpy at saturated liquid for T=24°C is equal to 100.647 kJ/kg.

Figure 3.9: Formula Evaluation for the Value Not Listed In Table

3.6 Double Interpolation for Superheated Vapor Properties

In completing double interpolation method using excel, manual interpolation method is needed first. After that, all the formula created manually need to be translated into excel file using excel formula. For double interpolation, all the methods that been used are the same as single interpolation mention before, but it needs twice of interpolation. There are three steps in completing this double interpolation. First, focus on temperature interpolation values for pressure that nearer but lower than pressure given. Second, focus on the temperature interpolation values for the pressure that nearer but higher than the pressure given. Lastly, with the new values of properties from the temperature interpolation, proceed to the pressure interpolation. For example, given temperature505°C, given pressure 26 MPaandthe value of enthalpy at saturated liquid for water is to be determined.

Formula created using Excel formula:
=IF(K60=L60;K60;K60+((H60-I60)/(J60-I60))*(L60-K60)

3.7 Interface of Water

Table 3.3 shows interface of the three different value for water table which are first for the exact value, second for the interpolation value and lastly for the value that is not in the range of the temperature values.

Table 3.3: Interface of Water

A SIMPLIFICATION OF READING THERMODYNAMIC PROPERTIES TABLE

Temp.	Saturation Pressure	Enthalpy			Entropy			Specific Heat		Thermal Conductivity	
°C	kPa	kJ/kg			kJ/kg			Cp, J/kg.K		k, W/m.K	
T	Psat	Sat. liquid,hf	Evaporator, hfg	Sat. vapor,hg	Sat. liquid,sf	Evaporator, sfg	Sat. vapor,sg	Liquid	Vapor	Liquid	Vapor
5	DaTa	21.020	2489.10	2510.10	0.07630	8.94870	9.02490	4205.0	1857.0	0.5710	0.01730
24	DaTa	100.647	2444.06	2544.68	0.35306	8.22552	8.57858	4180.4	1869.4	0.6052	0.01852
380	DaTa	out of range	out of range	out of range	out of range	out of range	out of range	out of range	out of range	out of range	out of range

Table 3.8 shows an interface of a simplification of reading thermodynamic properties table. It consist of three rows of different value of temperature which the first row shows the value of temperature that is listed in the table, second row shows the value of temperature that is not listed in the table and the last row shows the value of temperature that is not in the range of temperature value. The range of the temperature value for water table is from 0.01 to 373.95°C. Refer to the last row in the interface, the value of 380°C is higher than the highest value 373.95°C, so the result will be “out of range”.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, the results from the study will be analyzed. The comparison between the values of properties from the interface created using excel with the values of properties from the book of thermodynamic properties table in order to do the data validation.

4.2 RESULT OF EXACT VALUES FROM WATER TABLE

Table 4.1 shows an interface of a simplification of reading thermodynamic properties table using excel software for water properties.

Table 4.1: Interface Exact Values of Water

Temp.	Enthalpy			Entropy			Specific Heat		Thermal Conductivity		Internal Energy		
°C	kJ/kg			kJ/kg.K			Cp, J/kg.K		k, W/m.K		kJ/kg		
T	Sat. liquid, hf	Evaporator, hfg	Sat. vapor, hg	Sat. liquid, sf	Evaporator, sfg	Sat. vapor, sg	Liquid	Vapor	Liquid	Vapor	Sat. liquid, Uf	Evaporator, Ufg	Sat. vapor, Ug
5	21.02	2489.10	2510	0.076	8.9487	9.025	4205	1857	0.571	0.017	21.02	2360.8	2381.8
50	209.3	2382.00	2591	0.704	7.3710	8.075	4181	1900	0.644	0.020	210.2	2233.9	2443.9
95	398.1	2269.60	2668	1.250	6.1647	7.415	4212	2010	0.677	0.025	399.4	2107.0	2506
140	589.2	2144.30	2734	1.739	5.1901	6.929	4286	2244	0.683	0.030	588.5	1980.1	2568.1
185	785.2	1996.20	2781	2.188	4.3572	6.545	4435	2650	0.671	0.037	777.7	1853.2	2630.2

It consists of five rows of different exact values of temperature that are listed or can be obtained directly from the water properties table. Data validation is done by comparing the values of all properties obtained from the interface above with the values of all properties from the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Figure 4.1 shows the amount of enthalpy against the temperature of water. The relationship between temperature and enthalpy is directly proportional. The amount of enthalpy increases in uniform manner as the temperature of water increases. The amount of enthalpy is lowest (21.02 kJ/kg) results to temperature 5°C. When the temperature hits 185 °C, the amount of enthalpy reaches its highest point which is785.19kJ/kg.

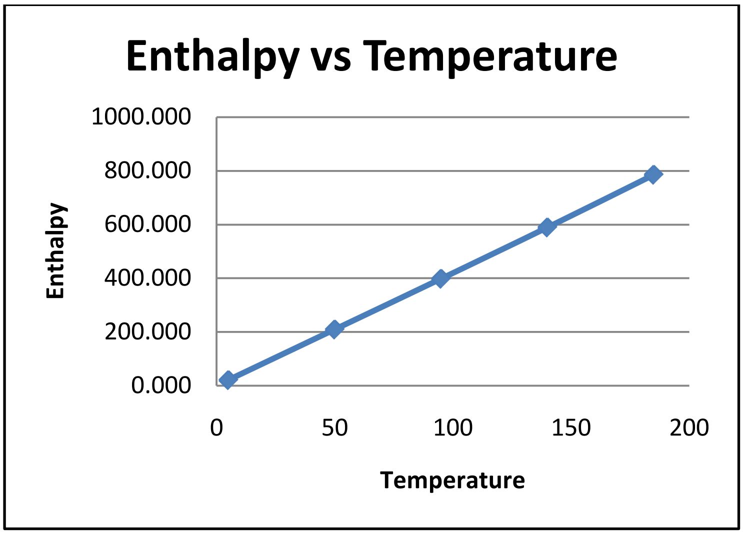

Figure 4.1: Graph of Enthalpy Versus Temperature with Exact Values of Water

4.3 RESULT OF EXACT VALUES FROM AIR TABLE

Table 4.2 shows an interface of a simplification of reading thermodynamic properties table using excel software for air properties.

Table 4.2: Interface of Exact Values of Air

Temp. K T	Enthalpy kJ/kg h	Entropy kJ/kg.K s	Relative Pressure Pr	Relative Specific Volume Vr	Internal Energy kJ/kg U
200	**199.97**	**1.2956**	**0.3363**	**1707**	**142.56**
400	**400.98**	**1.9919**	**1.9587**	**301.6**	**327.94**
600	**607.02**	**2.409**	**3.2067**	**105.8**	**470.54**
800	**821.95**	**2.7179**	**4.3299**	**48.08**	**598.88**
1000	**1046.04**	**2.9677**	**4.9539**	**25.17**	**670.18**

It consists of five rows of different exact values of temperature that are listed or can be obtained directly from the airproperties table. Data validation is done by comparing the values of all properties obtained from the interface above with the values of all properties from the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Figure 4.2 shows the amount of enthalpyagainst the temperature of air. The relationship between temperature and enthalpy is directly proportional. The amount of enthalpy increases in uniform manner as the temperature of air increases. The amount of enthalpy is lowest (199.97 kJ/kg) results to temperature 200 K. When the temperature hits 1000 K, the amount of enthalpy reaches its highest point which is1046.04 kJ/kg.

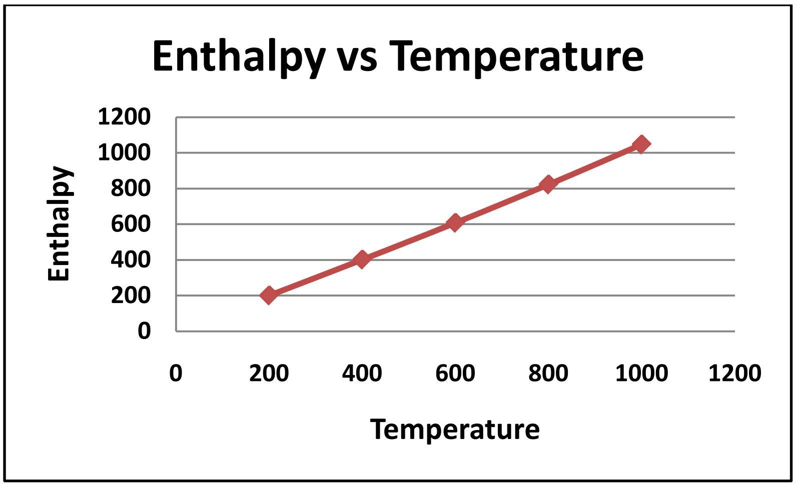

Figure 4.2: Graph of Enthalpy Versus Temperature with Exact Values of Air

4.4 RESULT OF EXACT VALUES FROM SUPERHEATED VAPOR TABLE AT CONTANT PRESSURE

Table 4.3 shows an interface of a simplification of reading thermodynamic properties table using excel software for superheated vapor at constant pressure properties.

Table 4.3: Interface of Exact Values of Superheated Vapor at Constant Pressure

Temp.	Pressure	Enthalpy	Entropy	Specific Volume	Internal Energy
°C T	MPa P	kJ/kg h	kJ/kg.K s	m^3/kg v	kJ/kg U
400	40	1931.4	4.1145	0.001911	1855.0
500	40	2906.5	5.4744	0.005623	2681.6
600	40	3350.4	6.0170	0.008089	3026.8
700	40	3679.2	6.3740	0.009930	3282.0
800	40	3972.6	6.6613	0.011521	3511.8

It consists of five rows of different exact values of temperature and five rows of constant exact values of pressure that are listed or can be obtained directly from the superheated vapor properties table. Data validation is done by comparing the values of all properties obtained from the interface above with the values of all properties from the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Figure 4.3 shows the amount of enthalpy against temperature for superheated vapor at constant pressure (40 MPa). The relationship between temperature and enthalpy is directly proportional. The amount of enthalpy increases in uniform manner as the temperature of superheated vapor increases. The amount of enthalpy is lowest (1931.4 kJ/kg) results to temperature 400 °C. When the temperature hits 800 °C, the amount of enthalpy reaches its highest point which is3972.6 kJ/kg.

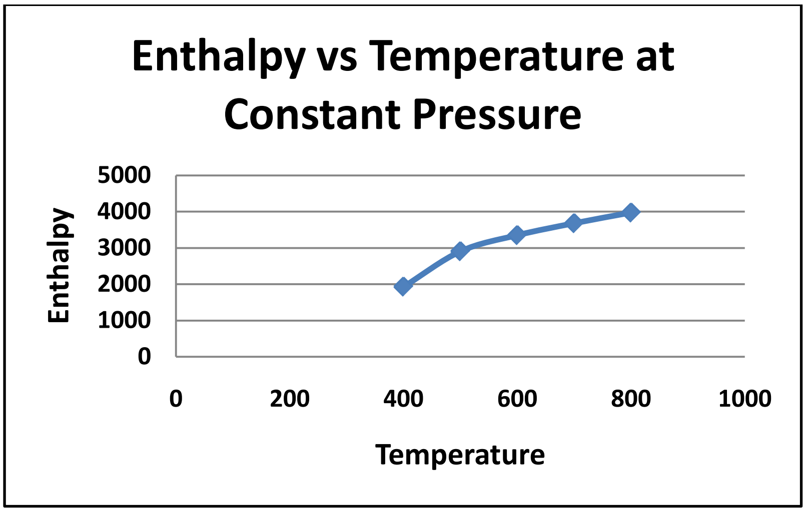

Figure 4.3: Graph of Enthalpy Versus Temperature with Exact Values of Superheated Vapor at Constant Pressure

4.5 RESULT OF EXACT VALUES FROM SUPERHEATED VAPOR TABLE AT CONTANT TEMPERATURE

Table 4.4 shows an interface of a simplification of reading thermodynamic properties table using excel software for superheated vapor at constant temperature properties.

Table 4.4: Interface of Exact Values of Superheated Vapor at Constant Temperature

Temp. K T	Pressure MPa P	Enthalpy kJ/kg h	Entropy kJ/kg.K s	Specific Volume m^3/kg v	Internal Energy kJ/kg U
400	**5**	**3196.7**	**6.6483**	**0.0578**	**2907.5**
400	**10**	**3097.5**	**6.2141**	**0.0264**	**2833.1**
400	**15**	**2975.7**	**5.8882**	**0.0157**	**2740.6**
400	**20**	**2816.9**	**5.5526**	**0.0100**	**2617.9**
400	**25**	**2578.7**	**5.1400**	**0.0060**	**2428.5**

It consists of five rows of different exact values of pressure and five rows of constant exact values of temperature that are listed or can be obtained directly from the superheated vapor table. Data validation is done by comparing the values of all properties obtained from the interface above with the values of all properties from the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Figure 4.4 shows the amount of enthalpy against pressure of superheated at constant temperature (400°C). The pattern of the graph shown is indirectly proportional. The pressure increases while the enthalpy decreases. At the lowest pressure for superheated vapor of water (5MPa), the amount of enthalpy is 3196.7 kJ/kg. The enthalpy of superheated vapor then decreases uniformly until it each its lowest value which is 2578.7 kJ/kg at 25Mpa.

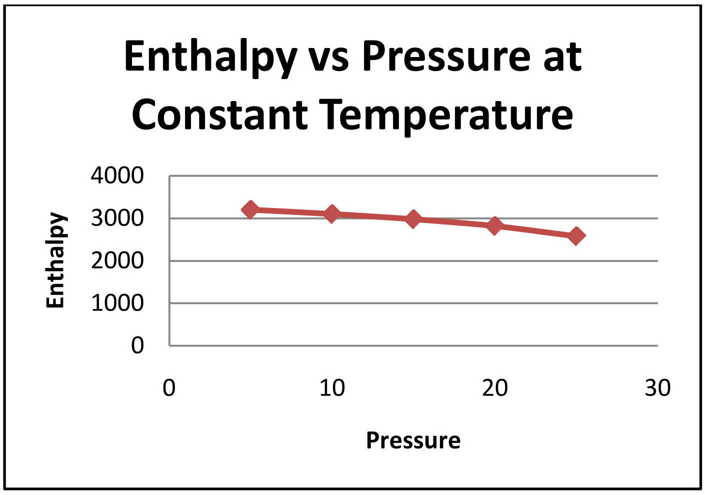

Figure 4.4: Graph of Enthalpy Versus Pressure with Interpolation Values of Superheated Vapor at Constant Temperature

4.6 RESULT OF INTERPOLATION VALUES FROM INTERFACE OF WATER

Table 4.5 shows an interface of a simplification of reading thermodynamic properties table using excel software for water properties.

Table 4.5: Interface of Interpolation of Water

Temp. °C	Enthalpy kJ/kg			Entropy kJ/kg.K			Specific Heat Cp, J/kg.K		Thermal Conductivity k, W/m.K		Internal Energy U, kJ/kg		
T	Sat. liquid, hf	Evaporator ,hfg	Sat. vapor,hg	Sat. liquid ,sf	Evaporator ,sfg	Sat. vapor, sg	Liquid	Vapor	Liquid	Vapor	Sat. liquid, Uf	Evaporator ,Ufg	Sat. vapor, Ug
20	83.92	2453.50	2537.4	0.297	8.3696	8.666	4182.0	1867.0	0.5980	0.0182	84.1	2318.50	2402.5
24	100.65	2444.06	2544.7	0.353	8.2255	8.579	4180.4	1869.4	0.6052	0.0185	100.9	2307.22	2408.0
25	104.83	2441.70	2546.5	0.367	8.1895	8.557	4180.0	1870.0	0.6070	0.0186	105.1	2304.40	2409.4

For example the desired temperature is 24°C and the enthalpy value is the value that must be determine. From the table of interface above, the value of enthalpy at 24 °C is 100.65 kJ/kg. Data validation is done by comparing the values of enthalpy from the table 4.5above with the value of enthalpy from the manual calculation that referred to the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Manual Calculation

$$\boldsymbol{x} = \boldsymbol{x}_1 + \{\frac{(\boldsymbol{y} - \boldsymbol{y}_1)}{(\boldsymbol{y}_2 - \boldsymbol{y}_1)} \times (\boldsymbol{x}_2 - \boldsymbol{x}_1)\} \quad \text{Eq (4.1)}$$

At 24°C,

x_1=83.915kJ/kg,x_2=104.830kJ/kg, y=24°C, y_1=20°C, y_2=25°C

Where x is the value of enthalpy and y is the value of temperature

$$\boldsymbol{x} = \mathbf{83.915} + \{\frac{(\mathbf{24} - \mathbf{20})}{(\mathbf{25} - \mathbf{20})} \times (\mathbf{104.830} - \mathbf{83.915})\}$$

=100.67kJ/kg

The value of enthalpy from the manual calculation is equal to 100.67kJ/kg and it is the same as the value of enthalpy from the table 4.5above. So, it proved that the value of the enthalpy from the table of interface of water above is valid.

4.7 RESULT OF INTERPOLATION VALUES FROM INTERFACE OF AIR

Table 4.6 shows an interface of a simplification of reading thermodynamic properties table using excel software for air properties.

Table 4.6: Interface of Interpolation of Air

Temp. K T	Enthalpy kJ/kg H	Entropy kJ/kg.K s	Relative Pressure Pr	Relative Specific Volume Vr	Internal Energy kJ/kg U
200	**199.97**	**1.29559**	**0.3363**	**1707**	**142.56**
205	**204.97**	**1.32002**	**0.3675**	**1609.5**	**146.125**
210	**209.97**	**1.34444**	**0.3987**	**1512**	**149.69**

For example, the desired temperature is 205 K and the enthalpy value is the value that must be determine. From the table of interface above, the value of enthalpy at 205 K is 204.97kJ/kg. Data validation is done by comparing the values of enthalpy from the table 4.6above with the value of enthalpy from the manual calculation that referred to the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Manual Calculation

At 205K,

Refer to Eq (4.1),

$$x_1=199.97\text{kJ/kg},\quad x_2=209.97\text{kJ/kg},\quad y=205\text{K}, y_1=200\text{K}, y_2=210\text{K}$$

Where x is the value of enthalpy and y is the value of temperature.

$$x = 199.97 + \{\frac{(205-200)}{(210-200)} \times (209.97 - 199.97)\}$$

$=204.97\text{kJ/kg}$

The value of enthalpy from the manual calculation is equal to 204.97kJ/kg and it is the same as the value of enthalpy from the table 4.6 above. So, it proved that the value of the enthalpy from the table of interface of air above is valid.

4.8 RESULT OF INTERPOLATION VALUES FROM INTERFACE OF SUPERHEATED VAPOR AT CONSTANT PRESSURE

Table 4.7 shows an interface of a simplification of reading thermodynamic properties table using excel software for superheated vapor at constant pressure properties.

Table 4.7: Interface of Interpolation of Superheated Vapor at Constant Pressure

Temp.	**Pressure**	**Enthalpy**	**Entropy**	**Specific Volume**	**Internal Energy**
°C	**Mpa**	**kJ/kg**	**kJ/kg.K**	**m^3/kg**	**kJ/kg**
T	**P**	**h**	**s**	**v**	**U**
400	15	2975.70	5.8882	0.01567	2740.60
435	15	3103.24	6.0668	0.01764	2838.74
450	15	3157.90	6.1434	0.01848	2880.80

For example, the desired temperature is 435 K and the enthalpy value is the value that must be determine. From the table of interface above, the value of enthalpy at 435 K is 3103.24 kJ/kg. Data validation is done by comparing the values of enthalpy from the table 4.7 above with the value of enthalpy from the manual calculation that referred to the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Manual Calculation

Refer to Eq (4.1),

x_1=2975.7kJ/kg , x_2=3157.9kJ/kg , y=435°C , y_1=400°C , y_2=450°C

Where x is the value of enthalpy and y is the value of temperature.

$$x = 2975.7 + \{\frac{(435 - 400)}{(450 - 400)} \times (204.97 - 2975.7)\}$$

=3103.24 kJ/kg

The value of enthalpy from the manual calculation is equal to 3103.24kJ/kg and it is the same as the value of enthalpy from the table 4.7 above. So, it proved that the value of the enthalpy from the table of interface of superheated vapor above is valid.

4.9 RESULT OF INTERPOLATION VALUES FROM INTERFACE OF SUPERHEATED VAPOR AT CONSTANT TEMPERATURE

Table 4.8 shows an interface of a simplification of reading thermodynamic properties table using excel software for air at constant temperature properties.

Table 4.8: Interface of Interpolation of Superheated Vapor at Constant Temperature

Temp. °C T	Pressure MPa P	Enthalpy kJ/kg h	Entropy kJ/kg.K s	Specific Volume m^3/kg v	Internal Energy kJ/kg U
400	25	2578.70	5.140	0.006005	2428.50
400	27	2408.34	4.874	0.004722	2284.66
400	30	2152.80	4.476	0.002798	2068.90

For example, the desired pressure is 27 MPa and the enthalpy value is the value that must be determine. From the table of interface above, the value of enthalpy at 27 MPa is 2408.34 kJ/kg. Data validation is done by comparing the values of enthalpy from the table 4.8 above with the value of enthalpy from the manual calculation that referred to the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Manual Calculation

Refer to Eq (4.1),

$$\boldsymbol{x} = \boldsymbol{x}_1 + \{\frac{(\boldsymbol{y} - \boldsymbol{y}_1)}{(\boldsymbol{y}_2 - \boldsymbol{y}_1)} \times (\boldsymbol{x}_2 - \boldsymbol{x}_1)\}$$

x_1=2578.70kJ/kg , x_2=2152.80kJ/kg , y=27°C , y_1=25°C , y_2=30°C

Where x is the value of enthalpy and y is the value of temperature.

$$\boldsymbol{x} = \mathbf{2578.70} + \{\frac{(\mathbf{27} - \mathbf{25})}{(\mathbf{30} - \mathbf{25})} \times (\mathbf{2152.80} - \mathbf{2578.70})\}$$

=2408.34 kJ/kg

The value of enthalpy from the manual calculation is equal to 2408.34 kJ/kg and it is the same as the value of enthalpy from the table 4.8 above. So, it proved that the value of the enthalpy from the table of interface of superheated vapor above is valid.

4.10 RESULT OF INTERPOLATION VALUES FROM INTERFACE OF SUPERHEATED VAPOR

Table 4.9 shows an interface of a simplification of reading thermodynamic properties table using excel software for superheated vapor.

Table 4.9: Interface of Interpolation of Superheated Vapor

Temp.	Pressure	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	MPa	kJ/kg	kJ/kg.K	m^3/kg	kJ/kg
T	P	h	s	v	U
500	25	3165.90	5.96430	0.01114	2887.30
525	27	3224.43	6.01095	0.01094	2932.13
550	30	3279.70	6.04030	0.01018	2974.50

For example, the desired temperature is 525 K and pressure is 27 MPa, finally the enthalpy value is the value that must be determine. From the table of interface above, the value of enthalpy at 525 °C and 27 MPa is 2408.34 kJ/kg. Data validation is done by comparing the values of enthalpy from the table 4.9 above with the value of enthalpy from the manual calculation that referred to the book of thermodynamic properties table. If the values of both compared are the same, so that the values from the interface above are valid.

Manual Calculation

Step 1: Focus on Temperature Interpolation for T=525°C at P=25MPa,

Refer to Eq (4.1),

x_1=3165.9 kJ/kg , x_2=3339.2 kJ/kg , y=525°C , y_1=500°C , y_2=550°C

Where x is the value of enthalpy and y is the value of temperature.

$$x = 3165.9 + \{\frac{(525 - 500)}{(550 - 500)} \times (3339.2 - 3165.9)\}$$

=3252.55 kJ/kg

Step 2: Focus on Temperature Interpolation for T=525°C at P=30MPa,

Refer to Eq (4.1),

x_1=3084.8kJ/kg , x_2=3279.7kJ/kg , y=525°C , y_1=500°C , y_2=550°C

Where x is the value of enthalpy and y is the value of temperature.

$$x = 3084.8 + \{\frac{(525 - 500)}{(550 - 500)} \times (3279.7 - 3084.8)\}$$

=3182.25 kJ/kg

Step 3: Pressure Interpolation for P=27MPa,

Refer to Eq (4.1),

x_1=3252.55kJ/kg , x_2=3182.25kJ/kg , y=27°C , y_1=25°C , y_2=30°C

Where x is the value of enthalpy and y is the value of temperature.

$$x = 3252.55 + \{\frac{(27 - 25)}{(30 - 25)} \times (3182.25 - 3252.55)\}$$

=3224.43 kJ/kg

The value of enthalpy from the manual calculation is equal to 3224.43 kJ/kg and it is the same as the value of enthalpy from the table 4.9 above. So, it proved that the value of the enthalpy from the table of interface of superheated vapor above is valid.

4.11 ANALYSIS OF INTERPOLATION VALUES FROM INTERFACE OF SUPERHEATED VAPOR AT CONSTANT PRESSURE

Table 4.10 shows an interface of a simplification of reading thermodynamic properties table using excel software for superheated vapor at constant pressure properties.

Table 4.10: Interface of Superheated Vapor at Constant Pressure

Temp. °C T	Pressure MPa P	Enthalpy kJ/kg h	Entropy kJ/kg.K s	Specific Volume m³/kg v	Internal Energy kJ/kg U
400	**25**	**2578.7**	**5.14**	**0.00601**	**2428.5**
435	**25**	**2863.2**	**5.55284**	**0.0084**	**2653.16**
470	**25**	**3036.7**	**5.79126**	**0.00996**	**2787.64**
505	**25**	**3183.2**	**5.98603**	**0.0113**	**2900.65**
540	**25**	**3304.5**	**6.13814**	**0.01242**	**2994.1**
575	**25**	**3416.4**	**6.27265**	**0.01344**	**3080.4**
610	**25**	**3522.3**	**6.39582**	**0.0144**	**3162.38**
645	**25**	**3623.3**	**6.50824**	**0.0153**	**3240.71**
680	**25**	**3720.7**	**6.61184**	**0.01616**	**3316.7**
715	**25**	**3816.2**	**6.7095**	**0.01698**	**3391.52**

Some of them are listed in the superheated vapor table but some of them are not listed in the superheated vapor table. The graphs below are just to show the pattern of the relationship between all properties with the temperature at constant pressure.

Figure 4.5 shows the amount of enthalpy against temperature of superheated vapor at constant pressure (25 Mpa). At the lowest temperature for superheated vapor (400 °C), the amount of enthalpy of water is 2578.7kJ/kg. The enthalpy of water at superheated vapor then increases uniformly until it each its highest value 3816.2 kJ/kg at 715 °C.

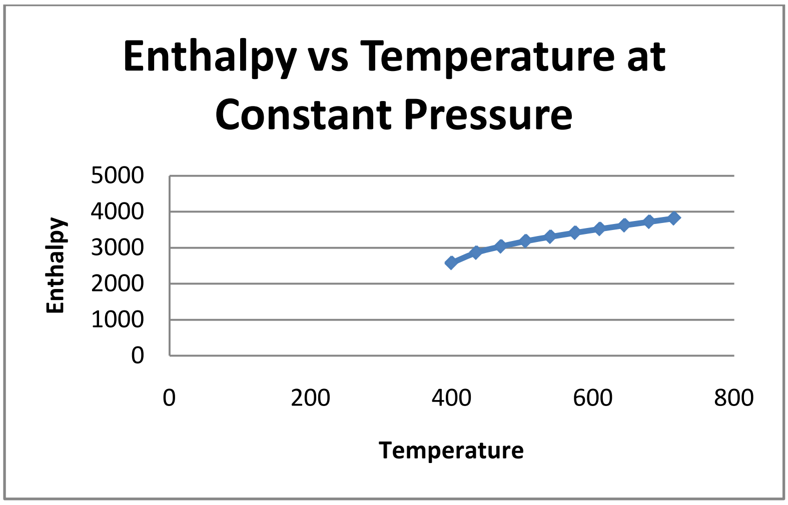

Figure 4.5: Graph of Enthalpy Versus Temperature with Interpolation Values of Superheated Vapor at Constant Pressure

Figure 4.6 shows the amount of entropy against temperature of superheated vapor at constant pressure (25 Mpa). At the lowest temperature for superheated vapor (400 °C), the amount of entropy is 5.14kJ/kg.K. The entropy at superheated vapor then increases uniformly until it each its highest value 6.7095 kJ/kg.K at 715 °C.

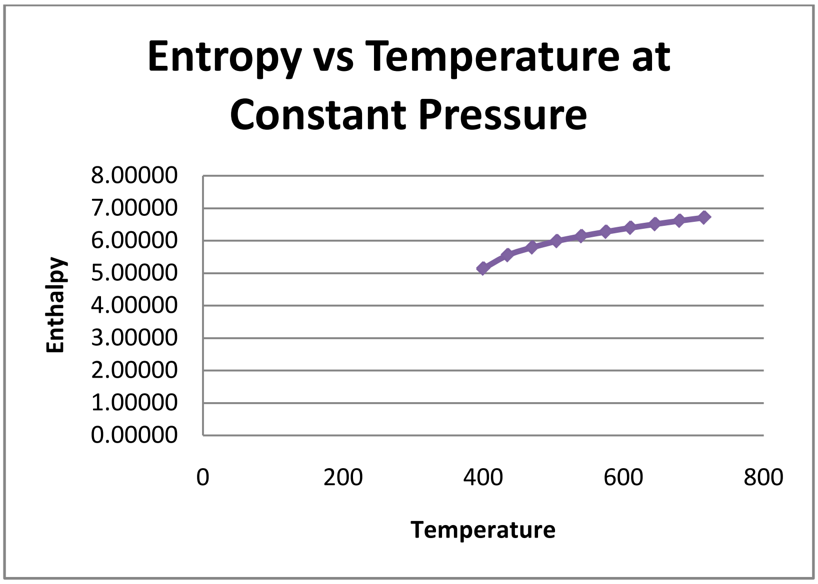

Figure 4.6: Graph of Entropy Versus Temperature with Interpolation Values of Superheated Vapor at Constant Pressure

Figure 4.7 shows the amount of specific volume against temperature of superheated vapor at constant pressure (25 Mpa). At the lowest temperature for superheated vapor (400 °C), the amount of specific volume is 0.00601m³/kg. The specific volume at superheated vapor then increases uniformly until it each its highest value 0.01698 m³/kg at 715 °C.

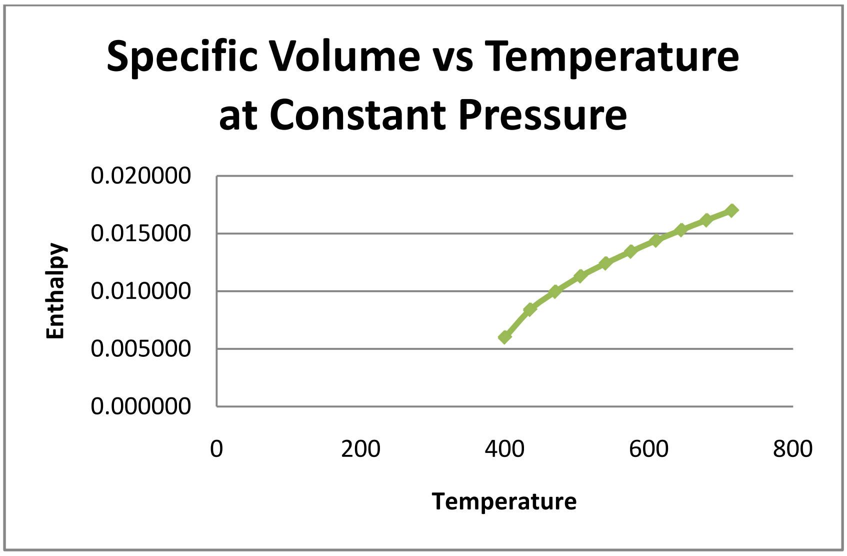

Figure 4.7: Graph of Specific Volume Versus Temperature with Interpolation Values of Superheated Vapor at Constant Pressure

Figure 4.8 shows the amount of internal energy against temperature of superheated vapor at constant pressure (25 Mpa). At the lowest temperature for superheated vapor (400 °C), the amount of internal energy is 2428.5 kJ/kg. The internal energy at superheated vapor then increases uniformly until it reach its highest value 3391.52 kJ/kg at 715 °C.

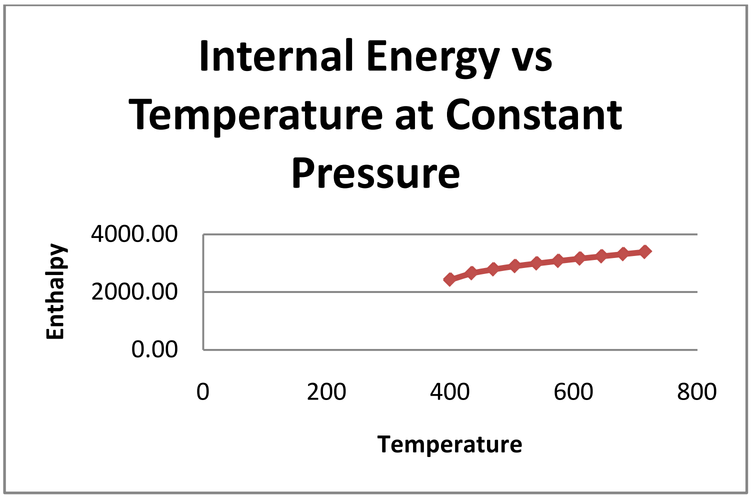

Figure 4.8: Graph of Internal Energy Versus Temperature with Interpolation Values of Superheated Vapor at Constant Pressure

4.12 ANALYSIS OF INTERPOLATION VALUES FROM INTERFACE OF SUPERHEATED VAPOR AT CONSTANT TEMPERATURE

Table 4.11 shows an interface of a simplification of reading thermodynamic properties table using excel software for superheated vapor at constant temperature properties.

Table 4.11: Interface of Superheated Vapor at Constant Temperature

Temp. °C T	Pressure MPa P	Enthalpy kJ/kg h	Entropy kJ/kg.K s	Specific Volume m³/kg v	Internal Energy kJ/kg U
400	5	3196.70	6.6483	0.0578	2907.50
400	8	3139.40	6.3658	0.0343	2864.60
400	11	3074.50	6.1458	0.0239	2815.70
400	14	3001.42	5.9502	0.0174	2760.20
400	17	2917.06	5.7545	0.0131	2695.56
400	20	2816.90	5.5526	0.0100	2617.90
400	23	2673.98	5.3050	0.0076	2504.26
400	26	2493.52	5.0072	0.0054	2356.58
400	29	2237.98	4.6086	0.0034	2140.82
400	32	2087.12	4.3712	0.0025	2007.30

Some of them are listed in the superheated vapor table but some of them are not listed in the superheated vapor table. The graphs below are just to show the pattern of the relationship between all properties with the temperature at constant pressure.

Figure 4.9 shows the amount of enthalpy against pressure of superheated vapor at constant temperature (400°C). The pattern of the graph shown is indirectly proportional. The pressure increases while the enthalpy decreases. At the lowest pressure for superheated vapor of water (5MPa), the amount of enthalpy is 3196.7 kJ/kg. The enthalpy of water at superheated vapor then decreases uniformly until it each its lowest value which is 2087.12 kJ/kg at 32Mpa.

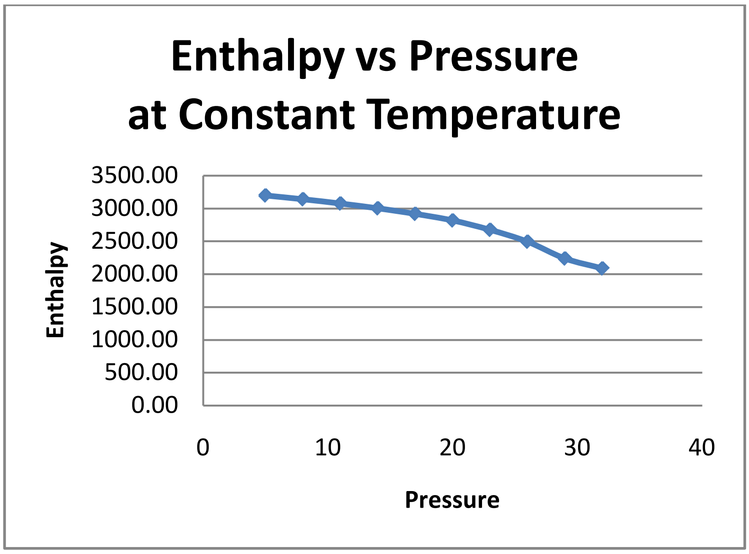

Figure 4.9: Graph of Enthalpy Versus Temperature with Interpolation Values of Superheated Vapor at Constant Temperature

Figure 4.10 shows the amount of entropy against pressure of superheated vapor at constant temperature (400°C). The pattern of the graph shown is indirectly proportional. The pressure increases while the entropy decreases. At the lowest pressure for superheated vapor of water (5MPa), the amount of entropy is 6.6483 kJ/kg.K. The entropy of water at superheated vapor then decreases uniformly until it each its lowest value which is 4.3712 kJ/kg.K at 32Mpa.

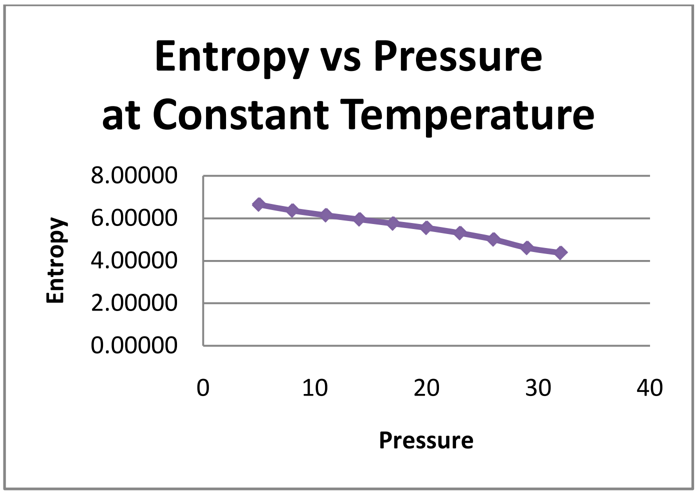

Figure 4.10: Graph of Entropy Versus Pressure with Interpolation Values of Superheated Vapor at Constant Temperature

Figure 4.11 shows the amount specific volumeagainst pressure superheated vapor at constant temperature (400°C). The pattern of the graph shown is indirectly proportional. The graph starts with a steep slope before decrement in gradient at the middle of the graph. The graph stabilize from pressure 11 Mpa to 32 Mpa.The pressure increases while the enthalpy decreases. At the lowest pressure for superheated vapor of water (5MPa), the amount of specific volume is 0.0578 m^3/kg. The specific volume at superheated vapor then decreases uniformly until it reach its lowest value which is 0.0025 m^3/kgat 32 Mpa.

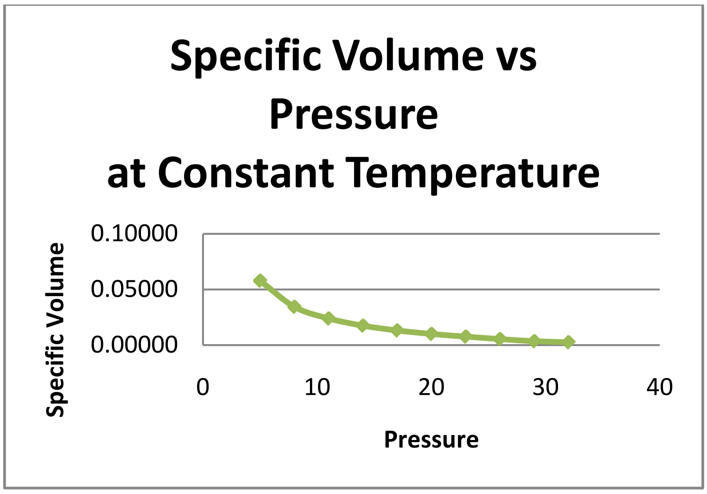

Figure 4.11: Graph of Specific Volume Versus Pressure with Interpolation Values of Superheated Vapor at Constant Temperature

Figure 4.12 shows the amount of enthalpy versus pressure of water at constant temperature (400°C). The pattern of the graph shown is indirectly proportional. The pressure increases while the enthalpy decreases. At the lowest pressure for superheated vapor of water (5MPa), the amount of enthalpy is 2907.5 kJ/kg. The enthalpy of water at superheated vapor then decreases uniformly until it each its lowest value which is 2007.3 kJ/kg at 32 Mpa.

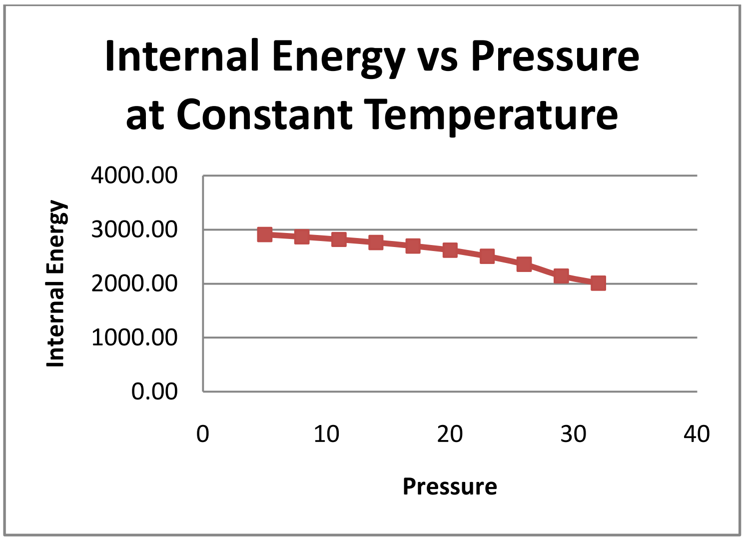

Figure 4.12: Graph of Internal Energy Versus Pressure with Interpolation Values of Superheated Vapor at Constant Temperature

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The main objective of this project was to develop an excel file to simply obtain thermodynamic properties without manually reading from thermodynamic properties table. The main objective was achieved by creating interface of reading thermodynamics properties table using excel file formula and software. The desired values were obtained directly from the interface created. Besides, this interface provided two ways of finding the properties values which are first, when the desired values is directly stated in the thermodynamics properties table and second, when the desired values is indirectly stated in the thermodynamics properties table and interpolation needed. Manual calculation was needed in order to validate the data obtained from the interface using excel software created.

5.2 RECOMMENDATION

After all process done in completing this project, there are several recommendations that can be added in the future research. The function of changing the units of thermodynamics properties to other standard, for example into American Standard, should be developed so that the software will become more user friendly. Besides that, several other commonly used properties, such as density and specific volume, should also be added into the software. The software should also be able to run on other operating systems such as MAC for Apple and LINUX for Linus Torvalds so that people using other operating systems will have the benefits of using the software.

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APPENDIX A

GANTT CHART

Table 6.1: Gantt chart FYP 1

Week / Project activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Title confirmation															
Set objectives and scopes															
Logbook writing															
Find journals															
Set problem statements															
Literature review															
Research methodology															
FYP1 Report															
FYP1 presentation															
Submit report															

Table 6.2: Gantt chart FYP 2

Week / Project activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Welding training																
Material preparation																
Logbook writing																
Preliminary																
Computational process																
Data validation																
Data analysis																
FYP 2 presentation																
FYP 2 report																
Submit report																

APPENDIX B

TABLES OF WATER, AIR AND SUPERHEATED VAPOR

Table 6.3: Table of Water

Temp.	Saturation Pressure	Enthalpy			Entropy			Specific Heat		Thermal Conductivity		Internal Energy		
°C	kPa	kJ/kg			kJ/kg.K			Cp, J/kg.K		k, W/m.K		U, kJ/kg		
T	Psat	Sat. liquid,hf	Evaporator ,hfg	Sat. vapor, hg	Sat. liquid, sf	Evaporator, sfg	Sat. vapor, sg	Liquid	Vapor	Liquid	Vapor	Sat. liquid, Uf	Evaporator, Ufg	Sat. vapor, Ug
0.01	0.61	0.00	2500.9	2500.6	0.000	9.156	9.156	4217	1854	0.561	0.017	0.0	2374.9	2374.9
5	0.87	21.02	2489.1	2510.1	0.076	8.949	9.025	4205	1857	0.571	0.017	21.0	2360.8	2381.8
10	1.23	42.02	2477.2	2519.2	0.151	8.749	8.900	4194	1862	0.580	0.018	42.0	2346.7	2388.7
15	1.08	62.98	2465.4	2528.3	0.225	8.556	8.780	4186	1863	0.589	0.018	63.1	2332.6	2395.6
20	2.34	83.92	2453.5	2537.4	0.297	8.370	8.666	4182	1867	0.598	0.018	84.1	2318.5	2402.5
25	3.17	104.83	2441.7	2546.5	0.367	8.190	8.557	4180	1870	0.607	0.019	105.1	2304.4	2409.4
30	4.25	125.74	2429.8	2555.6	0.437	8.015	8.452	4178	1875	0.615	0.019	126.1	2290.3	2416.3
35	5.63	146.64	2417.9	2564.6	0.505	7.847	8.352	4178	1880	0.623	0.019	147.1	2276.2	2423.2
40	7.39	167.53	2406.0	2573.5	0.572	7.683	8.256	4179	1885	0.631	0.020	168.2	2262.1	2430.1
45	9.60	188.44	2394.0	2582.4	0.639	7.525	8.163	4180	1892	0.637	0.020	189.2	2248.0	2437.0
50	12.35	209.34	2382.0	2591.3	0.704	7.371	8.075	4181	1900	0.644	0.020	210.2	2233.9	2443.9
55	15.76	230.26	2369.8	2600.1	0.768	7.222	7.990	4183	1908	0.649	0.021	231.2	2219.8	2450.8
60	19.95	251.18	2357.7	2608.8	0.831	7.077	7.908	4185	1916	0.654	0.021	252.2	2205.7	2457.7
65	25.04	272.12	2345.4	2617.5	0.894	6.936	7.830	4187	1926	0.659	0.022	273.2	2191.6	2464.6
70	31.20	293.07	2333.0	2626.1	0.955	6.799	7.754	4190	1936	0.663	0.022	294.3	2177.5	2471.5
75	38.60	314.03	2320.6	2634.6	1.016	6.666	7.681	4193	1948	0.667	0.023	315.3	2163.4	2478.4
80	47.42	335.02	2308.0	2643.0	1.076	6.536	7.611	4197	1962	0.670	0.023	336.3	2149.3	2485.3
85	57.87	356.02	2295.3	2651.4	1.135	6.409	7.544	4201	1977	0.673	0.024	357.3	2135.2	2492.2
90	70.18	377.04	2282.5	2659.6	1.193	6.285	7.478	4206	1993	0.675	0.024	378.3	2121.1	2499.1
95	84.61	398.09	2269.6	2667.6	1.250	6.165	7.415	4212	2010	0.677	0.025	399.4	2107.0	2506.0

Table 6.3: Continued

Temp.	Saturation Pressure	Enthalpy			Entropy			Specific Heat		Thermal Conductivity		Internal Energy		
°C	kPa	kJ/kg			kJ/kg.K			Cp, J/kg.K		k, W/m.K		U, kJ/kg		
T	Psat	Sat. liquid,hf	Evaporator ,hfg	Sat. vapor, hg	Sat. liquid, sf	Evaporator, sfg	Sat. vapor, sg	Liquid	Vapor	Liquid	Vapor	Sat. liquid, Uf	Evaporator, Ufg	Sat. vapor, Ug
100	101.42	419.17	2256.4	2675.6	1.307	6.047	7.354	4217	2029	0.679	0.025	420.4	2092.9	2512.9
105	120.90	440.28	2243.1	2683.4	1.363	5.932	7.295	4223	2050	0.681	0.026	441.4	2078.8	2519.8
110	143.38	461.42	2229.7	2691.1	1.419	5.819	7.238	4229	2071	0.682	0.026	462.4	2064.7	2526.7
115	169.18	482.59	2216.0	2698.6	1.474	5.709	7.183	4237	2096	0.683	0.027	483.4	2050.6	2533.6
120	198.67	503.81	2202.1	2706.0	1.528	5.601	7.129	4244	2120	0.683	0.028	504.5	2036.5	2540.5
125	232.23	525.07	2188.1	2713.1	1.582	5.496	7.077	4254	2149	0.684	0.028	525.5	2022.4	2547.4
130	270.28	546.38	2173.7	2720.1	1.635	5.392	7.027	4263	2177	0.684	0.029	546.5	2008.3	2554.3
135	313.22	567.75	2159.1	2726.9	1.687	5.290	6.977	4275	2211	0.684	0.029	567.5	1994.2	2561.2
140	361.53	589.16	2144.3	2733.5	1.739	5.190	6.929	4286	2244	0.683	0.030	588.5	1980.1	2568.1
145	415.68	610.64	2129.2	2739.8	1.791	5.092	6.883	4299	2279	0.683	0.031	609.6	1966.0	2575.0
150	476.16	632.18	2113.8	2745.9	1.842	4.995	6.837	4311	2314	0.682	0.032	630.6	1951.9	2581.9
155	543.49	653.79	2098.0	2751.8	1.892	4.900	6.793	4326	2367	0.681	0.033	651.6	1937.8	2588.8
160	618.23	675.47	2082.0	2757.5	1.943	4.807	6.749	4340	2420	0.680	0.034	672.6	1923.7	2595.7
165	700.93	697.24	2065.0	2762.8	1.992	4.714	6.707	4355	2455	0.679	0.034	693.6	1909.6	2602.6
170	792.18	719.08	2048.8	2767.9	2.042	4.623	6.665	4370	2490	0.677	0.035	714.6	1895.5	2609.5
175	892.60	741.02	2031.7	2772.7	2.091	4.534	6.624	4390	2540	0.675	0.036	735.7	1881.4	2616.4
180	1002.80	763.05	2014.2	2777.2	2.139	4.445	6.584	4410	2590	0.673	0.036	756.7	1867.3	2623.3
185	1123.50	785.19	1996.2	2781.4	2.188	4.357	6.545	4435	2650	0.671	0.037	777.7	1853.2	2630.2
190	1255.20	807.43	1977.9	2785.3	2.236	4.271	6.506	4460	2710	0.669	0.038	798.7	1839.1	2637.1
195	1398.80	829.78	1959.0	2788.8	2.283	4.185	6.468	4480	2775	0.666	0.039	819.7	1825.0	2644.0

Table 6.3: Continued

Temp. °C	Saturation Pressure kPa	Enthalpy kJ/kg			Entropy kJ/kg.K			Specific Heat Cp, J/kg.K		Thermal Conductivity k, W/m.K		Internal Energy U, kJ/kg		
T	Psat	Sat. liquid,hf	Evaporator ,hfg	Sat. vapor, hg	Sat. liquid, sf	Evaporator, sfg	Sat. vapor, sg	Liquid	Vapor	Liquid	Vapor	Sat. liquid, Uf	Evaporator, Ufg	Sat. vapor, Ug
200	1554.90	852.26	1939.8	2792.0	2.331	4.100	6.430	4500	2840	0.663	0.040	840.8	1810.9	2650.9
205	1724.30	874.87	1920.0	2794.8	2.378	4.015	6.393	4528	2908	0.660	0.041	861.8	1796.8	2657.8
210	1907.70	897.61	1899.7	2797.3	2.425	3.932	6.356	4555	2975	0.657	0.042	882.8	1782.7	2664.7
215	2105.90	920.50	1878.8	2799.3	2.471	3.849	6.320	4583	3043	0.653	0.043	903.8	1768.6	2671.6
220	2319.60	943.55	1857.4	2801.0	2.518	3.766	6.284	4610	3110	0.650	0.044	924.8	1754.5	2678.5
225	2549.70	966.76	1835.4	2802.2	2.564	3.684	6.248	4648	3213	0.646	0.045	945.9	1740.4	2685.4
230	2797.10	990.14	1812.8	2802.9	2.610	3.603	6.213	4685	3315	0.641	0.046	966.9	1726.3	2692.3
235	3062.60	1013.70	1789.5	2803.2	2.656	3.522	6.178	4723	3418	0.637	0.048	987.9	1712.2	2699.2
240	3347.00	1037.50	1765.5	2803.0	2.702	3.441	6.142	4760	3520	0.632	0.049	1008.9	1698.1	2706.1
245	3651.20	1061.50	1740.8	2802.2	2.748	3.360	6.107	4813	3658	0.626	0.050	1029.9	1684.0	2713.0
250	3976.20	1085.70	1715.3	2801.0	2.793	3.279	6.072	4865	3795	0.621	0.051	1051.0	1669.9	2719.9
255	4322.90	1110.10	1689.0	2799.1	2.839	3.198	6.037	4918	3933	0.615	0.053	1072.0	1655.8	2726.8
260	4692.30	1134.80	1661.8	2796.6	2.885	3.117	6.002	4970	4070	0.609	0.054	1093.0	1641.7	2733.7
265	5085.30	1159.80	1633.7	2793.5	2.930	3.036	5.966	5048	4261	0.602	0.056	1114.0	1627.6	2740.6
270	5503.00	1185.10	1604.6	2789.7	2.976	2.954	5.931	5125	4453	0.595	0.057	1135.0	1613.5	2747.5
275	5946.40	1210.70	1574.5	2785.2	3.022	2.872	5.894	5203	4644	0.588	0.059	1156.0	1599.4	2754.4
280	6416.60	1236.70	1543.2	2779.6	3.068	2.790	5.858	5280	4835	0.581	0.061	1177.1	1585.3	2761.3
285	6914.60	1263.10	1510.7	2773.7	3.114	2.707	5.821	5398	5121	0.573	0.063	1198.1	1571.2	2768.2
290	7441.80	1289.80	1476.9	2766.7	3.161	2.623	5.783	5515	5408	0.565	0.065	1219.1	1557.1	2775.1
295	7999.00	1317.10	1441.6	2758.7	3.208	2.537	5.745	5633	5694	0.556	0.067	1240.1	1543.0	2782.0

Table 6.3: Continued

Temp.	Saturation Pressure	Enthalpy			Entropy			Specific Heat		Thermal Conductivity		Internal Energy		
°C	kPa	kJ/kg			kJ/kg.K			Cp, J/kg.K		k, W/m.K		U, kJ/kg		
T	Psat	Sat. liquid,hf	Evaporator ,hfg	Sat. vapor, hg	Sat. liquid, sf	Evaporator, sfg	Sat. vapor, sg	Liquid	Vapor	Liquid	Vapor	Sat. liquid, Uf	Evaporator, Ufg	Sat. vapor, Ug
300	8587.90	1344.80	1404.8	2749.6	3.255	2.452	5.706	5750	5980	0.548	0.070	1261.1	1528.9	2788.9
305	9209.40	1373.10	1366.3	2739.4	3.302	2.363	5.666	5948	6460	0.538	0.073	1282.2	1514.8	2795.8
310	9865.00	1402.00	1325.9	2727.9	3.351	2.274	5.624	6145	6940	0.529	0.077	1303.2	1500.7	2802.7
315	10556.00	1431.60	1283.4	2715.0	3.399	2.182	5.582	6343	7420	0.519	0.080	1324.2	1486.6	2809.6
320	11284.00	1462.00	1238.5	2700.6	3.449	2.088	5.537	6540	7900	0.509	0.084	1345.2	1472.5	2816.5
325	12051.00	1493.40	1191.0	2684.3	3.500	1.991	5.491	6965	8893	0.499	0.090	1366.2	1458.4	2823.4
330	12858.00	1525.80	1140.3	2666.0	3.552	1.891	5.442	7390	9885	0.489	0.097	1387.3	1444.3	2830.3
335	13707.00	1559.40	1086.0	2645.4	3.605	1.786	5.391	7815	10878	0.479	0.103	1408.3	1430.2	2837.2
340	14601.00	1594.60	1027.4	2622.0	3.660	1.676	5.336	8240	11870	0.469	0.110	1429.3	1416.1	2844.1
345	15541.00	1631.70	963.4	2595.1	3.718	1.559	5.277	9853	15353	0.459	0.127	1450.3	1402.0	2851.0
350	16529.00	1671.20	892.7	2563.9	3.779	1.433	5.211	11465	18835	0.448	0.144	1471.3	1387.9	2857.9
355	17570.00	1714.00	812.9	2526.9	3.844	1.294	5.138	13078	22318	0.438	0.161	1492.3	1373.8	2864.8
360	18666.00	1761.50	720.1	2481.6	3.917	1.137	5.054	14690	25800	0.427	0.178	1513.4	1359.7	2871.7
365	19822.00	1817.20	605.5	2422.7	4.000	0.949	4.949	16303	29283	0.417	0.195	1534.4	1345.6	2878.6
370	21044.00	1891.20	443.1	2334.3	4.112	0.689	4.801	17915	32765	0.406	0.212	1555.4	1331.5	2885.5
373.95	22064.00	2084.30	0.0	2084.3	4.407	0.000	4.407	-	-	-	-	1576.4	1317.4	2892.4

Table 6.4: Table of Air

Temp. K T	Enthalpy h kJ/kg	Entropy s kJ/kg.K	Relative Pressure Pr	Relative Specific Volume Vr	Internal Energy U kJ/kg
200	199.970	1.29559	0.3363	1707.00	142.56
210	209.970	1.34444	0.3987	1512.00	149.69
220	219.970	1.39105	0.4611	1346.00	156.82
230	230.020	1.43557	0.5235	1205.00	163.95
240	240.020	1.47824	0.5859	1084.00	171.08
250	250.050	1.51917	0.6483	979.00	178.21
260	260.090	1.55848	0.7107	887.00	185.34
270	270.110	1.59634	0.7731	808.00	192.47
280	280.130	1.63279	0.8355	738.00	199.60
285	285.140	1.65055	0.8979	706.00	206.73
290	290.160	1.66802	0.9603	676.10	213.86
295	295.170	1.68515	1.0227	647.90	220.99
298	298.180	1.69528	1.0851	631.90	228.12
300	300.190	1.70203	1.1475	621.20	235.25
305	305.220	1.71865	1.2099	596.00	242.38
310	310.240	1.73498	1.2723	572.30	249.51
315	315.270	1.75106	1.3347	549.80	256.64
320	320.290	1.76690	1.3971	528.60	263.77
325	325.310	1.78249	1.4595	508.40	270.90
330	330.340	1.79783	1.5219	489.40	278.03
340	340.420	1.82790	1.5843	454.10	285.16
350	350.490	1.85708	1.6467	422.20	292.29
360	360.580	1.88543	1.7091	393.40	299.42
370	370.670	1.91313	1.7715	367.20	306.55
380	380.770	1.94001	1.8339	343.40	313.68
390	390.880	1.96633	1.8963	321.50	320.81
400	400.980	1.99194	1.9587	301.60	327.94
410	411.120	2.01699	2.0211	283.30	335.07
420	421.260	2.04142	2.0835	266.60	342.20
430	431.430	2.06533	2.1459	251.10	349.33
440	441.610	2.09214	2.2083	236.80	356.46
450	451.800	2.11161	2.2707	223.60	363.59
460	462.020	2.13407	2.3331	211.40	370.72
470	472.240	2.15604	2.3955	200.10	377.85
480	482.490	2.17760	2.4579	189.50	384.98
490	492.740	2.19876	2.5203	179.70	392.11
500	503.020	2.21952	2.5827	170.60	399.24
510	513.320	2.23993	2.6451	162.10	406.37

Table 6.4: Continued

Temp. K T	Enthalpy h kJ/kg	Entropy s kJ/kg.K	Relative Pressure Pr	Relative Specific Volume Vr	Internal Energy U kJ/kg
520	523.630	2.25997	2.7075	154.10	413.50
530	533.980	2.27967	2.7699	146.70	420.63
540	544.350	2.29906	2.8323	139.70	427.76
550	555.740	2.31809	2.8947	133.10	434.89
560	565.170	2.33685	2.9571	127.00	442.02
570	575.590	2.35531	3.0195	121.20	449.15
580	586.040	2.37348	3.0819	115.70	456.28
590	596.520	2.39140	3.1443	110.60	463.41
600	607.020	2.40902	3.2067	105.80	470.54
610	617.530	2.42644	3.2691	101.20	477.67
620	628.070	2.44356	3.3315	96.92	484.80
630	638.630	2.46048	3.3939	92.84	491.93
640	649.220	2.47716	3.4563	88.99	499.06
650	659.840	2.49364	3.5187	85.34	506.19
660	670.470	2.50985	3.5811	81.89	513.32
670	681.140	2.52589	3.6435	78.61	520.45
680	691.820	2.54175	3.7059	75.50	527.58
690	702.520	2.55731	3.7683	72.56	534.71
700	713.270	2.57277	3.8307	69.76	541.84
710	724.040	2.58810	3.8931	67.07	548.97
720	734.820	2.60319	3.9555	64.53	556.10
730	745.620	2.61803	4.0179	62.13	563.23
740	756.440	2.63280	4.0803	59.82	570.36
750	767.290	2.64737	4.1427	57.63	577.49
760	778.180	2.66176	4.2051	55.54	584.62
780	800.030	2.69013	4.2675	51.64	591.75
800	821.950	2.71787	4.3299	48.08	598.88
820	843.980	2.74504	4.3923	44.84	606.01
840	866.080	2.77170	4.4547	41.85	613.14
860	888.270	2.79783	4.5171	39.12	620.27
880	910.560	2.82344	4.5795	36.61	627.40
900	932.930	2.84856	4.6419	34.31	634.53
920	955.380	2.87324	4.7043	32.18	641.66
940	977.920	2.89748	4.7667	30.22	648.79
960	1000.550	2.92128	4.8291	28.40	655.92
980	1023.250	2.94468	4.8915	26.73	663.05
1000	1046.040	2.96770	4.9539	25.17	670.18
1020	1068.890	2.99034	5.0163	23.72	677.31
1040	1091.850	3.01260	5.0787	23.29	684.44

Table 6.4: Continued

Temp.	Enthalpy	Entropy	Relative Pressure	Relative Specific Volume	Internal Energy
K	**h**	**s**	**Pr**	**Vr**	**U**
T	**kJ/kg**	**kJ/kg.K**			**kJ/kg**
1060	1114.860	3.03449	5.1411	21.14	691.57
1080	1137.890	3.05608	5.2035	19.98	698.70
1100	1161.070	3.07732	5.2659	18.90	705.83
1120	1184.280	3.09825	5.3283	17.89	712.96
1140	1207.570	3.11883	5.3907	16.95	720.09
1160	1230.920	3.13916	5.4531	16.06	727.22
1180	1254.340	3.15916	5.5155	15.24	734.35
1200	1277.790	3.17888	5.5779	14.47	741.48
1220	1301.310	3.19834	5.6403	13.75	748.61
1240	1324.930	3.21751	5.7027	13.07	755.74
1260	1348.550	3.23638	5.7651	12.44	762.87
1280	1372.240	3.25510	5.8275	11.84	770.00
1300	1395.970	3.27345	5.8899	11.28	777.13
1320	1419.760	3.29160	5.9523	10.75	784.26
1340	1443.600	3.30959	6.0147	10.25	791.39
1360	1467.490	3.32724	6.0771	9.78	798.52
1380	1491.440	3.34474	6.1395	9.34	805.65
1400	1515.420	3.36200	6.2019	8.92	812.78
1420	1539.440	3.37901	6.2643	8.53	819.91
1440	1563.510	3.39586	6.3267	8.15	827.04
1460	1587.630	3.41247	6.3891	7.80	834.17
1480	1611.790	3.42892	6.4515	7.47	841.30
1500	1635.970	3.44516	6.5139	7.15	848.43
1520	1660.230	3.46120	6.5763	6.85	855.56
1540	1684.510	3.47712	6.6387	6.66	862.69
1560	1708.820	3.49276	6.7011	6.30	869.82
1580	1733.170	3.50829	6.7635	6.05	876.95
1600	1757.570	3.52364	6.8259	5.80	884.08
1620	1782.000	3.53879	6.8883	5.58	891.21
1640	1806.460	3.55381	6.9507	5.36	898.34
1660	1830.960	3.56867	7.0131	5.15	905.47
1680	1855.500	3.58335	7.0755	4.94	912.60
1700	1880.100	3.59790	7.1379	4.73	919.73
1750	1941.600	3.63360	7.2003	4.52	926.86
1800	2003.300	3.66840	7.2627	4.32	933.99
1850	2065.300	3.70230	7.3251	4.11	941.12
1900	2127.400	3.73540	7.3875	3.90	948.25
1950	2189.700	3.76770	7.4499	3.69	955.38

Table 6.4: Continued

Temp.	**Enthalpy**	**Entropy**	**Relative Pressure**	**Relative Specific Volume**	**Internal Energy**
K	**h**	**s**	**Pr**	**Vr**	**U**
T	**kJ/kg**	**kJ/kg.K**			**kJ/kg**
2000	2252.100	3.79940	7.5123	3.48	962.51
2050	2314.600	3.83030	7.5747	3.28	969.64
2100	2377.700	3.86050	7.6371	3.07	976.77
2150	2440.300	3.89010	7.6995	2.86	983.90
2200	2503.200	3.91910	7.7619	2.65	991.03
2250	2566.400	3.94740	7.8243	2.44	998.16

Table 6.5: Table of Superheated Vapor

Temp. °C T	Enthalpy kJ/kg h	Entropy kJ/kg s	Specific Volume m³/kg Cp	Internal Energy kJ/kg U
		P=0.01 Mpa		
45.81	2583.9	8.1488	14.670000	2437.2
50	2592.0	8.1741	14.867000	2443.3
100	2687.5	8.4489	17.196000	2515.5
150	2783.0	8.6893	19.513000	2587.9
200	2879.6	8.9049	21.826000	2661.4
250	2977.5	9.1015	24.136000	2736.1
300	3076.7	9.2827	26.446000	2812.3
400	3280.0	9.6094	31.063000	2969.3
500	3489.7	9.8998	35.680000	3132.9
600	3706.3	10.1631	40.296000	3303.3
700	3929.9	10.4056	44.911000	3480.8
800	4160.6	10.6312	49.527000	3665.4
900	4398.3	10.8429	54.143000	3856.9
1000	4642.8	11.0429	58.758000	4055.3
1100	4893.8	11.2326	63.373000	4260.0
1200	5150.8	11.4132	67.989000	4470.9
1300	5413.4	11.5857	72.604000	4687.4
		P=0.05 Mpa		
81.32	2645.2	7.5931	3.240300	2483.2
100	2682.4	7.6953	3.418700	2511.5
150	2780.2	7.9413	3.889700	2585.7
200	2877.8	8.1592	4.356200	2660.0
250	2976.2	8.3568	4.820600	2735.1
300	3075.8	8.5387	5.284100	2811.6
400	3279.3	8.8659	6.209400	2968.9
500	3489.3	9.1566	7.133800	3132.6
600	3706.0	9.4201	8.057700	3303.1
700	3929.7	9.6626	8.981300	3480.6
800	4160.4	9.8883	9.904700	3665.2
900	4398.2	10.1000	10.828000	3856.8
1000	4642.7	10.3000	11.751300	4055.2
1100	4893.7	10.4897	12.674500	4259.9
1200	5150.7	10.6704	13.597700	4470.8
1300	5413.3	10.8429	14.520900	4687.3
		P=0.10 Mpa		
99.61	2675.0	7.3589	1.694100	2505.6

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
100	2675.8	7.3611	1.695900	2506.2
150	2776.6	7.6148	1.936700	2776.6
200	2875.5	7.8356	2.172400	2875.5
250	2974.5	8.0346	2.406200	2974.5
300	3074.5	8.2172	2.638900	3074.5
400	3278.6	8.5452	3.102700	3278.6
500	3488.7	8.8362	3.565500	3488.7
600	3705.6	9.0999	4.027900	3705.6
700	3929.4	9.3424	4.490000	3929.4
800	4160.2	9.5682	4.951900	4160.2
900	4398.0	9.7800	5.413700	4398.0
1000	4642.6	9.9800	5.875500	4642.6
1100	4893.6	10.1698	6.337200	4893.6
1200	5150.6	10.3504	6.798800	5150.6
1300	5413.3	10.5229	7.260500	5413.3
		P=0.20 Mpa		
120.21	2706.3	7.1270	0.885780	2529.1
150	2769.1	7.2810	0.959860	2577.1
200	2870.7	7.5081	1.080490	2654.6
250	2971.2	7.7100	1.198900	2731.4
300	3072.1	7.8941	1.316230	2808.8
400	3277.0	8.2236	1.549340	2967.2
500	3487.7	8.5153	1.781420	3131.4
600	3704.8	8.7793	2.013020	3302.2
700	3928.8	9.0221	2.244340	3479.9
800	4159.8	9.2479	2.475500	3664.7
900	4397.7	9.4598	2.706560	3856.3
1000	4642.3	9.6599	2.937550	4054.8
1100	4893.3	9.8497	3.168480	4259.6
1200	5150.4	10.0304	3.399380	4470.5
1300	5413.1	10.2029	3.630260	4687.1
		P=0.30 Mpa		
133.52	2724.9	6.9917	0.605820	2543.2
150	2761.2	7.0792	0.634020	2571.0
200	2865.9	7.3132	0.716430	2651.0
250	2967.9	7.5180	0.796450	2728.9
300	3069.6	7.7037	0.875350	2807.0

Table 6.5: Continued

Temp. °C T	Enthalpy kJ/kg h	Entropy kJ/kg s	Specific Volume m³/kg Cp	Internal Energy kJ/kg U
400	3275.5	8.0347	1.031550	2966.0
500	3486.6	8.3271	1.186720	3130.6
600	3704.0	8.5915	1.341390	3301.6
700	3928.2	8.8345	1.495800	3479.5
800	4159.3	9.0605	1.650040	3664.3
900	4397.3	9.2725	1.804170	3856.0
1000	4642.0	9.4726	1.958240	4054.5
1100	4893.1	9.6624	2.112260	4259.4
1200	5150.2	9.8431	2.266240	4470.3
1300	5413.0	10.0157	2.420190	4686.9
		P=0.40 Mpa		
143.61	2738.1	6.8955	0.462420	2553.1
150	2752.8	6.9306	0.470880	2564.4
200	2860.9	7.1723	0.534340	2647.2
250	2964.5	7.3804	0.595200	2726.4
300	3067.1	7.5677	0.654890	2805.1
400	3273.9	7.9003	0.772650	2964.9
500	3485.5	8.1933	0.889360	3129.8
600	3703.3	8.4580	1.005580	3301.0
700	3927.6	8.7012	1.121520	3479.0
800	4158.9	8.9274	1.237300	3663.9
900	4396.9	9.1394	1.352980	3855.7
1000	4641.7	9.3396	1.468590	4054.3
1100	4892.9	9.5295	1.584140	4259.2
1200	5150.0	9.7102	1.699660	4470.2
1300	5412.8	9.8828	1.815160	4686.7
		P=0.50 Mpa		
151.83	2748.1	6.8207	0.374830	2560.7
200	2855.8	7.0610	0.425030	2643.3
250	2961.0	7.2725	0.474430	2723.8
300	3064.6	7.4614	0.522610	2803.3
350	3168.1	7.6346	0.570150	2883.0
400	3272.4	7.7956	0.617310	2963.7
500	3484.5	8.0893	0.710950	3129.0
600	3702.5	8.3544	0.804090	3300.4
700	3927.0	8.5978	0.896960	3478.6
800	4158.4	8.8240	0.989660	3663.6
900	4396.6	9.0362	1.082270	3855.4

Table 6.5: Continued

Temp. °C T	Enthalpy kJ/kg h	Entropy kJ/kg s	Specific Volume m³/kg Cp	Internal Energy kJ/kg U
1000	4641.4	9.2364	1.174800	4054.0
1100	4892.6	9.4263	1.267280	4259.0
1200	5149.8	9.6071	1.359720	4470.0
1300	5412.6	9.7797	1.452140	4686.6
		P=0.60 Mpa		
158.83	2756.2	6.7593	0.315600	2566.8
200	2850.6	6.9683	0.352120	2639.4
250	2957.6	7.1833	0.393900	2721.2
300	3062.0	7.3740	0.434420	2801.4
350	3166.1	7.5481	0.474280	2881.6
400	3270.8	7.7097	0.513740	2962.5
500	3483.4	8.0041	0.592000	3128.2
600	3701.7	8.2695	0.669760	3299.8
700	3926.4	8.5132	0.747250	3478.1
800	4157.9	8.7395	0.824570	3663.2
900	4396.2	8.9518	0.901790	3855.1
1000	4641.1	9.1521	0.978930	4053.8
1100	4892.4	9.3420	1.056030	4258.8
1200	5149.6	9.5229	1.133090	4469.8
1300	5412.5	9.6955	1.210120	4686.4
		P=0.80 Mpa		
170.41	2768.3	6.6616	0.240350	2576.0
200	2839.8	6.8177	0.260880	2631.1
250	2950.4	7.0402	0.293210	2715.9
300	3056.9	7.2345	0.324160	2797.5
350	3162.2	7.4107	0.354420	2878.6
400	3267.7	7.5735	0.384290	2960.2
500	3481.3	7.8692	0.443320	3126.6
600	3700.1	8.1354	0.501860	3298.7
700	3925.3	8.3794	0.560110	3477.2
800	4157.0	8.6061	0.618200	3662.5
900	4395.5	8.8185	0.676190	3854.5
1000	4640.5	9.0189	0.734110	4053.3
1100	4891.9	9.2090	0.791970	4258.3
1200	5149.3	9.3898	0.849800	4469.4
1300	5412.2	9.5625	0.907610	4686.1
		P=1.0 Mpa		

Table 6.5: Continued

Temp. °C T	Enthalpy kJ/kg h	Entropy kJ/kg s	Specific Volume m³/kg Cp	Internal Energy kJ/kg U
179.88	2777.1	6.5850	0.194370	2582.8
200	2828.3	6.6956	0.206020	2622.3
250	2943.1	6.9265	0.232750	2710.4
300	3051.6	7.1246	0.257990	2793.7
350	3158.2	7.3029	0.282500	2875.7
400	3264.5	7.4670	0.306610	2957.9
500	3479.1	7.7642	0.354110	3125.0
600	3698.6	8.0311	0.401110	3297.5
700	3924.1	8.2755	0.447830	3476.1
800	4156.1	8.5024	0.494380	3661.7
900	4394.8	8.7150	0.540830	3853.9
1000	4640.0	8.9155	0.587210	4052.7
1100	4891.4	9.1057	0.633540	4257.9
1200	5148.9	9.2866	0.679830	4469.0
1300	5411.9	9.4593	0.726100	4685.8
		P=1.20 Mpa		
187.96	2783.8	6.5217	0.163260	2587.8
200	2816.1	6.5909	0.169340	2612.9
250	2935.6	6.8313	0.192410	2704.7
300	3046.3	7.0335	0.213860	2789.7
350	3154.2	7.2139	0.234550	2872.7
400	3261.3	7.3793	0.254820	2955.5
500	3477.0	7.6779	0.294640	3123.4
600	3697.0	7.9456	0.333950	3296.3
700	3922.9	8.1904	0.372970	3475.3
800	4155.2	8.4176	0.411840	3661.0
900	4394.0	8.6303	0.450590	3853.3
1000	4639.4	8.8310	0.489280	4052.2
1100	4891.0	9.0212	0.527920	4257.5
1200	5148.5	9.2022	0.566520	4468.7
1300	5411.6	9.3750	0.605090	4685.5
		P=1.40 Mpa		
195.04	2788.9	6.4675	0.140780	2591.8
200	2803.0	6.4975	0.143030	2602.7
250	2927.9	6.7488	0.145280	2613.6
300	3040.9	6.9553	0.147530	2624.5
350	3150.1	7.1379	0.149780	2635.4
400	3258.1	7.3046	0.152030	2646.3

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
500	3474.8	7.6047	0.154280	2657.2
600	3695.5	7.8730	0.156530	2668.1
700	3921.7	8.1183	0.158780	2679.0
800	4154.3	8.3458	0.161030	2689.9
900	4393.3	8.5587	0.163280	2700.8
1000	4638.8	8.7595	0.165530	2711.7
1100	4890.5	8.9497	0.167780	2722.6
1200	5148.1	9.1308	0.170030	2733.5
1300	5411.3	9.3036	0.172280	2744.4
		P=1.60 Mpa		
201.37	2792.8	6.4200	0.123740	2594.8
225	2857.8	6.5537	0.132930	2645.1
250	2919.9	6.6753	0.141900	2692.9
300	3035.4	6.8864	0.158660	2781.6
350	3146.0	7.0713	0.174590	2866.6
400	3254.9	7.2394	0.190070	2950.8
500	3472.6	7.5410	0.220290	3120.1
600	3693.9	7.8101	0.249990	3293.9
700	3920.5	8.0558	0.279410	3473.5
800	4153.4	8.2834	0.308650	3659.5
900	4392.6	8.4965	0.337800	3852.1
1000	4638.2	8.6974	0.366870	4051.2
1100	4890.0	8.8878	0.395890	4256.6
1200	5147.7	9.0689	0.424880	4467.9
1300	5410.9	9.2418	0.453830	4684.8
		P=1.80 Mpa		
207.11	2795.9	6.3775	0.110370	2597.3
225	2847.2	6.4825	0.116780	2637.0
250	2911.7	6.6088	0.125020	2686.7
300	3029.9	6.8246	0.140250	2777.4
350	3141.9	7.0120	0.154600	2863.6
400	3251.6	7.1814	0.168490	2948.3
500	3470.4	7.4845	0.195510	3118.5
600	3692.3	7.7543	0.222000	3292.7
700	3919.4	8.0005	0.248220	3472.6
800	4152.4	8.2284	0.274260	3658.8

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	kJ/kg	kJ/kg	m³/kg	kJ/kg
T	h	s	Cp	U
900	4391.9	8..4417	0.300200	3851.5
1000	4637.6	8.6427	0.326060	4050.7
1100	4889.6	8.8331	0.351880	4256.2
1200	5147.3	9.0143	0.377660	4467.6
1300	5410.6	9.1872	0.403410	4684.5
		P=2.00 Mpa		
212.38	2798.3	6.3390	0.099590	2599.1
225	2836.1	6.4160	0.103810	2628.5
250	2903.3	6.5475	0.111500	2680.3
300	3024.2	6.7684	0.125510	2773.2
350	3137.7	6.9583	0.138600	2860.5
400	3248.4	7.1292	0.151220	2945.9
500	3468.3	7.4337	0.175680	3116.9
600	3690.7	7.7043	0.199620	3291.5
700	3918.2	7.9509	0.223260	3471.7
800	4151.5	8.1791	0.246740	3658.0
900	4391.9	8.3925	0.270120	3850.9
1000	4637.6	8.5936	0.293420	4050.2
1100	4889.6	8.7842	0.316670	4255.7
1200	5147.3	8.9654	0.339890	4467.2
1300	5410.6	9.1384	0.363080	4684.2
		P=2.50 Mpa		
223.95	2801.9	6.2558	0.079950	2602.1
225	2805.5	6.2629	0.080260	2604.8
250	2880.9	6.4107	0.087050	2663.3
300	3009.6	6.6459	0.098940	2762.2
350	3127.0	6.8424	0.109790	2852.5
400	3240.1	7.0170	0.120120	2939.8
450	3351.6	7.1768	0.130150	3026.2
500	3462.8	7.3254	0.139990	3112.8
600	3686.8	7.5979	0.159310	3288.5
700	3915.2	7.8455	0.178350	3469.3
800	4149.2	8.0744	0.197220	3656.2
900	4389.3	8.2882	0.215970	3849.4
1000	4635.6	8.4897	0.234660	4049.0
1100	4887.9	8.6804	0.253300	4254.7
1200	5146.0	8.8618	0.271900	4466.3
1300	5409.5	9.0349	0.290480	4683.4

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	kJ/kg	kJ/kg	m³/kg	kJ/kg
T	h	s	Cp	U
		P=3.00 Mpa		
233.85	2803.2	6.1856	0.066670	2603.2
225				
250	2856.5	6.2893	0.070630	2644.7
300	2994.3	6.5412	0.081180	2750.8
350	3116.1	6.7450	0.090560	2844.4
400	3231.7	6.9235	0.099380	2933.6
450	3344.9	7.0856	0.107890	3021.2
500	3457.2	7.2359	0.116200	3108.6
600	3682.8	7.5103	0.132450	3285.5
700	3912.2	7.7590	0.148410	3467.0
800	4146.9	7.9885	0.164200	3654.3
900	4387.5	8.2028	0.179880	3847.9
1000	4634.2	8.4045	0.195490	4047.7
1100	4886.7	8.5955	0.211050	4253.6
1200	5145.1	8.7771	0.226580	4465.3
1300	5408.8	8.9502	0.242070	4682.6
		P=3.50 Mpa		
242.56	2802.7	6.1244	0.057060	2603.0
225				
250	2829.7	6.1764	0.058760	2624.0
300	2978.4	6.4484	0.068450	2738.8
350	3104.9	6.6601	0.076800	2836.0
400	3223.2	6.8428	0.084560	2927.2
450	3338.1	7.0074	0.091980	3016.1
500	3451.7	7.1593	0.099190	3104.5
600	3678.9	7.4357	0.113250	3282.5
700	3909.3	7.6855	0.127020	3464.7
800	4144.6	7.9156	0.140610	3652.5
900	4385.7	8.1304	0.154100	3846.4
1000	4632.7	8.3324	0.167510	4046.4
1100	4885.6	8.5236	0.180870	4252.5
1200	5144.1	8.7053	0.194200	4464.4
1300	5408.0	8.8786	0.207500	4681.8
		P=4.00 Mpa		
250.35	2800.8	6.0696	0.049780	2601.7
275	2887.3	6.2312	0.054610	2668.9
300	2961.7	6.3639	0.058870	2726.2

Table 6.5: Continued

Temp. °C T	Enthalpy kJ/kg h	Entropy kJ/kg s	Specific Volume m³/kg Cp	Internal Energy kJ/kg U
350	3093.3	6.5843	0.066470	2827.4
400	3214.5	6.7714	0.073430	2920.8
450	3331.2	6.9386	0.080040	3011.0
500	3446.0	7.0922	0.086440	3100.3
600	3674.9	7.3706	0.098860	3279.4
700	3906.3	7.6214	0.110980	3462.4
800	4142.3	7.8523	0.122920	3650.6
900	4383.9	8.0675	0.134760	3844.8
1000	4631.2	8.2698	0.146530	4045.1
1100	4884.4	8.4612	0.158240	4251.4
1200	5143.2	8.6430	0.169920	4463.5
1300	5407.2	8.8164	0.181570	4680.9
		P=4.50 Mpa		
257.44	2798.0	6.0198	0.044060	2599.7
275	2864.4	6.1429	0.047330	2651.4
300	2944.2	6.2854	0.051380	2713.0
350	3081.5	6.5153	0.084200	2818.6
400	3205.7	6.7071	0.064770	2914.2
450	3324.2	6.8770	0.070760	3005.8
500	3440.4	7.0323	0.076520	3096.0
600	3670.9	7.3127	0.087660	3276.4
700	3903.3	7.5647	0.098500	3460.0
800	4140.0	7.7962	0.109160	3648.8
900	4382.1	8.0118	0.119720	3843.3
1000	4629.8	8.2144	0.130200	4043.9
1100	4883.2	8.4060	0.140640	4250.4
1200	5142.2	8.5880	0.151030	4462.6
1300	5406.5	8.7616	0.161400	4680.1
		P=5.00 Mpa		
263.94	2794.2	5.9737	0.039450	2597.0
275	2839.5	6.0571	0.041440	2632.3
300	2925.7	6.2111	0.045350	2699.0
350	3069.3	6.4516	0.051970	2809.5
400	3196.7	6.6483	0.057840	2907.5
450	3317.2	6.8210	0.063320	3000.6
500	3434.7	6.9781	0.068580	3091.8
600	3666.9	7.2605	0.078700	3273.3
700	3900.3	7.5136	0.088520	3457.7

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
800	4137.7	7.7458	0.098160	3646.9
900	4380.2	7.9619	0.107690	3841.8
1000	4628.3	8.1648	0.117150	4042.6
1100	4882.1	8.3566	0.126550	4249.3
1200	5141.3	8.5388	0.135920	4461.6
1300	5405.7	8.7124	0.145270	4679.3
		P=6.00 Mpa		
275.59	2784.6	5.8902	0.032500	2589.9
300	2885.6	6.0703	0.036190	2668.4
350	3043.9	6.3357	0.042250	2790.4
400	3178.3	6.5432	0.047420	2893.7
450	3302.9	6.7219	0.052170	2989.9
500	3423.1	6.8826	0.056670	3083.1
550	3541.3	7.0308	0.061020	3175.2
600	3658.8	7.1693	0.065270	3267.2
700	3894.3	7.4247	0.073550	3453.0
800	4133.1	7.6582	0.081650	3643.2
900	4376.6	7.8751	0.089640	3838.8
1000	4625.4	8.0786	0.097560	4040.1
1100	4879.7	8.2709	0.105430	4247.1
1200	5139.4	8.4534	0.113260	4459.8
1300	5404.1	8.6273	0.121070	4677.7
		P=7.00 Mpa		
285.83	2772.6	5.8148	0.027378	2581.0
300	2839.9	5.9337	0.029492	2633.5
350	3016.9	6.2305	0.035262	2770.1
400	3159.2	6.4502	0.039958	2879.5
450	3288.3	6.6353	0.044187	2979.0
500	3411.4	6.8000	0.048157	3074.3
550	3531.6	6.9507	0.051966	3167.9
600	3650.6	7.0910	0.055665	3261.0
700	3888.3	7.3487	0.062850	3448.3
800	4128.5	7.5836	0.069856	3639.5
900	4373.0	7.8014	0.076750	3835.7
1000	4622.5	8.0055	0.083571	4037.5
1100	4877.4	8.1982	0.090341	4245.0
1200	5137.4	8.3810	0.097075	4457.9
1300	5402.6	8.5551	0.103781	4676.1

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
		P=8.00 Mpa		
295.01	2758.7	5.7450	0.023525	2570.5
300	2786.5	5.7937	0.024279	2592.3
350	2988.1	6.1321	0.029975	2748.3
400	3139.4	6.3658	0.034344	2864.6
450	3273.3	6.5579	0.038194	2967.8
500	3399.5	6.7266	0.041767	3065.4
550	3521.8	6.8800	0.045172	3160.5
600	3642.4	7.0221	0.048463	3254.7
700	3882.2	7.2822	0.054829	3443.6
800	4123.8	7.5185	0.061011	3635.7
900	4369.3	7.7372	0.067082	3832.7
1000	4619.6	7.9419	0.073079	4035.0
1100	4875.0	8.1350	0.079025	4242.8
1200	5135.5	8.3181	0.084934	4456.1
1300	5401.0	8.4925	0.090817	4674.5
		P=9.00 Mpa		
303.35	2742.9	5.6791	0.020489	2558.5
325	2857.1	5.8738	0.023284	2647.6
350	2957.3	6.0380	0.025816	2725.0
400	3118.8	6.2876	0.029960	2849.2
450	3258.0	6.4872	0.033524	2956.3
500	3387.4	6.6603	0.036793	3056.3
550	3512.0	6.8164	0.039885	3153.0
600	3634.1	6.9605	0.042861	3248.4
650	3755.2	7.0954	0.045755	3343.4
700	3876.1	7.2229	0.048589	3438.8
800	4119.2	7.4606	0.054132	3632.0
900	4365.7	7.6802	0.059562	3829.6
1000	4616.7	7.8855	0.064919	4032.4
1100	4872.7	8.0791	0.077022	4240.7
1200	5133.6	8.2625	0.075492	4454.2
1300	5399.5	8.4371	0.080733	4672.9
		P=10.00 Mpa		
311	2725.5	5.6159	0.018028	2545.2
325	2810.3	5.7596	0.019877	2611.6
350	2924.0	5.9460	0.022440	2699.6
400	3097.5	6.2141	0.026436	2833.1

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
450	3242.4	6.4219	0.029782	2944.5
500	3375.1	6.5995	0.032811	3047.0
550	3502.0	6.7585	0.035655	3145.4
600	3625.8	6.9045	0.038378	3242.0
650	3748.1	7.0408	0.041018	3338.0
700	3870.0	7.1693	0.043597	3434.0
800	4114.5	7.4085	0.048629	3628.2
900	4362.0	7.6290	0.053547	3826.5
1000	4613.8	7.8349	0.058391	4029.9
1100	4870.3	8.0289	0.063183	4238.5
1200	5131.7	8.2126	0.067938	4452.4
1300	5398.0	8.3874	0.072667	4671.3
		P=12.50 Mpa		
327.81	2674.3	5.4638	0.013496	2505.6
350	2826.6	5.7130	0.016138	2624.9
400	3040.0	6.0433	0.020030	2789.6
450	3201.5	6.2749	0.023019	2913.7
500	3343.6	6.4651	0.025630	3023.2
550	3476.5	6.6317	0.028033	3126.1
600	3604.6	6.7828	0.030306	3225.8
650	3730.2	6.9227	0.032491	3324.1
700	3854.6	7.0540	0.034612	3422.0
800	4102.8	7.2967	0.038724	3618.8
900	4352.9	7.5195	0.042720	3818.9
1000	4606.5	7.7269	0.046641	4023.5
1100	4864.5	7.9220	0.050510	4233.1
1200	5127.0	8.1065	0.054342	4447.7
1300	5394.1	8.2819	0.058147	4667.3
		P=15.00 Mpa		
342.16	2610.8	5.3108	0.010341	2455.7
350	2693.1	5.4438	0.011481	2520.9
400	2975.7	5.8882	0.015671	2740.6
450	3157.9	6.1434	0.018477	2880.8
500	3310.8	6.3480	0.020828	2998.4
550	3450.4	6.5230	0.022945	3106.2
600	3583.1	6.6796	0.024921	3209.3
650	3712.1	6.8233	0.026804	3310.1
700	3839.1	6.9573	0.028621	3409.8

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
800	4091.1	7.2037	0.032121	3609.3
900	4343.7	7.4288	0.035503	3811.2
1000	4599.2	7.6378	0.038808	4017.1
1100	4858.6	7.8339	0.042062	4227.7
1200	5122.3	8.0192	0.045279	4443.1
1300	5390.3	8.1952	0.048469	4663.3
		P=17.50 Mpa		
354.67	2529.5	5.1435	0.007932	2390.7
400	2902.4	5.7211	0.012463	2684.3
450	3111.4	6.0212	0.015204	2845.4
500	3276.7	6.2424	0.017385	2972.4
550	3423.6	6.4266	0.019305	3085.8
600	3561.3	6.5890	0.021073	3192.5
650	3693.8	6.7366	0.022742	3295.8
700	3823.5	6.8735	0.024342	3397.5
800	4079.3	7.1237	0.027405	3599.7
900	4334.6	7.3511	0.030348	3803.5
1000	4592.0	7.5616	0.033215	4010.7
1100	4852.8	7.7588	0.036029	4222.3
1200	5117.6	7.9449	0.038806	4438.5
1300	5386.5	8.1215	0.041556	4659.2
		P=20.00 Mpa		
365.75	2412.1	4.9310	0.005862	2294.8
400	2816.9	5.5526	0.009950	2617.9
450	3061.7	5.9043	0.012721	2807.3
500	3241.2	6.1446	0.014793	2945.3
550	3396.2	6.3390	0.016571	3064.7
600	3539.0	6.5075	0.018185	3175.3
650	3675.3	6.6593	0.019695	3281.4
700	3807.8	6.9910	0.021134	3385.1
800	4067.5	7.0531	0.023870	3590.1
900	4325.4	7.2829	0.026484	3795.7
1000	4584.7	7.4950	0.029020	4004.3
1100	4847.0	7.6933	0.031504	4216.9
1200	5112.9	7.8802	0.033952	4433.8
1300	5382.7	8.0574	0.036371	4655.2
		P=25.00 Mpa		
375	1849.4	4.0345	0.001978	1799.9

Table 6.5: Continued

Temp. °C T	Enthalpy kJ/kg h	Entropy kJ/kg s	Specific Volume m³/kg Cp	Internal Energy kJ/kg U
400	2578.7	5.1400	0.006005	2428.5
425	2805.0	5.4708	0.007886	2607.8
450	2950.6	5.6759	0.009176	2721.2
500	3165.9	5.9643	0.011143	2887.3
550	3339.2	6.1816	0.012736	3020.8
600	3493.5	6.3637	0.014140	3140.0
650	3637.7	6.5243	0.015430	3251.9
700	3776.0	6.6702	0.016643	3359.9
800	4043.8	6.9322	0.018922	3570.7
900	4307.1	7.1668	0.021075	3780.2
1000	4570.2	7.3821	0.023150	3991.5
1100	4835.4	7.5825	0.025172	4206.1
1200	5103.5	7.7710	0.027157	4424.6
1300	5375.1	7.9494	0.029115	4647.2
		P=30.00 Mpa		
375	1791.9	3.9313	0.001792	1738.1
400	2152.8	4.4758	0.002798	2068.9
425	2611.8	5.1473	0.005299	2452.9
450	2821.0	5.4422	0.006737	2618.9
500	3084.8	5.7956	0.008691	2824.0
550	3279.7	6.0403	0.010175	2974.5
600	3446.8	6.2373	0.011445	3103.4
650	3599.4	6.4074	0.012590	3221.7
700	3743.9	6.5599	0.013654	3334.3
800	4020.0	6.8301	0.015628	3551.2
900	4288.8	7.0695	0.017473	3764.6
1000	4555.8	7.2880	0.019240	3978.6
1100	4823.9	7.4906	0.020954	4195.2
1200	5094.2	7.6807	0.022630	4415.3
1300	5367.6	7.8602	0.024279	4639.2
		P=35.00 Mpa		
375	1762.4	3.8724	0.001701	1702.8
400	1988.6	4.2144	0.002105	1914.9
425	2373.5	4.7751	0.003434	2253.3
450	2671.0	5.1946	0.004957	2497.5
500	2997.9	5.6331	0.006933	2755.3
550	3218.0	5.9093	0.008348	2925.8
600	3390.0	6.1229	0.009523	3065.6

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
700	3711.6	6.4623	0.011523	3380.3
800	3996.3	6.7409	0.013278	3531.6
900	4270.6	6.9853	0.014904	3749.0
1000	4541.5	7.2069	0.016450	3965.8
1100	4812.4	7.4118	0.017942	4184.4
1200	5085.0	7.6034	0.019398	4406.1
1300	5360.2	7.7841	0.020827	4631.2
		P=40.00 Mpa		
375	1742.6	3.8290	0.001641	1677.0
400	1931.4	4.1145	0.001911	1855.0
425	2199.0	4.5044	0.002538	2097.5
450	2511.8	4.9449	0.003692	2364.2
500	2906.5	5.4744	0.005623	2681.6
550	3154.4	5.7857	0.006985	2875.1
600	3350.4	6.0170	0.008089	3026.8
650	3521.6	6.2078	0.009053	3159.5
700	3679.2	6.3740	0.009930	3282.0
800	3972.6	6.6613	0.011521	3511.8
900	4252.5	6.9107	0.012980	3733.3
1000	4527.3	7.1355	0.014360	3952.9
1100	4801.1	7.3425	0.015686	4173.7
1200	5075.9	7.5357	0.016976	4396.9
1300	5352.8	7.7175	0.018239	4623.3
		P=50.00 Mpa		
375	1716.6	3.7642	0.001560	1638.6
400	1874.4	4.0029	0.001731	1787.8
425	2060.7	4.2746	0.002009	1960.3
450	2284.7	4.5896	0.002487	2160.3
500	2722.6	5.1762	0.003890	2528.1
550	3025.4	5.5563	0.005118	2769.5
600	3252.6	5.8245	0.006108	2947.1
650	3443.5	6.0373	0.006957	3095.6
700	3614.6	6.2179	0.007717	3228.7
800	3925.8	6.5225	0.009073	3472.2
900	4216.8	6.7819	0.010296	3702.0
1000	4499.4	7.0131	0.011441	3927.4
1100	4778.9	7.2244	0.012534	4152.2
1200	5058.1	7.4207	0.013590	4378.6

Table 6.5: Continued

Temp.	Enthalpy	Entropy	Specific Volume	Internal Energy
°C	**kJ/kg**	**kJ/kg**	**m³/kg**	**kJ/kg**
T	**h**	**s**	**Cp**	**U**
1300	5338.5	7.6048	0.014620	4607.5
		P=60.00 Mpa		
375	1699.9	3.7149	0.001503	1609.7
400	1843.2	3.9317	0.001633	1745.2
425	2001.8	4.1630	0.001816	1892.9
450	2180.2	4.4140	0.002086	2055.1
500	2570.3	4.9356	0.002952	2393.2
550	2901.9	5.3517	0.003955	2664.6
600	3156.8	5.6527	0.004833	2866.8
650	3366.8	5.8867	0.005591	3031.3
700	3551.3	6.0814	0.006265	3175.4
800	3880.0	6.4033	0.007456	3432.6
900	4182.1	6.6725	0.008519	3670.9
1000	4472.2	6.9099	0.009504	3902.0
1100	4757.3	7.1255	0.010439	4130.9
1200	5040.8	7.3248	0.011339	4360.5
1300	5324.5	7.5111	0.012213	5324.5