What Every Energy Engineer Needs to Know about Thermodynamics and Liquefication Systems - Part 2

An Online Continuing Education Course for Engineers

Course Number: O-7004

Credit: 7 Hours / 7 PDH / 7 CPD

O-7004: What Every Energy Engineer Needs to Know about Thermodynamics and Liquefication Systems - Part 2

Steven Vitale, P.E., PhD

1. Learning Objectives

This course is the first in a 4-course series.

- Part 1 is based on understanding thermodynamic concepts and using pressure enthalpy charts.
- Part 2 builds onto Part 1 but uses thermodynamic software instead of pressure enthalpy charts for analysis and goes into additional depth.
- Part 3 (consisting of Parts 3A and 3B) builds on parts 1 and 2 to apply thermodynamics to understand air conditioning and refrigeration systems from ¼ hp size units to 300,000 hp size units. Part 3A focuses on pure substances and mixed refrigerant liquefaction systems. Part 3B focuses on nitrogen expansion liquefaction systems.

Note that each course in the series is a “stand-alone” course. It is not necessary to first complete Parts 1 and 2 in order to study Parts 3A & 3B, provided the learner already possesses the prerequisite knowledge needed.

This course (Part 2) introduces the learner to using thermodynamic software instead of charts for performing thermodynamic analyses. Such software is much more time-efficient, accurate, and flexible. Thermodynamic software allows the learner to dive deeper into their understanding of the field of thermodynamics. In this part, we will build on the learning of Part 1 and expand our ability to deal with mixtures rather than solely the pure fluid of methane.

In Part 2, a major focus is made on broadening the scope of understanding thermodynamics. Pump and compressor efficiencies and understanding many facets of thermodynamics that would not be adequately explained without using thermodynamic software are explained.

Portions © 2024 Decatur Professional Development, LLC. All rights reserved.

2. Acknowledgments

Thanks are given to the National Institute of Science and Technology (NIST) for making relatively inexpensive software available to aid in the understanding of thermodynamic processes. NIST has made the software very user-friendly. The identifying information on this software is shown in Figure 1.

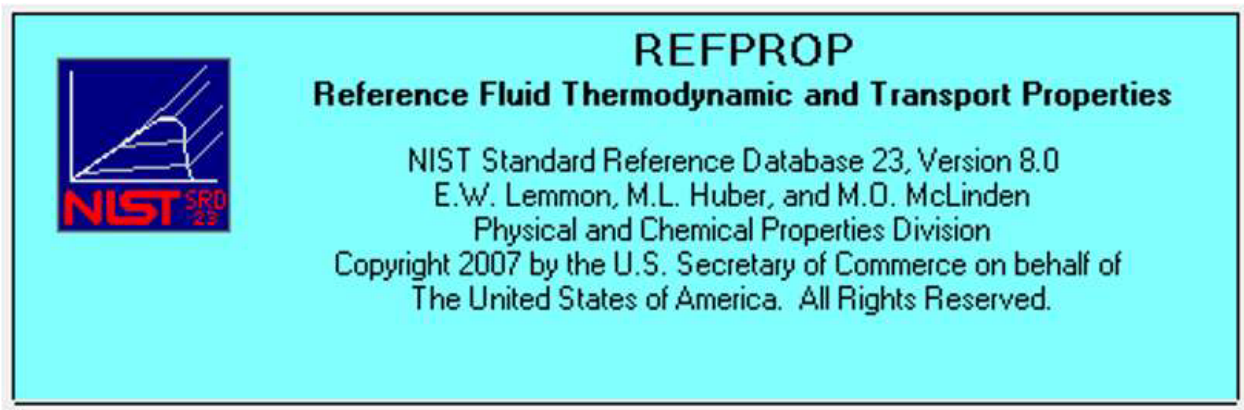


Figure 1: REFPROP information. *Source REFPROP Software*

A special thanks is given to Dr. Eric Lemmon of NIST. Over the past 15 years, he has continued to enhance this software and has always made himself available to explain its use. His contribution to making thermodynamic computation available to the masses has greatly benefited science and technology. His inspiring knowledge and willingness to help me to train others in the understanding of thermodynamics has been career changing and is much appreciated.

3. What Every Energy Engineer Needs to Know about Thermodynamics and Liquefaction Systems Part 2

What Every Energy Engineer Needs to Know about Thermodynamics and Liquefaction Systems Part 1, explained the basics of thermodynamics as applied to natural gas and LNG. It relied heavily on the use of pressure enthalpy charts for the pure substance methane. The use of these charts was good for building an understanding of the basics. However, the shortcomings of using these charts are the inaccuracy of reading the charts by eye and the inability to easily manage data for hydrocarbon mixtures. Also, it was tedious to scrutinize and interpolate the fine lines of various properties on the Ph diagrams, which sometimes resulted in learner frustration.

What Every Energy Engineer Needs to Know about Thermodynamics and Liquefaction Systems Part 2 builds on the information presented in Part 1 and introduces the use of software for understanding more complex concepts.

Portions © 2024 Decatur Professional Development, LLC. All rights reserved.

Although not essential, a companion list of conversions should be used with this book. The one used in this work is that published by the Sequoia Publishing Company in their pocket reference 4th edition. Further, although not essential, it is recommended that the Ph diagram used in the Part 1 learning (published in 1962 by Hydrocarbon Research) be used along with this work as there is some reference made to that diagram Ph diagram. The source information on the 1962 Ph diagram is shown in Figure 2.

FROM: Canjar, Lawrence N.; Tejada, Victo1 M.; Manning, Francis S. "Thermo Proper- amic properties of methane". Hydrocarbon Processing, vol. 41, no. 9, Sep. 1962. pp

Figure 2: Source of Ph diagram used in Part 1 and Part 2 of this course

A copy of that Ph diagram accompanies this course.

4. Disclaimers

Although I believe this information to be correct, no guarantee is given to its accuracy or completeness. The user must evaluate and use this information safely and comply with all applicable laws and regulations. No statement made in this document shall be construed as a permission or recommendation for the use of any product that might infringe existing patents or put persons or property at risk. No warranty is made, either express or implied.

The NIST software used in this book has its limitations. Cautions are given in the software and the NIST documentation. The reader of this course is asked to read the NIST software documentation to better understand the limitations of the software. In particular, I show below, in Figure 3, the NIST caution that appears upon opening the software.

NIST uses its best efforts to deliver a high quality copy of the Database and to verify that the data contained therein have been selected on the basis of sound scientific judgement. However, NIST makes no warranties to that effect, and NIST shall not be liable for any damage that may result from errors or omissions in the Database.

Figure 3: NIST disclaimer *(Source: REFPROP software)*

5. Cautionary Notes

This document is intended to teach basic concepts. To accomplish this, it explains thermodynamic processes using a simplified approach.

Portions © 2024 Decatur Professional Development, LLC. All rights reserved.

Real plants have pressure drops associated with flows through piping, heat exchangers, and other process equipment. Such pressure drops are not taken into account in the simplified examples given herein. Parts of the plant, such as the CO_2 and water removal systems, were not included in the Part 2 analysis because their study is outside the scope of Part 2 but will be discussed in Part 3 of this course.

Rounded-off numbers are often used throughout to allow the reader to focus on the concept and not get bogged down in numerical detail. Also, pure methane is often used as a study fluid when the real-world fluid would be natural gas, which is a mixture of many components.

It needs to be realized that different agencies use different values for Standard Temperature and Pressure or Normal Temperature and Pressure. Therefore, the reader needs to understand that before any analysis is attempted, the analyst needs to know the definition of Normal or Standard conditions for the calculation being made. Some of the various standard reference conditions are shown below.

Table 1: Standard Reference Conditions. Source: Wikipedia

Standard reference conditions in current use

Temperature	Absolute pressure	Relative humidity	Publishing or establishing entity
°C	kPa	% RH	
0	100.000		IUPAC (present definition)[1]
0	101.325		NIST,[7] ISO 10780,[8] formerly IUPAC[1]
15	101.325	0[9][10]	ICAO's ISA,[9] ISO 13443,[10] EEA,[11] EGIA[12]
20	101.325		EPA,[13] NIST[14]
25	101.325		EPA[15]
25	100.000		SATP[16]
20	100.000	0	CAGI[17]
15	100.000		SPE[18]
20	101.3	50	ISO 5011[19]
°F	psi	% RH	
60	14.696		SPE,[18] U.S. OSHA,[20] SCAQMD[21]
60	14.73		EGIA,[12] OPEC,[22] U.S. EIA[23]
59	14.503	78	U.S. Army Standard Metro[24][25]
59	14.696	60	ISO 2314, ISO 3977-2[26]
°F	in Hg	% RH	
70	29.92	0	AMCA,[27][28] air density = 0.075 lbm/ft³. This AMCA standard applies only to air.
59 (15c)	29.92 (1013.25 hPa)		FAA, FAA's Pilot Handbook of Aeronautical Knowledge, Chapter 3[29]

In this document, the SI Normal Temperature and Pressure used are 1.01325 bar and 0 C unless otherwise stated. The English Standard Temperature and Pressure used are 60 F and 14.696 unless otherwise stated.

Portions © 2024 Decatur Professional Development, LLC. All rights reserved.

5.1. A word about standard conditions

Take note that an scf is a mass measurement because it is a measure of a fixed number of molecules. That is because an scf is 1 cf at 60 F and 14.696 psia for the standard condition I chose to use. You need to determine which "Standard Conditions" you should use depending on what industry you are in and what your suppliers and customers are using.

For example, many in the Natural Gas Industry use 60 F and 14.73 psia as standard conditions. Although the difference in properties between 14.696 psia and 14.73 psia is small, when multiplied by billions of cubic feet, the mass delivered and associated dollar value can be large. For example, if an LNG ship is delivering $30,000,000 worth of LNG, the difference between a standard pressure of 14.696 psia and 14.73 psia for contract calculations can equate to a difference of approximately $70,000 per shipload. If that error is made for 100 ships per year, the cumulative effect can be an error of $7,000,000 per year.

Unless otherwise stated or obvious by the nature of the problem, all process problems presented in this learning are to be considered steady-state, steady-flow processes.

6. Prerequisites for Learning from this Book

The work herein presumes that the learner has completed and understands the concepts from *What Every Energy Engineer Needs to Know about Thermodynamics and Liquefaction Systems Part 1.*

7. Units

In Part 1 of this course, English units were used. It is expected that the learner will need to easily be able to switch between English and SI units in the workplace. Thus, in order to maximize the learning experience and since our industry uses both English and SI units, both units are used in Part 2 of this course. See Figure 4.

> In this work, unless otherwise stated, mixtures are molar mixtures and not mass mixtures. Thus, if a mixture is stated to be a 97/3 methane ethane mixture it is a molar mixture and not a mass mixture unless defined as a mass mixture in the text.

Figure 4: Statement on how to understand mixtures. Source: *Self-made*

8. Introduction

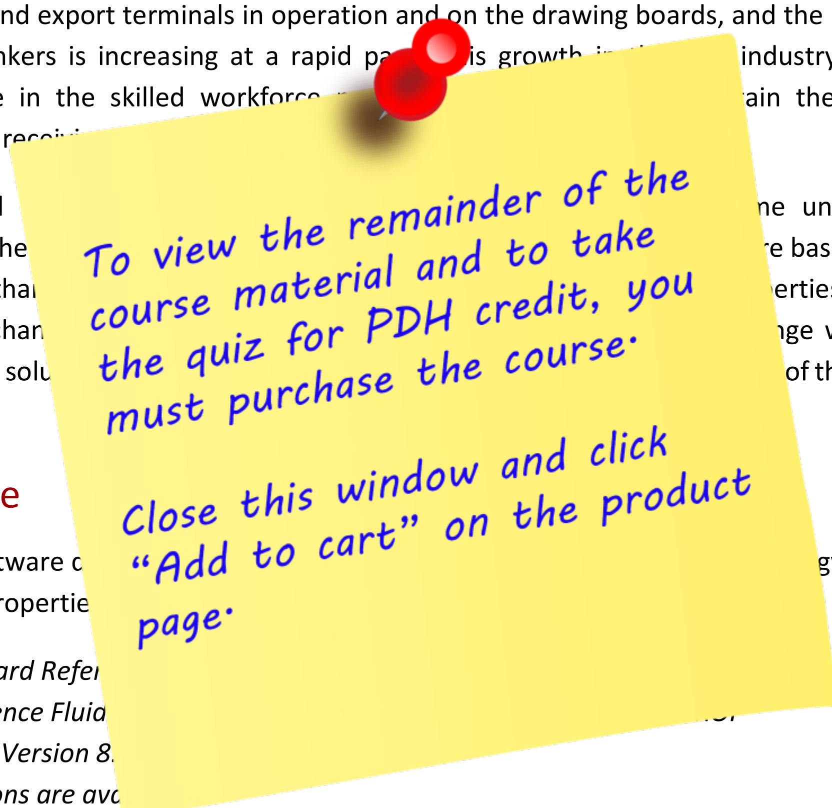
This course is intended to help Liquefied Natural Gas (LNG) engineers better understand the basic thermodynamic principles they deal with daily. Although this learning specifically deals with LNG, methane gas, and mixtures of natural gas, the principles certainly pertain to propane, refrigerants, and other gases that engineers manage.

Portions © 2024 Decatur Professional Development, LLC. All rights reserved.

LNG is an essential part of the gas industry's supply portfolio. It is used during our most critical supply times and is available only because we have reliable equipment and a highly skilled staff of operators and engineers.

Currently, LNG accounts for only a few percent of the U.S. gas supply. However, during a peak day, LNG may account for 30% of a local distribution company's sendout. LNG also allows local gas production and stored natural gas supplies to contribute to the global energy picture as this gas can be transported in liquid form around the world. LNG utilization has grown significantly over the next 10 years, and it is highly likely that LNG will play a very important role in the future U.S and global energy picture. Today there are numerous import and export terminals in operation and on the drawing boards, and the present fleet of worldwide LNG tankers is increasing at a rapid pa ... is growth ... industry will require a significant increase in the skilled workforc ... ain these production, processing, export, r...

To better respond ... ne understanding of thermodynamics. The ... e basic and based on application rather tha ... erties of the fluid at any point do not chan ... ge with time) type problems. All of the solu ... of thermodynamics or software.



9. Software

In this learning, software c ... gy (NIST) is used to determine the propertie...

NIST Standard Refer...
NIST Reference Fluid...
April 2007, Version 8...
Later versions are av...

It should be noted that, at the time of this writing, Version 10 is available. For this work, Version 8.0 is being used. The program will always be referred to as REFPROP.

9.1. Mechanics of using the Software

The first thing you will need to do is to obtain the software, read the related documentation and install the software on your computer. Once REFPROP is installed, the icon, shown in Figure 5, should appear on your computer desktop. The file name should also appear in your list of programs.

Start the program by double-clicking the REFPROP icon on your desktop or via your all programs list.

Portions © 2024 Decatur Professional Development, LLC. All rights reserved.