Fuels and Combustion of Fuels

Thermal Processing

ESSENTIALS OF FOOD PROCESS ENGINEERING

Chandra Gopala Rao

Physical Variables

FLUID MECHANICS

ENGINEERING CALCULATIONS

DIMENSIONS

Refrigeration

NATURAL VARIABLES

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Essentials of
Food Process Engineering

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Essentials of
Food Process Engineering

Preface

Food Technology mainly consists of post harvest engineering and value addition to raw food material and as such is more an engineering than other related courses. Government of India has created a separate ministry for food processing with an objective of encouraging farmers to go on large scale for processing of agricultural and horticultural crops into directly edible food forms. This is also true with meat and fish. Many agricultural universities in the country has a Post Graduation programme in food technology. The graduates in Agriculture, Horticulture, Food Science and Biology are opting to do Post Graduation in Food technology as this course has good job potential in India and also in abroad. In most of the universities there are 3 Core courses of Engineering in Post Graudation programmes of food technology namely, Basic Food Engineering, Food Process Equipment, Food Plant Sanitation and one or two supporting courses like Milling Technology etc. The educational qualification for admission into this programme is any degree other than the degree in Arts. Our past experience in ANGRAU has shown that mostly the students with B.Sc (Ag), B.Sc (Hort.), B.Sc (Nutrition) and B.Sc. (Food Science) are taking admission in M.Sc. Food Technology. These students are facing lot of difficulty in studying the courses of engineering as they do not have exposure in these subjects prior to admission into this programme. There is no single book where they can get all the fundamentals of food engineering in a simplest and easiest way. This has resulted in getting low overall grade point average (OGPA) by most of the students in spite of putting hard work. This is also true with the students in other universities.

There are several books on basics of food engineering available in the market, but these generally assume that the reader has already some background in mathematics and engineering principles.

The primary aim of this book is to present the principles of food process engineering in a way that is understandable to biology students studying M.Sc. food technology. It is mainly to give an exposure in engineering concepts and some basic equipment used in food process industries to the students of Biology, Chemistry, Animal Science etc.

One of the biggest challenges in preparing the test was determining the appropriate level of mathematics. In general, biology students do not often encounter detailed mathematical analysis. A great deal of engineering involves formulation and solution of mathematical models and many important aspects about principles of working of equipment. It is neither easy nor desirable to eliminate all mathematics from a textbook as this. Mathematical treatment is necessary to show how design equations depend on crucial assumption. However, the equations are so simple and their application so useful that the biology students can become familiar with them once they go through the chapters.

Food parameters like brix, viscosity, moisture content and process parameters like pressure, temperature and flow rates are to be measured as their values guide in running the plant efficiently and also in monitoring the quality of the food products. Realizing the importance of this a separate chapter is given on measurements in Food Processing Industry.

Every academic course in general consists of the components of theory as well as practicals. To conduct practicals for courses where the basic engineering concepts are involved is rather difficult and also the ready made equipment is not available at present. The best way for covering the practical contents in such courses is by solving problems. With this idea, at the end of each chapter numericals are given which, if solved by students in practical classes, will make them as if they have actually conducted the experiments in that aspect of engineering principle. Similar concept is practiced in almost all engineering colleges and even by the national institutes like IITs and NITs.

In this book there are more than 50 solved problems encompassing a wide range of basics such as units and dimensions, mass and energy balance, fluid mechanics, heat and mass transfer etc.

Once the student completes the course by reading this book, he will become aware about all the engineering principles governing the working of food process equipment. The same fundamental principles can be readily applied to a variety of vegetative, non-vegetative and aqua food industries.

Although this book is written primarily for biology student, it will also be useful in dairy industry and for other food industry practitioners.

I would like to express a deep sense of gratitude to our Vice-chancellor Dr. S. Raghuvardhan Reddy garu, and to our Dean of Agriculture I/c, and Director of Research Dr .A. Padmaraju garu, for their support in preparing this book. I am grateful to, Dr. C. R. Sukumaran, Associate Dean College of Food Science and Technology, Bapatla and to Dr. N. Radhakrishnamoorthy, Associate Dean, College of Agricultural Engineering, Bapatla for the help rendered in compiling the contents.

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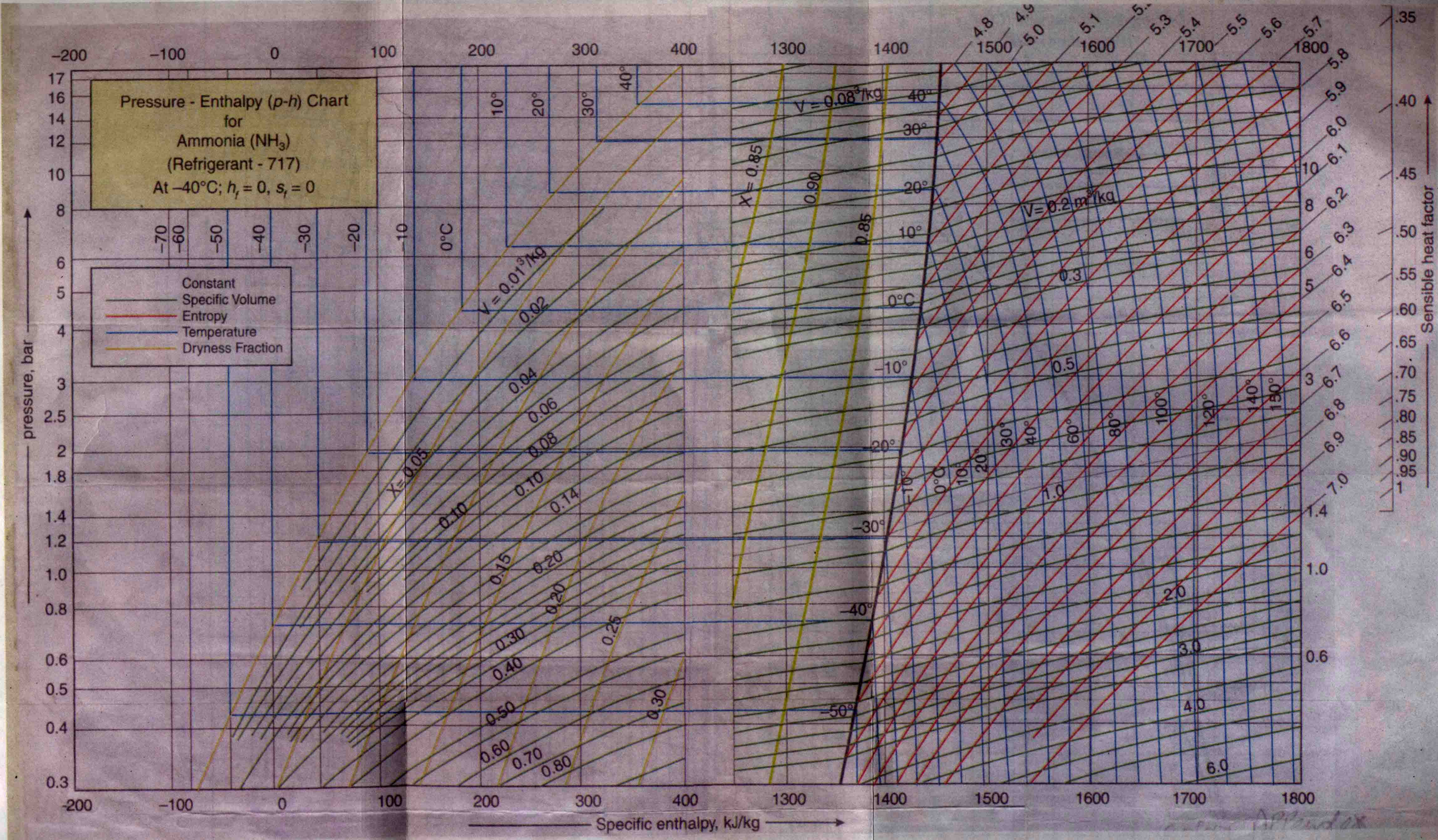
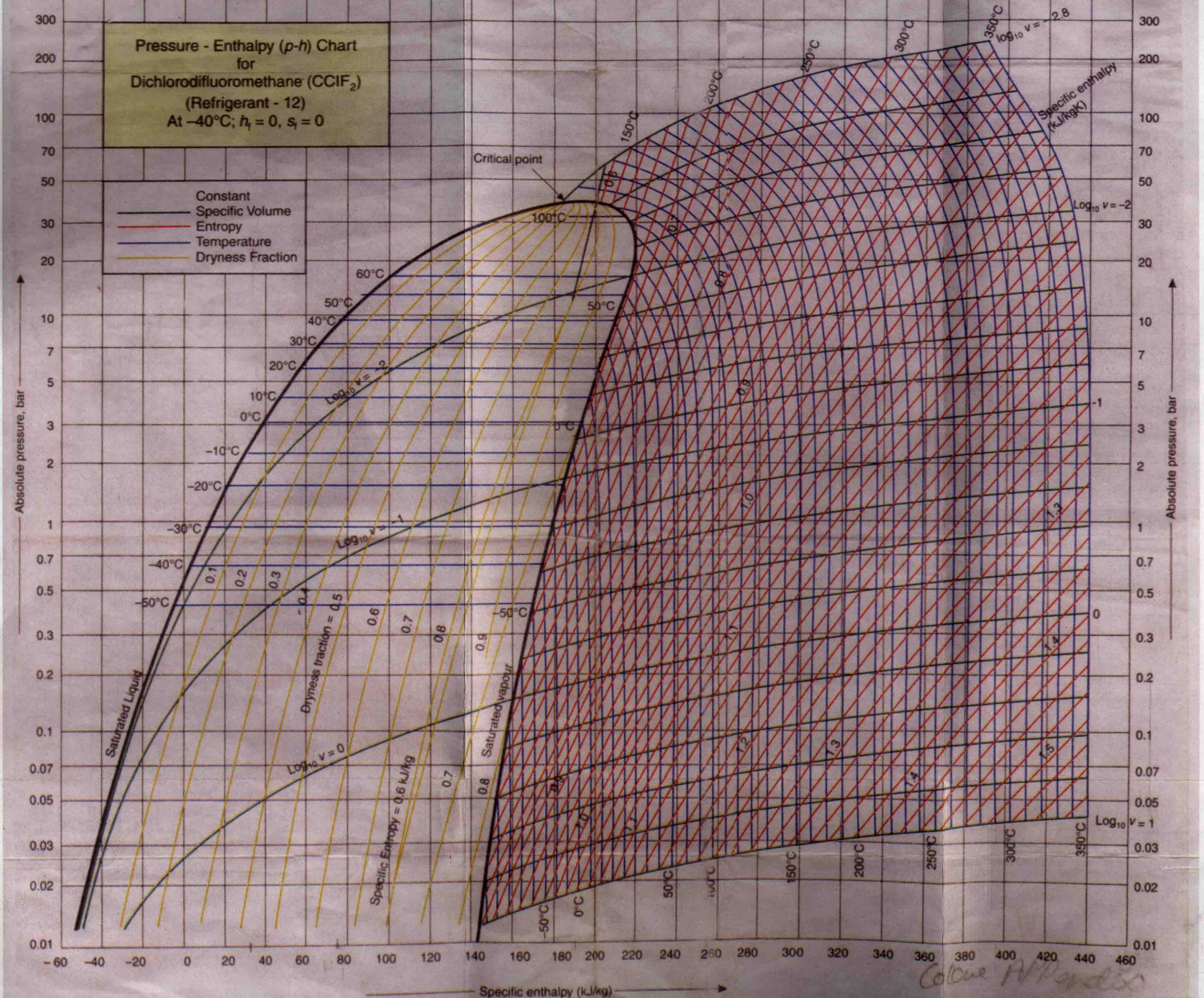


Pressure - Enthalpy (p-h) Chart
for
Ammonia (NH_3)
(Refrigerant - 717)
At –40°C; h_f = 0, s_f = 0
Constant
Specific Volume
Entropy
Temperature
Dryness Fraction
pressure, bar
Specific enthalpy, kJ/kg
Sensible heat factor
X = 0.05
X = 0.85
V = 0.01 m^3/kg
V = 0.08 m^3/kg
V = 0.2 m^3/kg



Pressure - Enthalpy (p-h) Chart
for
Dichlorodifluoromethane (CClF2)
(Refrigerant - 12)
At –40°C; h_f = 0, s_f = 0
Constant
Specific Volume
Entropy
Temperature
Dryness Fraction
Critical point
Saturated Liquid
Saturated vapour
Dryness fraction = 0.5
Specific Entropy = 0.6 kJ/kg
Specific enthalpy (kJ/kgK)
Absolute pressure, bar
Specific enthalpy (kJ/kg)
Log10 v = –2.8
Log10 v = –2
Log10 v = 1
Colour Appendix

Contents

Chapter 1

Introduction to Engineering Calculations

Calculations used in food process engineering require a systematic approach with well-defined methods and rules. Conventions and definitions which form the backbone of engineering analysis are presented in this chapter. In laying the foundation for calculations and problem-solving, this chapter will be a useful reference which you may need to review from time to time.

The first step in quantitative analysis of systems is to express the system properties using mathematical language. The nature of physical variables, dimensions and units are discussed, and formalized procedures for unit conversions outlined. Worked examples and problems are used to illustrate and reinforce the material described in the text.

Physical Variables, Dimensions and Units

Engineering calculations involve manipulation of numbers. Most of these numbers represent the magnitude of measurable *physical variables,* such as mass, length, time, velocity, area, viscosity, temperature, density, and so on. Other observable characteristics of nature, such as taste or aroma, cannot at present be described completely using appropriate numbers; we cannot, therefore, include these in calculations.

From all the physical variables in the world, the seven quantities listed in the Table 1.1 have been chosen by international agreement as a basis for measurement. Two further supplementary units are used to express angular quantities. The base quantities are called *dimensions,* and it is from these that the dimensions of other physical variables are derived. For example, the dimensions of velocity, defined as distance travelled per unit time, are LT^{-1}; the dimensions of force, being mass × acceleration, are LMT^{-2}. A list of useful derived dimensional quantities is given in Table 1.2.

Table 1.1 Base quantities.

Base quantity	**Dimensional symbol**	**Base SI unit**	**Unit symbol**
Length	L	Metre	M
Mass	M	Kilogram	kg
Time	T	Second	S
Electric current	I	Ampere	A
Temperature	Θ	Kelvin	K
Amount of substance	N	gram-mole	mol or gmol
Luminous intensity	J	candela	cd
Supplementary units			
Plane angle	–	Radian	rad
Solid angle	–	Steradian	Sr

Table 1.2 Dimensional quantities (dimensionless quantities have dimension 1).

Quantity	**Dimensions**	**Quantity**	**Dimensions**
Acceleration	LT^{-2}	Angular velocity	T^{-1}
Area	L^2	Atomic weight ('relative atomic mass')	1
Concentration	$L^{-3}N$		
Conductivity	$L^{-3}M^{-1}T^3I^2$	Density	$L^{-3}M$
Diffusion coefficient	L^2T^{-1}	Distribution coefficient	1
Effectiveness factor	1	Efficiency	1
Energy	$L^2MT^{-2}\,\Theta^{-1}$	Equilibrium constant	1
Force	L^2MT^{-2}	Enthalpy	L^2MT^{-2}
Frequency	T^{-1}	Friction coefficient	1
Gas hold-up	1	Half life	T
Heat	L^2MT^{-2}	Heat flux	MT^{-3}
Heat transfer coefficient	$MT^{-3}\,\Theta^{-1}$	Illuminance	$L^{-2}J$
Maintenance coefficient	T^{-1}	Mass flux	$L^{-2}MT^{-1}$
Mass-transfer coefficient	LT^{-1}	Momentum	LMT^{-1}
Molar mass	MN^{-1}	Molecular weight ('relative molecular mass')	1
Osmotic pressure	$L^{-1}MT^{-2}$		
Partition coefficient	$L^{-1}MT^{-2}$	Period	T

Table 1.2 ***Contd...***

Quantity	Dimensions	Quantity	Dimensions
Power	L^2MT^{-3}	Pressure	$L^{-1}MT^{-2}$
Rotational frequency	T^{-1}	Shear rate	T^{-1}
Shear stress	$L^{-1}MT^{-2}$	Specific death constant	T^{-1}
Specific gravity	1	Specific growth rate	T^{-1}
Specific heat capacity	$L^2T^{-2}\Theta^{-1}$	Specific interfacial area	L^{-1}
Specific latent heat	L^2T^{-2}	Specific production rate	T^{-1}
Specific volume	L^3M^{-1}	Shear strain	1
Stress	$L^{-1}MT^{-2}$	Surface tension	MT^{-2}
Thermal conductivity	$LMT^{-3}\Theta^{-1}$	Thermal resistance	$L^{-2}M^{-1}t^3\,\Theta$
Torque	L^2MT^{-2}	Velocity	LT^{-1}
Viscosity (dynamic)	$L^{-1}MT^{-1}$	Viscosity (kinematic)	L^2T^{-1}
Void faction	1	Volume	L^3
Weight	LMT^{-2}	Work	L^2MT^{-2}
Yield coefficient	1		

Physical variables can be classified into two groups: *substantial variables* and *natural variables.*

Substantial Variables

Examples of substantial variables are mass, length, volume, viscosity and temperature. Expression of the magnitude of substantial variables requires a precise physical standard against which measurement is made. These standards are called units. You are already familiar with many units, e.g., metre, foot and mile are units of length; hour and second are units of time. Statements about the magnitude of substantial variables must contain two parts: the number and the unit used for measurement. Clearly, reporting the speed of a moving car as 20 has no meaning unless information about the units, say km h^{-1}, is also included.

As numbers, substantial variables are multiplied, subtracted, divided or added, their units must also be combined. The values of two or more substantial variables may be added or subtracted only if their units are the same, e.g.:

$$5.0 \text{ kg} + 2.2 \text{ kg} = 7.2 \text{ kg}.$$

On the other hand, the values and units of *any* substantial variables can be combined by multiplication or division, e.g.:

$$\frac{1500}{12.5}\frac{\text{km}}{\text{h}} = 120 \text{ km h}^{-1}$$