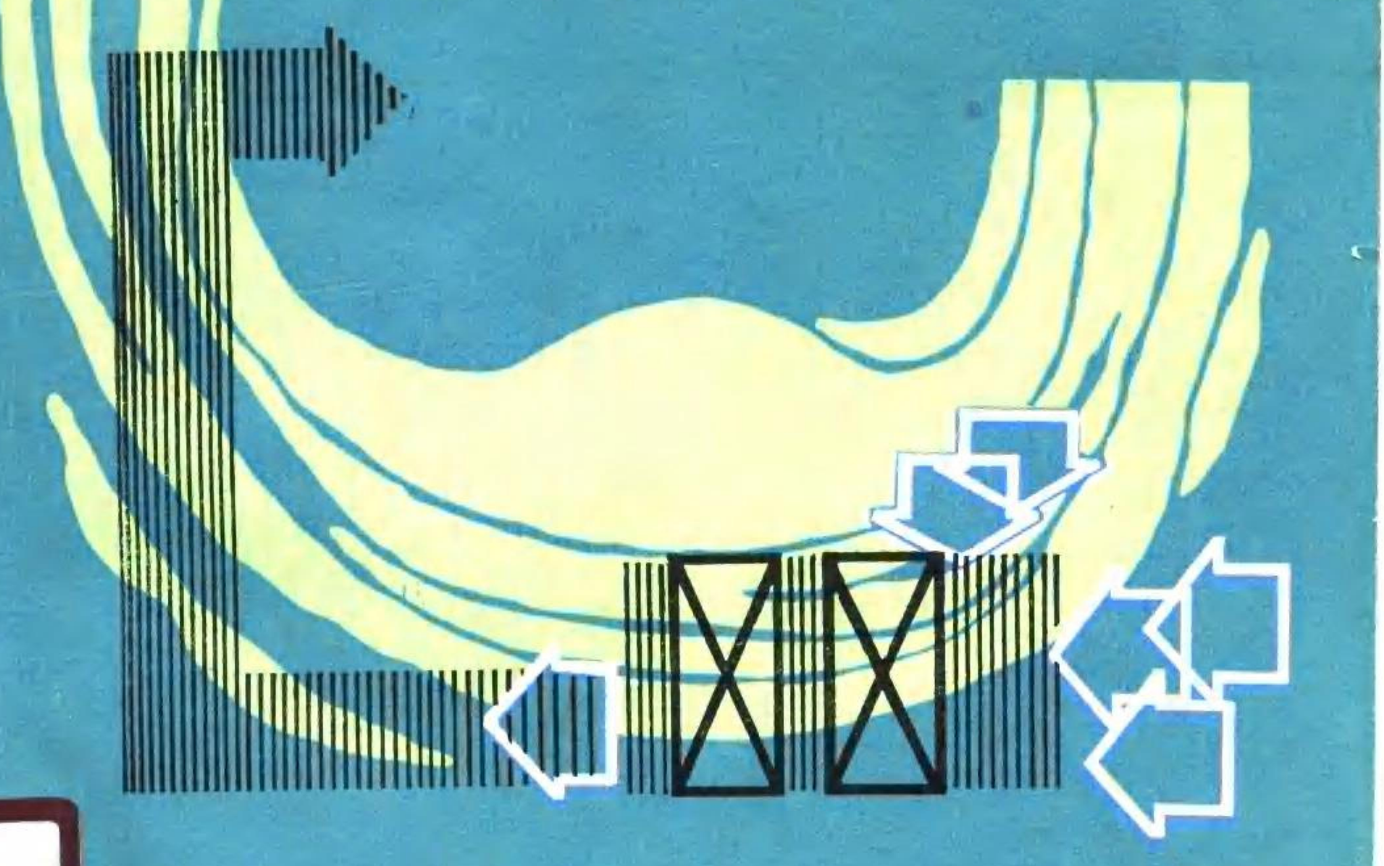
制冷与空调

REFRIGERATION AND AIR CONDITIONING

侯曼西 编



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Symbols

English Letter Symbols

A	area
a	air
a	absorber
Btu	British thermal unit
C	specific heat
C	unit thermal conductance
C	centigrade
C	clearance factor
CLF	cooling load factor
$CLTD$	cooling load temperature difference
COP	coeficient of performance
cfm	volume flow rate
DD	degree day
DR	daily range temperature
Dx	direct expansion
d	degree
E	effective emittance
F	fahrenheit
F	fuel consumption
F	factor
Fu	use factor
Fs	special allowance factor
F	area
f	feet
f	fluid
G	mass velocity
g	gas
H	enthalpy
h	film or surface coefficient
h	shading coefficient
I	solar heat gain
i	enthalpy
in	inch
i	internal
K	unit thermal conductivity

L	length
L_F	length of space exterior wall
L	leaving
l	liquid
M	mixing
m	mass
m	mentius
O	outside
o	outdoor
P	pressure
PD	piston displacement
Q	heat gain
q	heat transfer rate
R	gas constant
R	heat resistance
R	refrigeration
R	return
r	radius
r	return
r	room
S	entropy
S	supply
SC	shading coefficient
T	absolute temperature
t	temperature
t_b	average air temperature
U	over all coefficient of heat transfer
V	volume
v	specific volume
W	power
w	humidity ratio
w	water
x	length
x	homogeneous thickness
x	concentration

Subscripts

a	air
a	area
a	average

b	mixed air bypass cycle
c	cross section
d	mass of air
d	discharge
d	dephlegmator
e	evaporator
g	gas
g	saturated
g	generator
h	heat transfer
i	inside
i	interface
i	inter
l	latent
l	liquid or water
m	mass
o	outside
om	out door meaning temperature
s	sensible
s	frame wall
s	suction
t	total
t	trasmission
w	water
z	room air bypass cycle

Greek Letter Symbols

ε	effective emittance factor
η	efficient factor
θ	time
ρ	density
ϕ	relative humidity

Preface

Refrigeration and Air Conditioning Engineering has been widely used in the fields of modern science, engineering, and productien. Not only can Refrigeration and Air Conditioning help to complete production process very well, but it may also increase the quantity of the products and improve the quality. In order to meet the demand of the people for comfort, refrigeration and air conditioning have come to most areas of modern living of people such as shopping centers, schools, hospitals, hotels, theaters, and homes. Today using the devices of refrigeration and air conditioning is one of the marks of measuring the level of modern architecture. Refrigeration and Air Conditioning commonly used in almost every city and town in America, Japan and many western European industrial countries, is now increasingly popular all over the world and is regarded as a commercial and business necessity in everywhere on the earth.

In the last ten years, "refrigeration and air conditioning" engineering has been progressing rapidly in our country. The idea that refrigeration and air conditioning can only be used in industrial production, has been changed. Every family in cities is going to buy the device of refrigeration and air conditioning. Now, the refrigerator ii common in use but the air conditioner still needs to be developed. There are more than one hundred equipment manufacturers in China. Some products are modeled upon the equipments of western countries, some new products are being researched and developed in our country according to our energy production and consumption and people's economic conditions. Refrigeration and Air Conditioning production is a prosperous industrial item in our country.

I wrote the primary text book of Refrigeration and Air Conditioning for the students of Heat Power Engineering Dept. of Chongqing University in P. R. C. when I stayed at the University of Florida in U. S. A. as a visiting scholar from Feburary 1981 to march 1983. During that period I took refresher courses and engaged in research work under the guidance of Dr. E. A. Farker, Dr. C. K. Hsieh, and Dr. H. A. Ingley. This textbook is based on the primary book, several "Refrigeration and Air conditioning" reference books, the lecture sheets written by myself, and many years' experience in teaching, researching and engineering design of Refrigeration and Air Conditioning. The distinguishing feature of this book is that it describes systematically the basic theory and engineering technology of refrigeration and air conditioning and it also presents some living examples of refrigeration and air conditioning design. The theory and practice of piping design, pump and fan, solar energy have been described in many specialized courses of Heat Power Engineering, so I am not going to present them in this book.

This book can be used by the University students and graduate students of Heat Power

Engineering field, i. e. Heat Energy Engineering, Engineering Thermolphysics, Heat Power Engineering, Heating, Ventilating and Air Conditioning Engineering. It can also provide engineers and technicians with references of refrigeration and air conditioning. In order to make the Refrigeration and Air Conditioning undertaking keep pace with the world, I wrote this book in English.

We offer this book as a tribute to those who are interested in Refrigeration and Air Conditioning Engineering!

I wish to express my gratitude to ASHRAE for providing a great deal of material. I am very grateful to the following equipment manufacturers, which support me with funds to publish this book.

Beijing Air Conditioner Factory

Yantai Refrigeration Machinery Works

Kaifeng General Machinery Factory

Chongqing General Machinery Factory

Goangzhou Refrigeration Machinery Factory

And many thanks to Professor E. A. Farber, Professor C. K. Hsieh and Professor H. A. Ingley (University of Florida, U.S.A.), Professor Wu Zhongfu (Vice President of Chongqing University), Professor Lei Hengshun and Professor Chen Yuangou (Chairman of Heat Power Engineering Department, 1982-1990) and other Professors of Heat Power Engineering Department of Chongqing University for their support and suggestions.

Hou Manxi

Contents

Chapter 1

Introduction

Today, the refrigeration and air conditioning industry is becoming more and more extensive and varied. It was wrong for some people to think in the past that the principle use of refrigeration was produce ice, in fact, the major uses of refrigeration and air conditioning have been divided into four groups:

1. Food production and distribution
2. Chemical and process industry uses
3. Special application of refrigeration
4. Industrial and comfort air conditioning

1-1. Food Production and Distribution

Much food to be produceed, stored and distributed by use of refrigeration and air conditioning process, such as fruits and vegetables, dairy products, meat, fish, beverages etc. Refrigeration is often a key factor in the processing. For some examples, at the farm bulk-milk cooler is a refrigerated tank which cools the milk to about 50-60°F(10-16℃), in order to preserve the quality of the milk, it's cooled to 36-38°F (2.2-3.3℃). In making ice cream, refrigeration equipment cools and maintains the ingredients between −10 to −21°F (−23 to −29℃), other desserts also require 10°F (−12℃) in their manufacture. For long period of storage, the meat remains in rooms in which maintains at 32 to 34°F(0 to 1.1℃), when the meat is packaged in cusumer-size containers and frozen after freezing it is maintained at 0 to −10°F (−17 to −23°C), Freezing fish aboard ship at sea uses mechanical refrigeration for preserving. Refrigeration is essential in the production of such beverages as concentrated fruit juice, bear, and wine, because it is less expensive to concentrate juice and ship it in its frozen state than to ship the raw fruit. Refrigeration is needed for freezing the juice after it comes from the concentrator and for maintaining a temperature of 0°F (−17.7°C) during transport and storage.

The food after grading and preparation must be "sharp-frozen" at the temperatures of −20°F (−28.8°C). Some foods don't lend themselves to freezing but their life can be extended by "cooler" storage at temperatures slightly above 32°F (0°C). Many fruits such as apples, pears, grapes can be stored perhaps for several months if maintained at proper temperatures. Eggs, nuts, dried fruits and vegetables also keep longer when stored at the temperature slightly above 32°F (0 ℃)than when stored at room temperature.

1-2. Chemical and Process Industries Uses

In petrochemical plants low temperatures are used to separate gases and the low temperature needs to be −250°F (−155℃). The refrigeration equipment requires more than 10,000 Hp (7,455kw) to drive it. The ammonia gas is condensed with temperature between 0 and 50°F(−17.7 and 10℃) before storage or shipment in synthetic ammonia processes. In the dewaxing of oil, the wax solidifies at about −15°F(−26℃) and can then be filtered off, it is to cool wax to 10°F(−12.2℃)to harden it on paper in the process of manufacture papers. Refrigeration maintains temperatures of 40 to 50°F(4.4 to 10℃) which are required in the formation of alcohol and penicillin. Natural rubber, certain drugs, explosives etc will keep longer when stored at the temperature from 40 to 60°F(4.4 to 16℃). In film manufacture, acetone can be reclaimed by refrigeration.

1-3. Special Uses of Refrigeration

Some of the special uses of refrigeration, which will be mentioned, have come into prominence only in recent years, such as cold treatment of metals, medical production,desalting of sea water, construction process, ice manufacture etc.

A 30mm soaking of carburized steel at a temperature of −125°F(−87℃) will increase its hardness and wear resistance, refrigeration will also improve its ductility for deep drawing. The magnetic strength and stability of magnets are improved by a low-temperature treatment at −120°F(−84℃) for 8 hr. In casting technology, frozen mercury patterns can produce close tolerances and accurate surface finishes.

The medical technique has used localized refrigeration as surgical anesthesia, while blood plasma and antibiotics are manufactured by a method called "Freeze drying". Freeze drying is the removal of water by sublimation at low temperature and pressure, which is less damaging to the tissues than driving off the water at high temperatures.

The process is basic one of freezing ice, which is relatively salt-free, from the sea water through removing it from the brine and thawing it to redeem fresh water.

In the construction industry, refrigeration equipment may cool concrete to prevent cracking and freeze soil to facilitate excavations.

1-4. Industrial and Comfort Air Conditioning

Industrial air conditioning and comfort air conditioning are used in common. Typical industrial applications of air conditioning are in laboratories, printing plants textiles, steel plants, pharmaceuticals factories and in the fields of photograpohic products and the manufacture of precision parts.

Control of humidity is one of the primary reasons for air conditioning of printing plants, paper and textile mills in which the changes of humidity are more sensitive than the changes in temperature.

In manufacture of precision parts, air conditioning performs three services for manufactures of precision metal parts by keeping the temperatures uniform, the metal will not expand and contract, by maintaining a humidity, the rust on the metal is prevented and by filtering the air the parts keep clean.

Pharmaceuticals plants need air conditioning to remove air-borne bacteria and dirt and to preserve products. Gelation capsules require a very dry air.

Raw photographic material deteriorates rapidly in high temperature and humidities, and other materials used in coating film require careful control of temperature.

Early experiments indicate that keeping animals cool during the summer results in a more efficient conversion of feed into gain of weight or increase in production.

For residence, restaurants, theaters, stores, large buildings, air conditioning brings comfort, increased personal efficiency, longer visits by customers, and increased sales for stores.

1-5. The Contents of This Textbook

The principle of this book is based on ASHRAE Handbooks consisting of four volumes entitled: Fundamental, Applications, Equipment and Systems. The achievements in research, design, and production of heating ventilation refrigeration and air conditioning field of thousands engineers are edited by these volumes at the early to eighties of the twentieth century. Unquestionably the ASHRAE Handbooks are the encyclopedias of this field throughout the world.

The contents of this book are enclosed fourteen chapters. From chapter 1 to 5 is described the fundamental of refrigeration and air conditioning. In chapter 6 and 7 is summarized the design of heating and cooling loads. In chapter 8 to 14 are described systems and equipments consisting of the refrigeration and air conditioning systems, refrigerant, the refrigeration of compression, centrifugure, absorption, and heat pump technology.

Because English Units are used in many important materials of research result so both English Units and SI Units should be found in this book. In addition the Official Units of People's Republic of China are as same as SI Units in this book. The contrast of the Official Units of People's Republic of China, SI and English Units in HVAC field is listed in Appendix A-2. The conversion factors of them are listed in Appendix A-3.

Chapter 2

Psychrometrics

Atmospheric air is a mixture of many gases, water vapor and countless pollutants. Aside from the pollutants, which may vary considerably from place to place, the composition of the dry air alone is relatively constant varying slightly with time, location, and altitude. The *ASHRAE Handbook of Fundamentals* gives approximate composition of dry air by volume fraction as shown in Table 2-1, and the

Table 2-1 Composition of dry air

Nitrogen	0.78084
Oxygen	0.20948
Argon	0.00934
Carbon dioxide	0.00031
Neon, helium, methane, Sulfur dioxide, hydrogen and other minor gases	0.00003
	100.00000

following definition of the U.S. standard atmosphere:

1. Acceleration due to gravity is constant at 32.174 $ft/_{sec}^{2}$. ($9.8m/_{sec}^{2}$)
2, Temperature at sea level is 59°F(15℃).
3. Pressure at sea is 29.921 in. (760mm) of mercury.
4. The atmosphere of dry air, which behaves as a perfect gas.

The proporties of moist air (an air-water-vapor mixture) are important in many industrial processes and comfort air conditioning and in the design of cooling towers for use in heat-removal systems. For this reason, moist air has been studied in great detail, and the name psychrometric has been given to this chapter.

2-1. Thermophysical Properties of Moist Air

In this section we shall introduce some of the more important terms and definitions from the vocabulary of psychrometrics to facilitate our discussion.

1. Dry air

By definition, dry air exists when all water vapor and contaminants have been removed from atmospheric air. Extensive measurements have shown the composition of dry air is relatively constant, but small variations in the amount of individual components occur with time, geographical location, and altitude.

2. Moist air

Moist air defined as a binary (or two-component) mixture of dry air and water vapor. The amount of water vapor in moist air varies from zero (dry air) to a maximum which depends on temperature and pressure.

3. Molecular weight

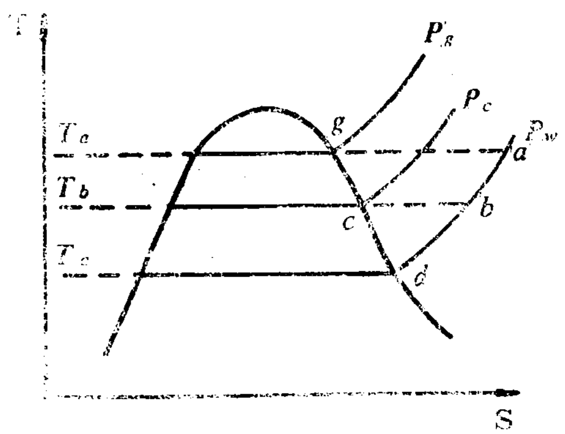
(1) The molecular weight of dry air is 28.9648 on the carbon-12 scale. The gas constant for dry air is

$$Ra=(1545.32)/28.9645=53.325(\text{ft lb force})/(\text{lb mass})(\text{degR})$$
$$\text{or } 287\ \text{J}/(\text{kg}-\text{k})$$

(2) The molecular weight of water is 18.01534 on the carbon-12 scale. The gas constant for water vapor is

$$R_w=(1545.32)/(18.01534)=85.778(\text{ft lb force})/(\text{lb mass})(\text{deg R})$$
$$\text{or } 462\ \text{J}/(\text{kg}-\text{k})$$

4. Thermodynamic properties of water at saturated



T_a—dry bulb temperature at p_w
T_b—wet bulb temperature at p_w
T_d—dew—point temperature at p_w
Figure 2—1 Thermodynamic state of the vapor in moist air

(1) Saturation state

The thermodynamic state of the vapor in moist air (an air-water-vapor mixture) is fixed by its partial pressure and temperature. If the partial pressure of the water vapor corresponds to the saturation pressure of water at the mixture temperature, the mixtured to be saturated.

For example, in Figure 2-1 at point a pressure equals P_w, temperature equals T_a, it is a superheated vapor. If the pressure is changed to pressured pg, but keep temperature as same as T_a, the moist air to be saturated because of the partial pressure of the water vapor corresponds to the saturation pressure of water at temperature T_a. It from unsaturated air becomes saturated air at the constant temperature.

In determining saturation parameters, some tables and accurate equations are shown in thermodynamic engineering books.

(2) Unsaturated air

By definition, unsaturated air is a mixture of dry air and superheated vapor, such as point a shown in Fig.2-1.

(3) Saturated air

By definition, saturated air is a mixture of dry air and saturated water vapor, such as point g shown in Fig. 2-1.

(4) Dew-point temperature

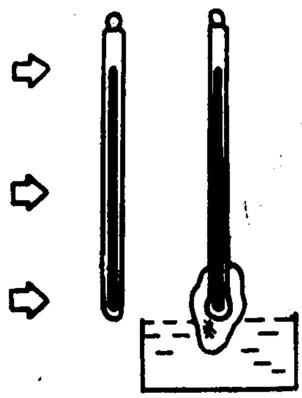
If an unsaturated air is cooled at constant pressure, the mixture will eventually reach the saturation temperature corresponding to the partial pressure of the water vapor. This is called the dew point temperature because at this temperature the vapor starts to condense, resulting in the formation of liquid droplets or dew. The dew point temperature T_d corresponding to a partial pressure of P_w is shown in Fig. 2-1.

(5) Dry-bulb temperature

The dry-bulb temperature is simply the equilibrium temperature of the unsaturated air indicated by an ordinary thermometer, such as T_a shown in Fig. 2-1, 2-2.

(6) Wet-bulb tempe rature

The wet-bulb temperat ure is the temperature indicated by a wet-bulb thermometer which has its temperature-sensitve elements covered with a wicklike material soaked in water, such as T_b shown in Fig. 2-1, 2-2. It shows that the moist air cooled to point b at the constant pressure P_w.



Air flow Dry-bulb thermometer Wet-bulb thermomter

Figure 2-2 Wet-and-dry-bulb thermometer

It will be seen that for an unsaturated air, the wet-bulb temperature is always less than the dry-bulb temperature but greater than the dew-point temperature.

For the saturated air, the dry-bulb, wet bulb and dew-point temperatures are the same.

5. Humidity parameters

(1) Humidity ratio

Humidity ratio is defined as the ratio of the mass of water vapor to the mass of dry air in a given volume of moist air or

$$w = \frac{m_w}{m_a} \qquad (2\text{-}1)$$

where w = humidity ratio (1bmv/1bma) or (kgv/kg a)

m_w = mass of water vapor (1bm) or (kg)

m_a = mass of dry air (1bm) or (kg)

(2) Relative humidity ϕ

Relative humidity ϕ is defined as the ratio of the partial pressure of water vapor in a moist air to the saturation pressure of water at the dry-bulb temperature, or

$$\phi = \frac{P_w}{P_g} \qquad (2\text{-}2)$$

where

P_g = the saturation pressure of water at the temperature of the dry air (psia) or (kpa)

P_w = the partial pressure of the water vapor in the moist air (psia) or (kpa)

(3) An expression for the relation between the relative humidity ϕ and the humidity ratio w.

From equation (2-1) can be obtained the followiug equations

$$w = \frac{m_w}{m_a}$$

Assuming ideal-gas behavior for both the dry air and the water vapor, we have

$$m_w = \frac{P_w V}{R_w T} \qquad m_a = \frac{P_a V}{R_a T}$$

Substituting into Eq.(2-1), we get

$$w = \frac{R_a P_w}{R_w P_a} = \frac{53.35}{85.76} \cdot \frac{P_w}{P_a} = 0.622 \frac{P_w}{P_a}$$

$$w = 0.622 \frac{P_w}{P_a} \qquad (2\text{-}3)$$

where

P_w = the partial pressure of water vapor in the moist air (psia) or (kpa)

P_a = the partial pressure of dry air in the same volume of moist air. (psia) or (kpa)

From Daltom's rule of partial pressure, the pressure of moist air P is given as

$$P = P_a + P_w$$

Thus Eq. (2-3) may be written as

$$w = 0.622 \frac{P_w}{P - P_w} \qquad (2\text{-}4)$$

$$P_w = \frac{wP}{w + 0.622} \qquad (2\text{-}5)$$

Combining Eq. (2-2) with Eq. (2-4) such an expression for a moist air is

$$w = 0.622\phi \frac{P_g}{P_a} \qquad (2\text{-}6)$$

6. Specific volume

Specific volume of moist air is defined as the volume of moist air (ft^3) per (lbm) dry air

$$v = \frac{ft^3 \text{moist air}}{lbm\ da} \quad \text{or} \quad \frac{m^3}{kg} \tag{2-7}$$

7. Enhtalpy

The enthalpy h of a given moist air is simply the sum of the enthalpies of the dry air and the water vapor. That is

$$\begin{aligned} H &= H_a + H_w \\ &= m_a h_a + m_w h_w \end{aligned} \tag{2 8}$$

Dividing Eq. (2-7) by m_a

$$h = h_a + \frac{m_w}{m_a} h_w \quad \text{or} \quad h = h_a + w h_w$$

where

h =specific enthalpy of moist air in Btu/1bma or kJ/kg

h_a=specific enthalpy of the dry air in Btu/1bma or kJ/kg

h_w=specific enthalpy of water vapor in Btu/1bma or kJ/kg

* **Notes:**

psia=Pounds per square inch absolute

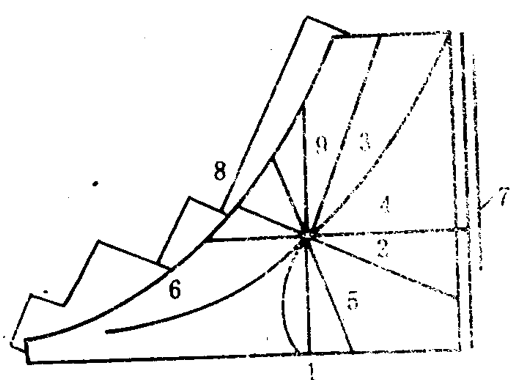
psig=Pounds per square inch gage

Btu=British thermal unit

The British thermal unit is defined as the quantity of heat required to change the temperature of 1 1bm of water 1F.

2-2. Psychrometric Chart

A psychrometric chart is a graphical representation of the thermodynamic properties of moist air. It's distinctive features are of practical value in solving engineering problems.



1—Dry-bulb temperature—*DB*
2—Wet-bulb temperature—*WB*
3—Relative humidity—*RH*
4—Humidity ratio—*w*
5—Specific volume—*SPV*.
6—Dew-point temperature—*DP*
7—Sensible heat factor—*SHF*
8—Enthalpy—*H*
9—Enthalpy deviation—*ED*

Figure 2-3 Psychrometric chart

These include coordinates are shown in Figure 2-3.

1. Dry-bulb temperature lines, shown in 1 deg c intervals, are drawn straight, not precisely parallel to each other, and inclined slightly from vertical position.

2. Thermodynamic wet-bulb temperature lines are obligue lines shown in intervals