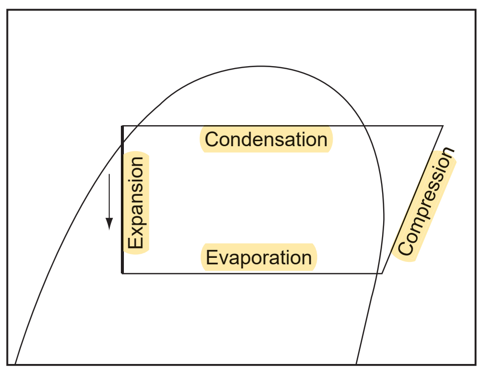
Fig.2-13



2.2.2 How to draw actual operating state on P-h Chart

In order to draw the refrigeration cycle on the P-h Chart, the following four operating conditions are required. In other words, if the four conditions are known, the refrigeration cycle can be drawn on the P-h Chart.

Conditions:

1. Evaporating pressure or evaporating temperature
2. Suction gas temperature or superheated degree
3. Condensing pressure or condensing temperature
4. Liquid temperature at expansion valve inlet or sub-cooled degree

Superheated degree = Suction gas temperature - Evaporating temperature

Sub-cooled degree = Condensing temperature - Liquid temperature at expansion valve inlet

■ Procedure

Draw the refrigeration cycle on the R22 P-h Chart based on the following operating conditions.

Conditions

Evaporating temperature = 6˚C

Condensing temperature = 36˚C

Superheated degree =

Liquid temperature at expansion valve inlet = 31˚C

1. Evaporation process

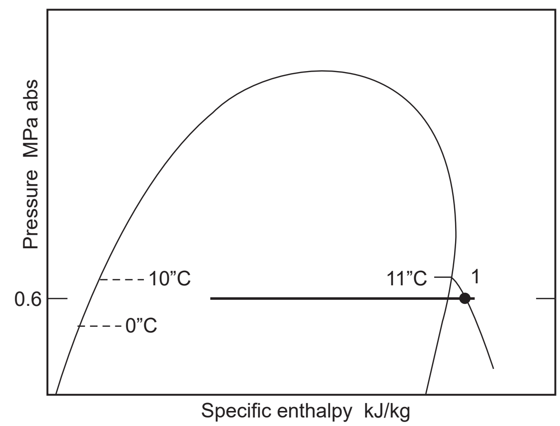
Even though the refrigeration cycle can be started to draw from anywhere on the P-h Chart, it is usually started from the compressor suction point, that is, the completion point of the evaporation process.

Since the evaporating temperature is 6˚C, a horizontal line is drawn from the 6˚C graduations on the saturated liquid line and the saturated vapor line. The starting point of the evaporation process has not yet been known at this stage. Therefore, the horizontal line may be tentatively drawn to the right from a point with a dryness factor of about 0.4.

The evaporation process is represented with a horizontal line due to changes under constant pressure. In this case, the pressure is 0.6MPa abs, which is referred to as the evaporating (or low) pressure.

Check the superheated degree given in the above conditions to determine the point where the refrigerant is discharged from the evaporator and sucked into the compressor. In this case, since the superheated degree is 5˚C, the suction gas temperature rises by 5˚C from the evaporating temperature of 6˚C, thus reaching a temperature of 11˚C. The pressure is kept constant up to this point, therefore the Point 1 of intersection of the extension of the constant pressure line of 0.6MPa abs and the 11˚C constant temperature line that tilts toward the right by 1˚C from the 10˚C constant temperature line is taken as the suction point of the compressor.

Fig.2-14



Note: Strictly speaking, the pressure varies while showing a slight drop in the evaporation process, while the pressure is assumed to be constant on the P-h Chart.

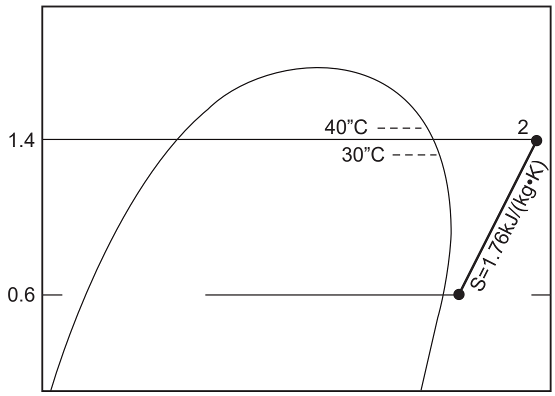
2. Compression process

The compression process starts from the Point 1. While in this process, a line is drawn according to the changes of the constant specific entropy, that is, in parallel with the specific entropy line up to the Point 2 of intersection with the line of condensing pressure (high pressure) of 1.4MPa abs corresponding to 36˚C condensing temperature.

Whereas, this specific entropy line is slightly curved, and the Point 1 does not always comes on the specific entropy line on the Chart. Therefore, it is practical to find the Point 2 according to a position on the condensing pressure line having the numerical value of specific entropy equal to that at the Point 1 and draw the line of the compression process by connecting the Points 1 and 2.

The Point 2 represents the discharge gas state from the compressor.

Fig.2-15



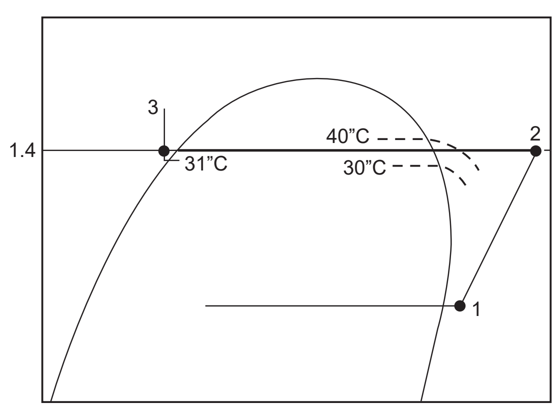
Note: The compression process is drawn as theoretical adiabatic compression. Therefore, it may be slightly different from that in actual operation.

3. Condensation process

The condensation process starts from the Point 2. Heat exchange in this process is performed mostly in the condenser, but the condensation process itself starts at the discharge point of the compressor.

At the Point 2, the condensing (high) pressure is 1.4MPa abs, which is equal to the condensing temperature of 36˚C. Since the condensation process is a heat radiation process under constant pressure, draw a line horizontally to the left from the Point 2. While in the condensation process, the refrigerant changes from superheated vapor to moist vapor, and further to sub-cooled liquid, thus proceeding to the expansion process. In this case, the temperature of liquid at the expansion valve inlet is 31˚C. Therefore, the Point 3 of intersection of the pressure line of 1.4MPa abs with the 31˚C constant temperature line that tilts toward the right by 1˚C immediately before the 30˚C constant temperature line is taken as the point where the condensation process is complete.

Fig.2-16



Note: The pressure also varies while showing a slight drop in the condensation process, while the pressure is assumed to be constant on the P-h Chart.

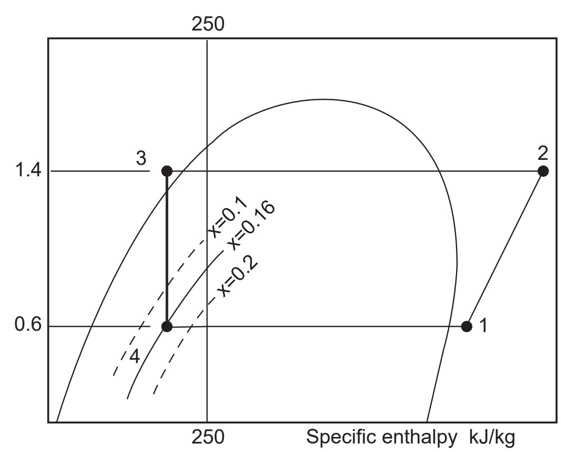
4. Expansion process

The expansion process starts from the Point 3. While in this process, a line is drawn according to the changes of the constant specific enthalpy, that is, in parallel with and perpendicular to the specific enthalpy line up to the Point 4 of intersection with the line of the evaporating pressure of 0.6MPa abs.

The distance between the Point 4 where the evaporation starts and the Point 1 represents the evaporation process.

The expansion process is performed according to the constant change of the specific enthalpy. Even though there are no external heat exchanges, the temperature of the liquid refrigerant falls from 31˚C to 6˚C. The reason is that when the liquid refrigerant pressure is reduced due to the frictional resistance while passing through the expansion valve or capillary tube, part of the liquid instantaneously vaporizes to decrease the liquid temperature.

Fig.2-17



Note: It is understood that, even though the refrigerant is in the low-temperature low- pressure liquid state when it is discharged from the expansion valve, actually moist vapor having a dryness factor of 0.16 enters the evaporator.

Exercise 2

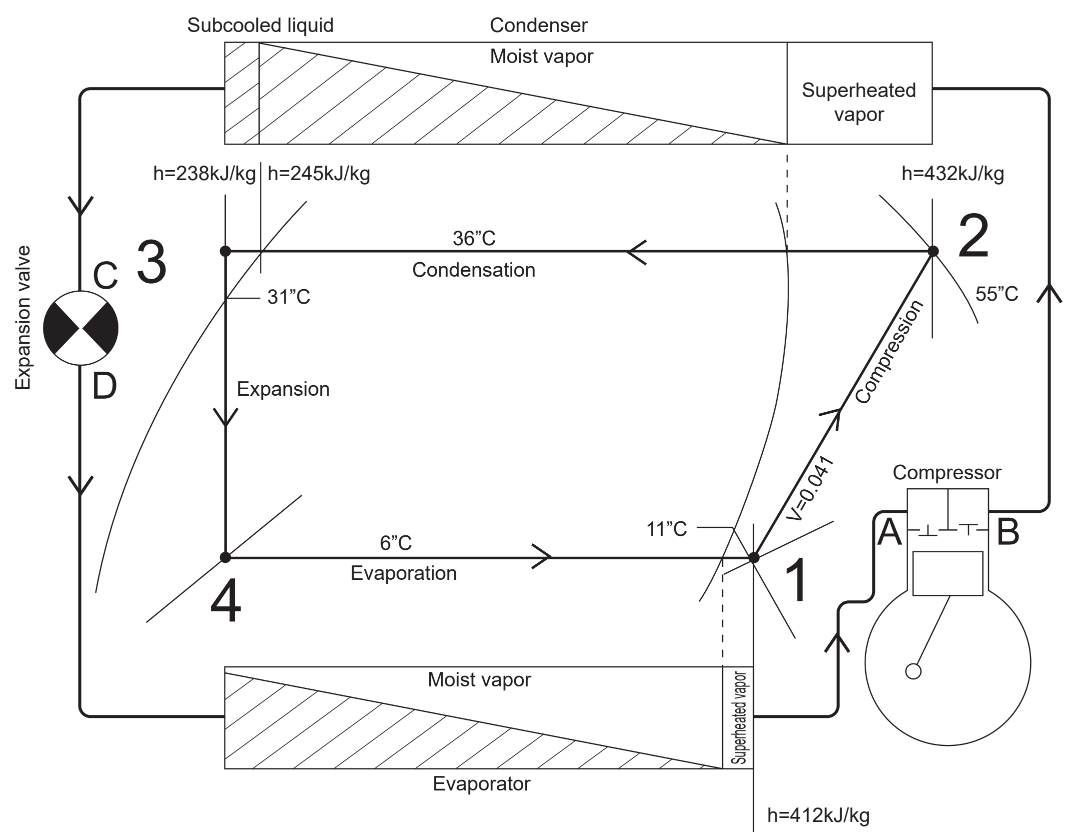
Draw a refrigeration cycle on the P-h Chart under the above-mentioned conditions. Then, read the following numerical values of the four Points 1, 2, 3, and 4. (If the column which cannot be read from the Chart, fill it with an oblique line.)

Table 2-2

	P Absolute pressure MPa abs	t Temperature C	h Specific enthalpy kJ/kg	v Specific volume m^3/kg	x Dryness factor	s Specific entropy kJ/(kg•K)
Point						
Point						
Point						
Point						

2.2.3 Summary

Fig.2-18



The four Points 1, 2, 3, and 4 on the chart represent the following states respectively.

Point 1: Refrigerant gas, which is discharged from the evaporator and sucked into the compressor, is the superheated vapor having a slightly higher superheated degree than dry saturated vapor.

Point 2: Refrigerant vapor, which is discharged from the compressor and sucked into the condenser is the superheated vapor having a considerably high superheated.

Point 3: Sub-cooled liquid, which is produced by slight subcooling in the condenser and enters the expansion valve.

Point 4: Moist vapor, which is produced by reducing pressure through the expansion valve and entering the evaporator.

The compression process (Point 1 → Point 2) is drawn in parallel to the constant specific entropy line. The condensation process (Point 2 → Point 3) and the evaporation process (Point 4 → Point 1) are performed according to the constant pressure changes and, therefore, drawn with horizontal lines.

The expansion process (Point 3 → Point 4) represents the throttling process and is drawn in parallel to the constant specific enthalpy lines.

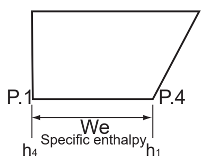
Thus, the Chart is represented in a remarkably simple form, facilitating the calculation of the amount of heat as well.

2.2.4 Calculation method of refrigeration cycle

1. Refrigeration effect We [kJ/kg]

The amount of heat (We(absorbed by 1-kg mass of refrigerant in the evaporation process is called refrigeration effect or the refrigerating capacity, which is found by the difference in the specific enthalpy between the suction gas of the compressor (Point 1) and the liquid at the evaporator inlet (Point 4).
The refrigeration effect represents the amount of heat absorbed by 1-kg mass of refrigerant flowing through the evaporator but does not represent the refrigerating capacity (kJ/h).
On the same compressor, it can be said that the larger the refrigeration effect is0, the better its operation is.
We (kJ/kg) = h1 (kJ/kg) - h4 (kJ/kg)

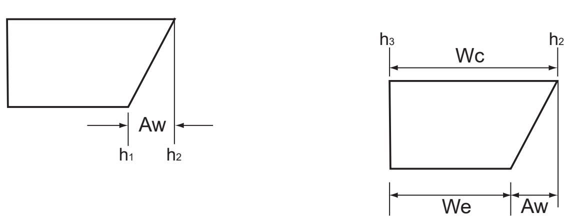
F.A



2. Thermal equivalent of compressor work Aw [kJ/kg]

The change in the refrigerant state while in the compression process, that is, the increase of specific enthalpy is performed by adding the compressor work of an electric motor as the amount of heat due to adiabatic compression, in other words, no external heat exchanges.
This value is found by drawing the refrigeration cycle on the P-h Chart, and based on the calculation of the specific enthalpy difference with the work volume taken as the amount of heat.
It means that the amount of heat has been found by taking the work volume of a electric motor required for compressing 1-kg mass of refrigerant as heat energy.
Aw [kJ/kg] = h2 [kJ/kg] - h1[kJ/kg]

F.B



3. Condensing load Wc [kJ/kg]

The amount of heat extracted while in the condensation process is called condensing load, which is found by the difference in the specific enthalpy between the discharge gas from the compressor (Point 2) and the refrigerant at the inlet of the expansion valve (Point 3).
Wc [kJ/kg] = h2 [kJ/kg] - h3[kJ/kg]
In addition, it is found by the sum of the refrigerating effect [We] and the thermal equivalent of compressor work [Aw]. Thus, the transfer of the refrigerant heat is balanced.
Wc [kJ/kg] = We + Aw

F.C

4. Coefficient of performance (COP)

The coefficient of performance represents how much cooling capacity is obtained per input of an electric motor (the thermal equivalent). Comparing evaporation heat [We] absorbed while in the evaporation process with the amount of heat [Aw] required for compression work, it is understood that the amount of heat absorbed while cooling is many times higher than the thermal equivalent of the compressor work, which is called "coefficient of performance". Namely, the larger the coefficient of performance is, the higher effective operation is performed. In other words, energy saving operation is enabled.

$$COP = \frac{We}{Aw} = \frac{h1 - h4}{h2 - h1}$$ There are no measured of the COP.

5. Compression ratio

The ratio of high (condensing) pressure to low (evaporating) pressure is called "compression ratio".
In this case, absolute pressure (MPa abs) is used.
While in the compression process, low-pressure gas is compressed to high-pressure gas and discharged. The high-pressure gas remains in the narrow space on top of the cylinder (referred to as "top clearance"). This residual high-pressure gas expands while the piston moves downward, thus disabling the suction valve to open until the internal pressure of the cylinder becomes lower than the low pressure and resulting in no suction of the refrigerant gas.
Therefore, the larger the compression ratio is, the smaller refrigerant circulated and capacity become.

$$\text{Compression ratio} = \frac{PH(MPa\ abs)}{PL(MPa\ abs)}$$

There are no measured of the compression ratio.
PH: High pressure(MPa abs)
PH: Low pressure(MPa abs)

6. Suction gas density · [kg/m^3]

The suction gas density [·] is found using the reciprocal of the specific volume v [m^3/kg].
While in the compression process, the larger the gas density absorbed in the cylinder is, the higher amount of refrigerant circulated and the higher capacity are achieved. Therefore, the smaller the specific volume of suction gas is, the larger capacity operation becomes.

$$\text{Suction gas density [kg/m}^3\text{]} = \frac{1}{V(m^3/kg)}$$

Exercise 3

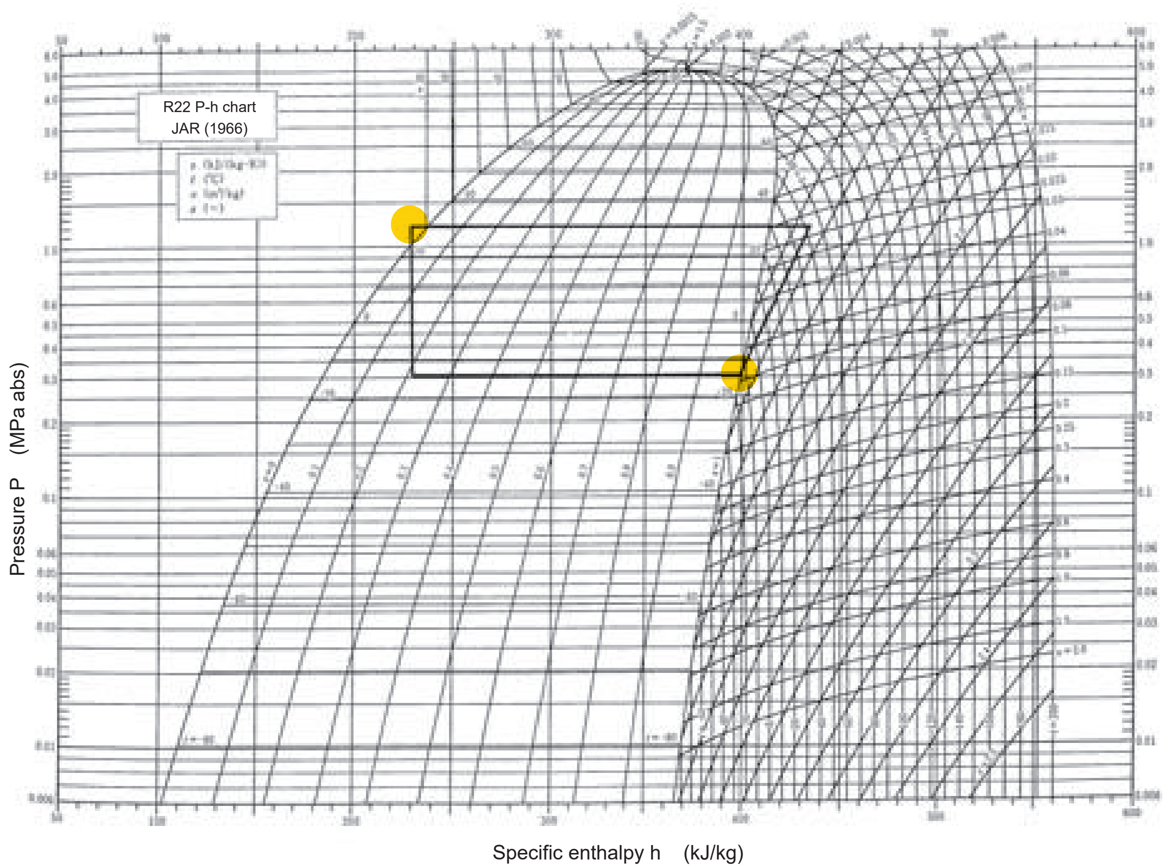
Perform the following calculations using the numerical values of Exercise 2.

(1) Refrigerating effect
(2) Thermal equivalent of compressor work
(3) Condensing load
(4) Coefficient of performance
(5) Compression ratio
(6) Suction gas density

2.3 Basic cycle by model

2.3.1 Standard refrigeration cycle

Fig.2-19



- **Operating Conditions**

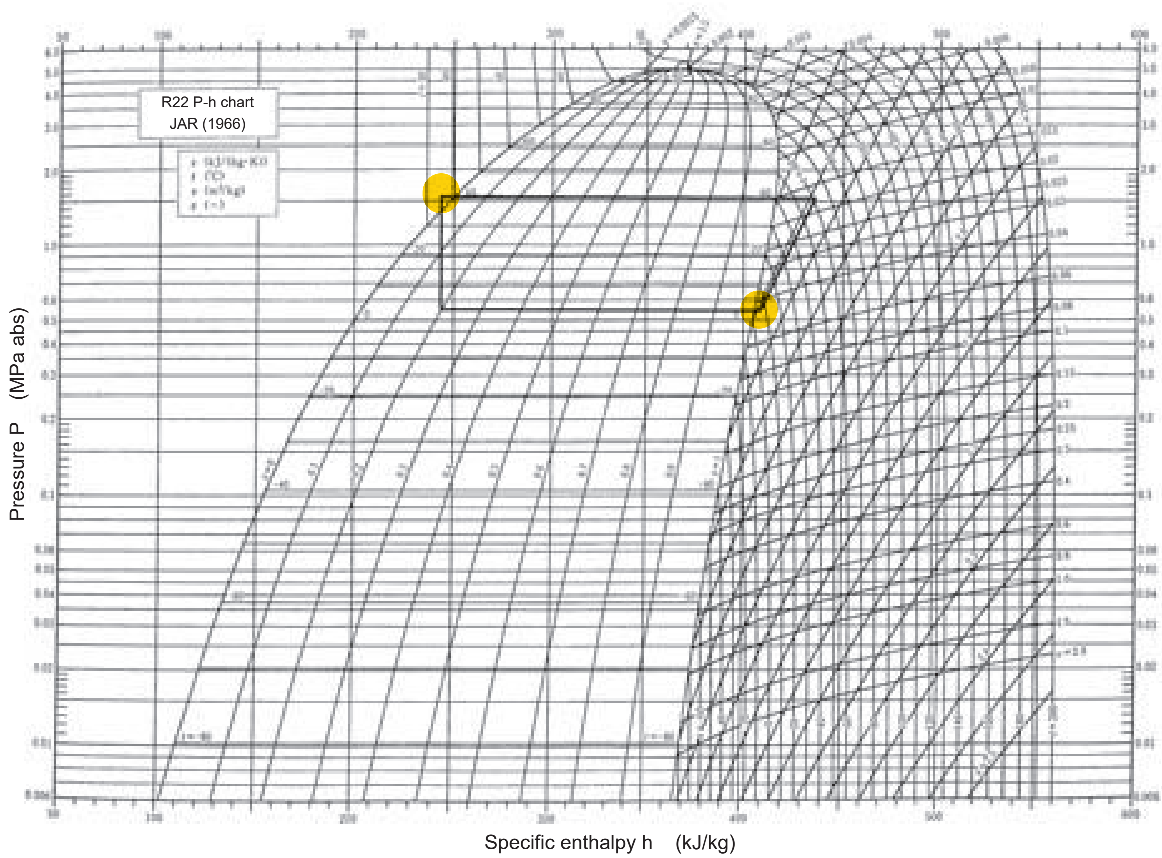
Evaporating temperature	-15˚C
Superheated degree	0˚C
Condensing temperature	30˚C
Liquid temperature at expansion valve inlet	25˚C

- **Data**

Evaporating pressure	0.3MPa abs
Suction gas	
Temperature	-15˚C
Specific enthalpy	399 kJ/kg
Specific volume	0.08 m^3/kg
Specific enthalpy at expansion valve inlet	230 kJ/kg
Sub-cooled degree	5˚C
Refrigerating effect	169 kJ/kg
Thermal equivalent of compressor work	36 kJ/kg
Condensing load	205 kJ/kg
Coefficient of performance	4.69
Compression ratio	4.0
Condensing pressure	1.2MPa abs
Discharged gas	
Temperature	54˚C
Specific enthalpy	435 kJ/kg

2.3.2 Cooling cycle in water-cooled air conditioner

Fig.2-20



- **Operating Conditions**

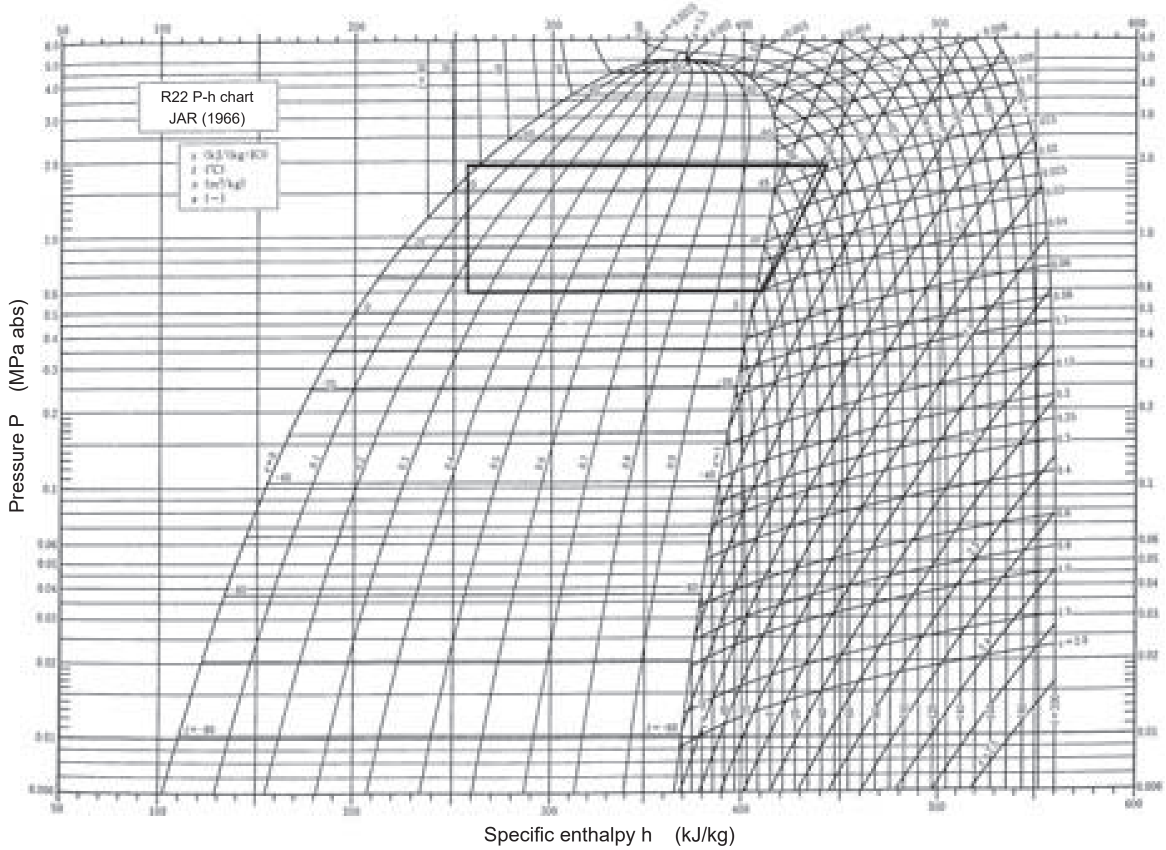
Evaporating temperature	2˚C
Superheated degree	5˚C
Condensing temperature	40˚C
Liquid temperature at expansion valve inlet	35˚C

- **Data**

Evaporating pressure	0.53MPa abs
Suction gas	
Temperature	7˚C
Specific enthalpy	410 kJ/kg
Specific volume	0.046 m^3/kg
Specific enthalpy at expansion valve inlet	243 kJ/kg
Sub-cooled degree	5˚C
Refrigerating effect	167 kJ/kg
Thermal equivalent of compressor work	26 kJ/kg
Condensing load	193 kJ/kg
Coefficient of performance	6.42
Compression ratio	2.89
Condensing pressure	1.53MPa abs
Discharged gas	
Temperature	61˚C
Specific enthalpy	436 kJ/kg

2.3.3 Cooling cycle in air-cooled air conditioner

Fig.2-21



■ Operating Conditions

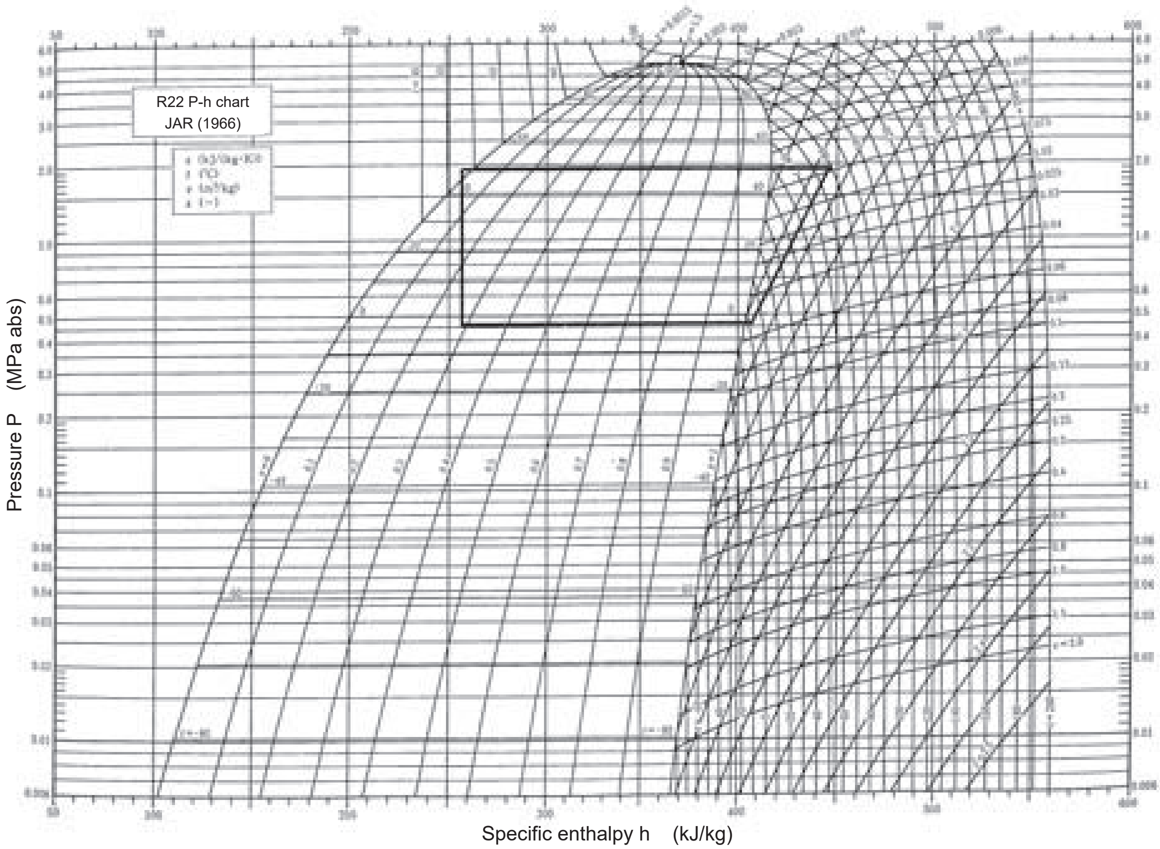
Evaporating temperature	5˚C
Superheated degree	5˚C
Condensing temperature	50˚C
Liquid temperature at expansion valve inlet	45˚C

■ Data

Evaporating pressure	0.6MPa abs
Suction gas	
Temperature	10˚C
Specific enthalpy	410 kJ/kg
Specific volume	0.04 m^3/kg
Specific enthalpy at expansion valve inlet	257 kJ/kg
Sub-cooled degree	5˚C
Refrigerating effect	153 kJ/kg
Thermal equivalent of compressor work	33 kJ/kg
Condensing load	186 kJ/kg
Coefficient of performance	4.64
Compression ratio	3.27
Condensing pressure abs	1.96MPa
Discharged gas	
Temperature	75˚C
Specific enthalpy	443 kJ/kg

2.3.4 Heating cycle in air-cooled air conditioner

Fig.2-22



- **Operating Conditions**

Evaporating temperature	-3˚C
Superheated degree	5˚C
Condensing temperature	50˚C
Liquid temperature at expansion valve inlet	45˚C

- **Data**

Evaporating pressure	0.46MPa abs
Suction gas	
Temperature	2˚C
Specific enthalpy	407 kJ/kg
Specific volume	0.053 m^3/kg
Specific enthalpy at expansion valve inlet	257 kJ/kg
Sub-cooled degree	5˚C
Refrigerating effect	150 kJ/kg
Thermal equivalent of compressor work	41 kJ/kg
Condensing load	191 kJ/kg
Coefficient of performance	4.66
Compression ratio	4.26
Condensing pressure	1.96MPa abs
Discharged gas	
Temperature	80˚C
Specific enthalpy	448 kJ/kg

Exercise 4

Find each data from the P-h Chart according to the following conditions:

Evaporating temperature	-10˚C
Superheated degree	10˚C
Condensing temperature	50˚C
Liquid temperature at expansion valve inlet	40˚C