



Republic of Iraq
Ministry of Higher education and Scientific
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Air Conditioning and Refrigeration Techniques
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THERMODYNAMIC I

FIRST STAGE

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lecture number: **Eighth Lecture**

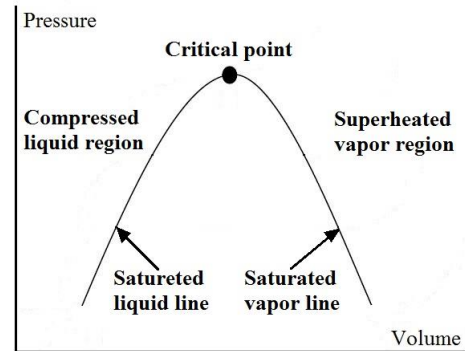
lecture name: **Water properties tables**

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When the heating process is carried out at a pressure higher than the triple point pressure, the substance would pass from solid phase to liquid phase and then from liquid phase to vapor phase at higher temperature.

Water Properties Tables

The term steam is solely used for water vapor. For most substances, the relationships among thermodynamic properties are too complex to be expressed by simple equations. Therefore, properties are frequently presented in the form of tables. Some thermodynamic properties can be measured easily, but others cannot and are calculated by using the relations between them and measurable properties. The results of these measurements and calculations are presented in tables in a convenient format. In the following discussion, the steam tables are used to demonstrate the use of thermodynamic property tables.



Property tables of other substances are used in the same manner. For each substance, the thermodynamic properties are listed in more than one table. In fact, a separate table is prepared for each region of interest such as the superheated vapor, compressed liquid, and saturated (mixture) regions.

1. Saturated liquid and vapor: when water is in the saturated phase, (table 2) and (table 3) are used to get the required properties. Both tables give the same information, the only difference is that in (table 2) properties are listed under temperature and in (table 3) under pressure. Therefore, it is more convenient to use (table 2) when temperature is given and (table 3) when pressure is given. Knowing only one property of the water, we can extract any other property from these tables. For saturated liquid, the properties with the subscript (*f*) are used. For saturated vapor, the properties with the subscript (*g*) are used. The properties with the subscript (*fg*) are the difference between the two phases (*g* – *f*). For example: $h_{fg} = h_g - h_f$ which is called the **latent heat**.

2. Wet vapor: it is a state in which a mixture of both saturated vapor and liquid are present. To calculate the properties of water in this phase, a property known as the **dryness fraction (x)** is used alongside the saturation properties of (table 2) and (table 3).

Dryness Fraction can be defined as the mass of dry saturated vapor in 1 kg of a mixture of liquid and vapor. It is also called **vapor quality**.

$$x = \frac{m_v}{m_m} = \frac{m_v}{m_v + m_l} \quad \dots \dots \dots (6.1)$$

For saturated liquid line $x = 0$ (which is said to have a quality of 0%)

For dry saturated vapor $x = 1$ (which is said to have a quality of 100%)

For mixed region $0 < x < 1$

Wetness Fraction: is defined as the mass of liquid in 1 kg of a mixture of liquid and vapor.

$$\text{Wetness Fraction} = 1 - \text{Dryness Fraction} \quad \dots \dots \dots (6.2)$$

For one kilogram of wet vapor, there are x kg of vapor, and $(1 - x)$ kg of liquid. Hence to calculate the specific volume at this point:

$$v = (1 - x)v_f + xv_g \quad \dots \dots \dots (6.3)$$

The volume of the liquid is negligibly small compared to the volume of dry saturated vapor. Moreover, for practical problems:

$$v = xv_g \quad \dots \dots \dots (6.4)$$

The enthalpy of a wet vapor is given by the sum of the enthalpy of the liquid plus the enthalpy of the dry vapor:

$$h = (1 - x)h_f + xh_g$$

$$h = h_f + x(h_g - h_f)$$

$$h = h_f + xh_{fg} \quad \dots \dots \dots (6.5)$$

Similarly the internal energy equation is:

$$u = u_f + xu_{fg} \quad \dots \dots \dots (6.6)$$

And the entropy equation is:

$$s = s_f + xs_{fg} \quad \dots \dots \dots (6.7)$$

3. Superheated vapor: when water is in the superheated vapor phase, (table 4) is used to get the required properties. To use this table, two properties must be known:

$P + T \rightarrow$ Table 4 \rightarrow required property

$P +$ any other property (v, u, h, s) \rightarrow Table 4 \rightarrow required property

$T +$ any other property (v, u, h, s) \rightarrow Table 4 \rightarrow required property

4. Compressed (Subcooled) liquid: when water is in the compressed liquid phase, (table 5) is used to get the required properties. To use this table, two properties must be known. So the same rules as with the superheated vapor are applied here.

Finding the Phase of Water

We can identify the state of water using the saturation tables (i.e. table 2 and table 3). Two known properties are required to identify the state of water as follows:

- If $P < P_{sat.}$ at T
 $T > T_{sat.}$ at P
 $v > v_g$ at T or P
 $u > u_g$ at T or P
 $h > h_g$ at T or P
 $s > s_g$ at T or P

then the water is in the superheated vapor state.

- If $P > P_{sat.}$ at T
 $T < T_{sat.}$ at P
 $v < v_f$ at T or P
 $u < u_f$ at T or P
 $h < h_f$ at T or P
 $s < s_f$ at T or P

then the water is in the compressed liquid state.

If the property equals the saturation value, then the water is in the saturated state (vapor or liquid).

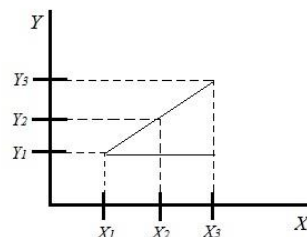
If ($property_f < property < property_g$), then the water is in the wet vapor state.

Linear Interpolation

When the required property value is located between two known values in the tables, we can calculate the required value by linear interpolation. Assume that $(Y_1, Y_2, Y_3, X_1, X_3)$ are known and (X_2) is the required value. By assuming a linear relationship:

$$Slop = \frac{(X_2 - X_1)}{(Y_2 - Y_1)} = \frac{(X_3 - X_1)}{(Y_3 - Y_1)}$$

$$X_2 = X_1 + \left(\frac{Y_2 - Y_1}{Y_3 - Y_1} \right) (X_3 - X_1)$$



Example (6.1): A rigid tank contains saturated liquid water at 90°C. Determine the pressure in the tank and the specific volume of the water.

Solution:

From table 2 at 90°C for saturated liquid, we get:

$$P_{sat.} = 70.14 \text{ kPa} \quad \text{Ans.}$$

$$v = v_f = 0.001036 \text{ m}^3/\text{kg} \quad \text{Ans.}$$

Example (6.2): Determine the specific volume, internal energy, enthalpy and entropy for a mixture of 10% quality at 0.15 MPa.

Solution:

$$\text{Given, } x = 0.1$$

At 0.15 MPa, from table 3:

$$v_g = 1.1593 \text{ m}^3/\text{kg}$$

$$u_f = 466.94 \text{ kJ/kg}, \quad u_{fg} = 2052.7 \text{ kJ/kg}$$

$$h_f = 467.11 \text{ kJ/kg}, \quad h_{fg} = 2226.5 \text{ kJ/kg}$$

$$s_f = 1.4336 \text{ kJ/kg.K}, \quad s_{fg} = 5.7897 \text{ kJ/kg.K}$$

Specific volume, $v = x \cdot v_g$

$$= 0.1 \times 1.159 = 0.1159 \text{ m}^3/\text{kg}$$

Internal energy, $u = u_f + x \cdot u_{fg}$

$$= 466.94 + 0.1 \times 2052.7 = 672.21 \text{ kJ/kg}$$

Enthalpy, $h = h_f + x \cdot h_{fg}$

$$= 467.11 + 0.1 \times 2226.5 = 689.759 \text{ kJ/kg}$$

Entropy, $s = s_f + x \cdot s_{fg}$

$$= 1.4336 + 0.1 \times 5.7897 = 2.01257 \text{ kJ/kg.K}$$

$$v = 0.1159 \text{ m}^3/\text{kg} \quad \text{Ans.}$$

$$u = 672.21 \text{ kJ/kg} \quad \text{Ans.}$$

$$h = 689.759 \text{ kJ/kg} \quad \text{Ans.}$$

$$s = 2.01257 \text{ kJ/kg.K} \quad \text{Ans.}$$

Example (6.3): Determine the temperature of superheated steam at a state of 0.5 MPa and enthalpy 2960.7 kJ/kg.

Solution:

From table 4 at $P = 0.5 \text{ MPa}$ and $h = 2960.7 \text{ kJ/kg}$, we get:

$T = 250 \text{ }^\circ\text{C}$ Ans.

Example (6.4): Determine the phase for each of the following water states:

a. 120°C , 500 kPa

b. 120°C , $0.5 \text{ m}^3/\text{kg}$

Solution:

a. From table 2 with 120°C . The saturation pressure is 198.5 kPa , so we have a compressed liquid. We could also have used table 3 with 500 kPa and found the saturation temperature as 151.86°C , so we would say that it is a subcooled liquid.

b. From table 2 with 120°C we notice that:

$$v_f = 0.00106 < v < v_g = 0.89186 \text{ m}^3/\text{kg}$$

So the state is a two-phase mixture of liquid and vapor.

Example (6.5): Determine the temperature for water at a pressure of 300 kPa and $1 \text{ m}^3/\text{kg}$.

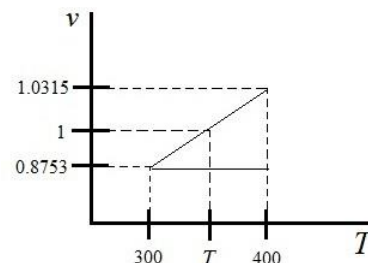
Solution:

From table 3 at 300 kPa , we can see that $v > v_g$, so we have superheated vapor.

From table 4 at 300 kPa and $v = 1 \text{ m}^3/\text{kg}$, we can see that the value of T can be found by interpolation between 300°C and 400°C at 300 kPa .

$$\frac{T - 300}{1 - 0.8753} = \frac{400 - 300}{1.0315 - 0.8753}$$

$T = 379.8^\circ\text{C}$ Ans.



Exercises

Problem (6.1): For water at 0.1 MPa with a quality of 10%, find the specific volume, internal energy, enthalpy and entropy.

Problem (6.2): Determine the temperature and quality for water at a pressure of 0.3 MPa and $0.5 \text{ m}^3/\text{kg}$.

Problem (6.3): Determine the phase of water at the state of 10°C and 10 kPa.

Problem (6.4): Determine the properties of water at the state of 1 MPa and 200°C .

Problem (6.5): Determine the pressure of water at 200°C with $v = 0.4 \text{ m}^3/\text{kg}$.