Chemical Engineering (Thermodynamics I) (UCH305)

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Lecture 6

Properties of pure substances

Outline

- Pure substances
- Phase change process

Pure Substance

A substance that has a ***fixed chemical composition*** throughout is called a **pure substance.**

- Water,
- Nitrogen,
- Helium, and
- Carbon dioxide,

* are all pure substances.

- A mixture of two or more phases of a pure substance is still a pure substance as long as the ***chemical composition*** of ***all phases*** is the same.

- For example,
  - a mixture of ice and liquid water is a pure substance (H_2O)
  - a mixture of liquid water and water vapour (steam) is a pure substance
  - because both phases have the same chemical composition.

- A mixture of ***liquid air*** and ***gaseous air*** is not a pure substance since the composition of liquid air is different from the composition of gaseous air, and thus the mixture is no longer chemically homogeneous.

- This is due to different components in air ***condensing*** at different temperatures at a specified pressure.

Composition of air

Constituent	Chemical symbol	Mole percent
Nitrogen	N_2	78.084
Oxygen	O_2	20.947
Argon	Ar	0.934
Carbon dioxide	CO_2	0.0350
Neon	Ne	0.001818
Helium	He	0.000524
Methane	CH_4	0.00017
Krypton	Kr	0.000114
Hydrogen	H_2	0.000053
Nitrous oxide	N_2O	0.000031
Xenon	Xe	0.0000087
Ozone	O_3	trace to 0.0008
Carbon monoxide	CO	trace to 0.000025
Sulfur dioxide	SO_2	trace to 0.00001
Nitrogen dioxide	NO_2	trace to 0.000002
Ammonia	NH_3	trace to 0.0000003
Water vapor	H_2O (v)	10 ppm (0.001%–5%)

Phases of a pure substance

- A substance ***exists*** in different phases.

- At room temperature and pressure,
  - copper is a solid,
  - water is a liquid, and
  - nitrogen is a gas.

- Under different ***operating conditions (P & T)***, each substance may appear in a **different phase**.

- Even though there are three principal phases:
  - solid, liquid, and gas

Phase-change processes of pure substances

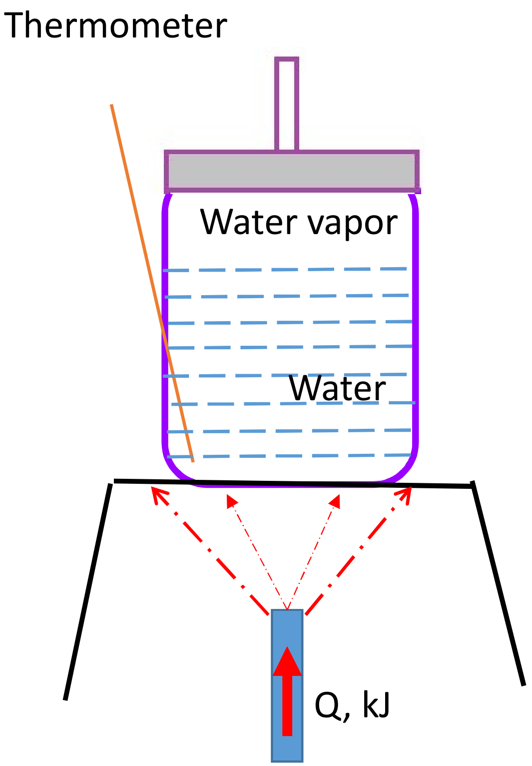
- There are many practical situations where two phases of a pure substance coexist in equilibrium.

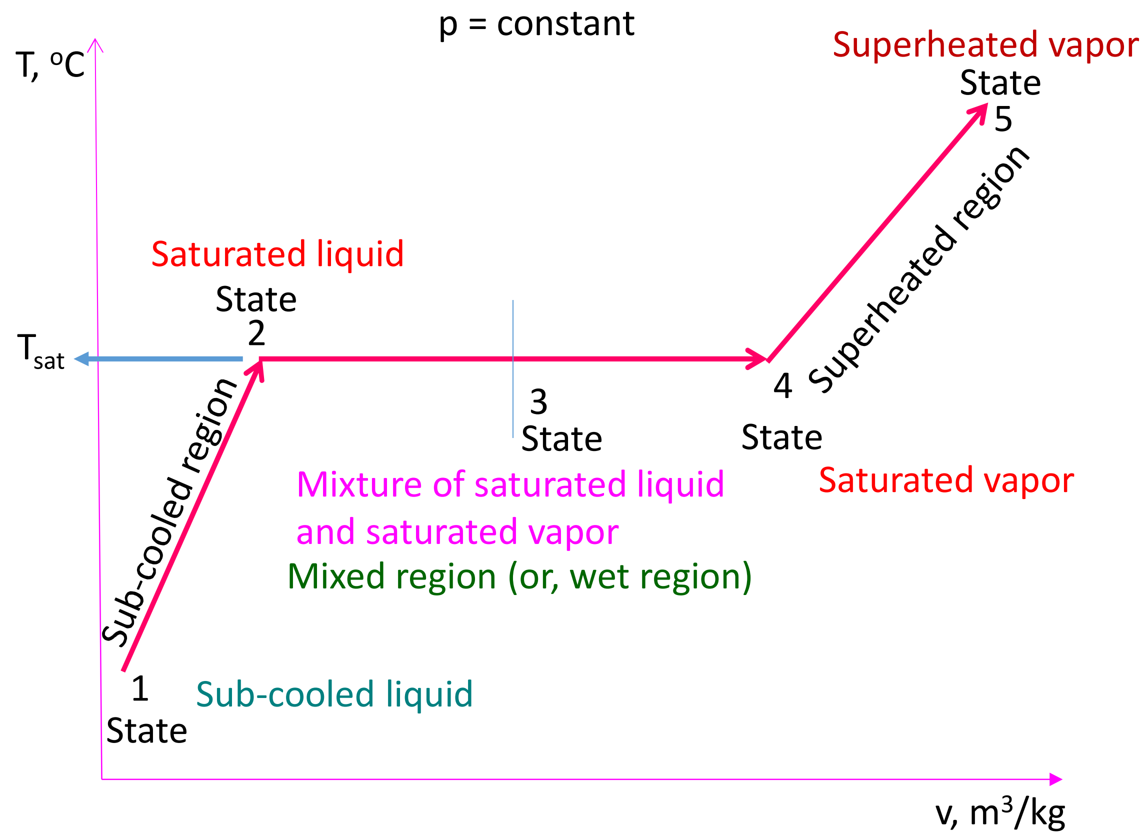
- Water exists as a mixture of liquid and vapour in:
  - the boiler and
  - the condenser of a thermal (steam) power plant.

- The refrigerant turns ***from liquid to vapor*** in the freezer of a refrigerator.

Phase change process

Constant pressure process
p = Constant





States

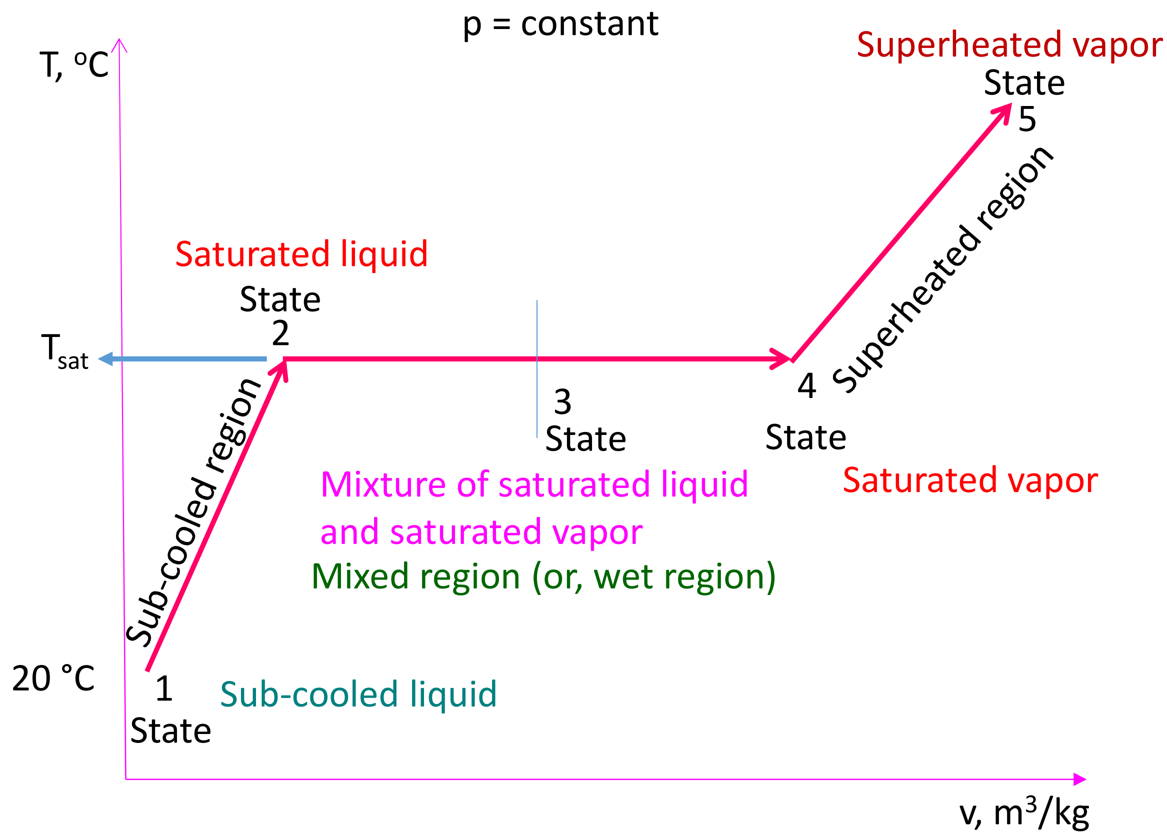
State-1: Subcooled liquid or compressed liquid (T_1°C)

State-2: Saturated liquid (T_2°C = T_{sat})

State-3: Mixture of saturated liquid and saturated vapor (T_2°C = T_3 °C = T_{sat})

State-4: Saturated vapor (T_4°C = T_{sat})

State-5: Superheated vapor (T_5°C)



Regions

- State 1 $\rightarrow$ State 2 = Sub-cooled region (Compressed liquid region)

$$Q_{12} = m \times c_{p,l} \times \left(T_2 - T_1\right)$$

- State 2 $\rightarrow$ State 4 = mixed region (or, wet region)

$$Q_{24} = m \times h_{fg} = m \times \left(h_g - h_f\right) = m \times L = m \times \lambda$$

- State 4 $\rightarrow$ State 5 = Superheated region

$$Q_{45} = m \times c_{p,v} \times \left(T_5 - T_4\right)$$

- Energy at state 3 = mixed point

$$Q_3 = m \times h_3 = m \times (h_f + x\, h_{fg}),$$

  - *where 'x' is quality (or dryness fraction), i.e.*
  - $\mathrm{x} = \dfrac{\text{Mass of vapor}}{\text{Total mass of liquid and vapor}} = \dfrac{m_v}{(m_f + mv)}$

References

1. *Rao, Y.V.C., Thermodynamics, Universities Press (2004).*
2. *Smith J. M. and Van Ness H. C., Chemical Engineering Thermodynamics, Tata McGraw-Hill (2007).*
3. *Nag, P.K., Engineering Thermodynamics, Tata McGraw Hill (2008) 3rd ed.*
4. *Cengel, Y. A. and Boles, M., Thermodynamics: An Engineeing Approach, Tata McGraw Hill (2008).*

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Thank you for your Patience