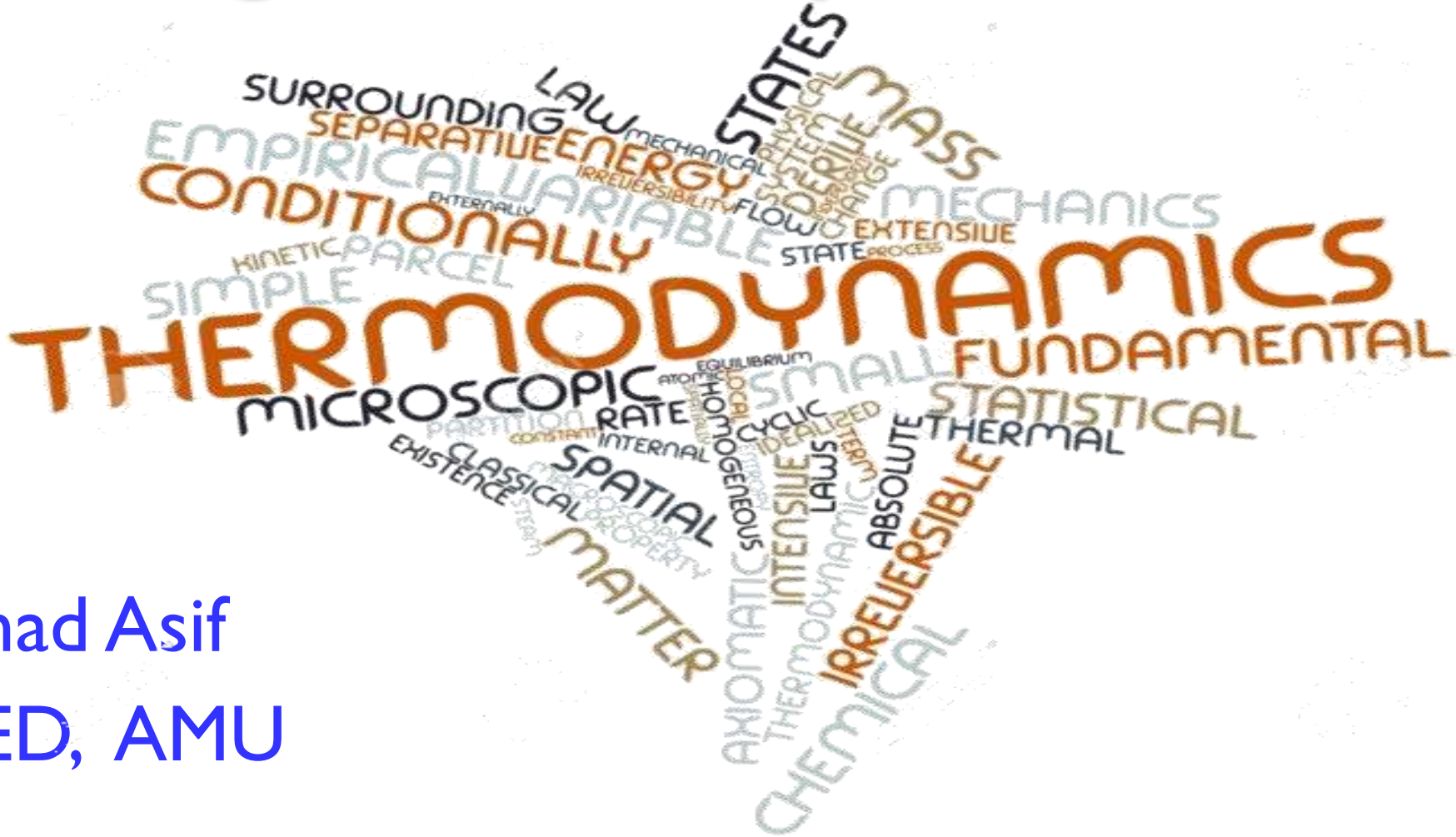
Engineering Thermodynamics

MEA1110



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Unit-3

Pure Substance

Different Phases of Pure Substance, Two-Property Rule, Property Diagrams, Tables and Charts, T~ s, T~ P, P~ v, P~ h and Mollier (h~s) diagrams, Phase Boundaries, S-L-V region, CP and TP, Dryness Fraction and its Measurement, Separating and Throttling Calorimeters.

Lecture-1

Introduction

- **Simple System:** A simple system is one in which the effects of motion, viscosity, fluid shear, capillarity, anisotropic stress, and external force fields are absent

- **Homogeneous Substance:** A substance that has uniform thermodynamic properties throughout is said to be homogeneous

- **Pure Substance**: A pure substance has a homogeneous and invariable chemical composition and may exist in more than one phase

Examples:

1. Water (solid, liquid, and vapor phases)
2. Mixture of liquid water and water vapor
3. Carbon dioxide, CO2
4. Nitrogen, N2
5. Mixtures of gases, such as air, as long as there is no change of phase

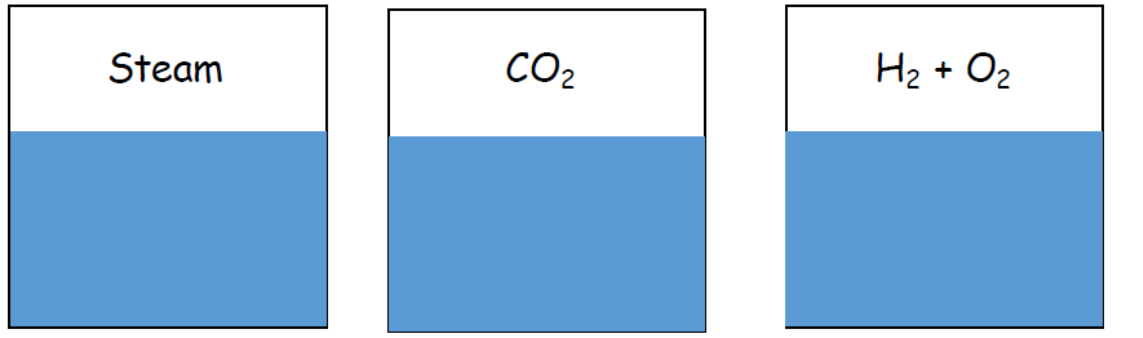
Pure substance : Definition

A pure substance is a system which is

- homogeneous in composition
- homogeneous in chemical aggregation
- invariable in chemical aggregation

the chemical elements must be combined chemically in the same way in all parts of the system

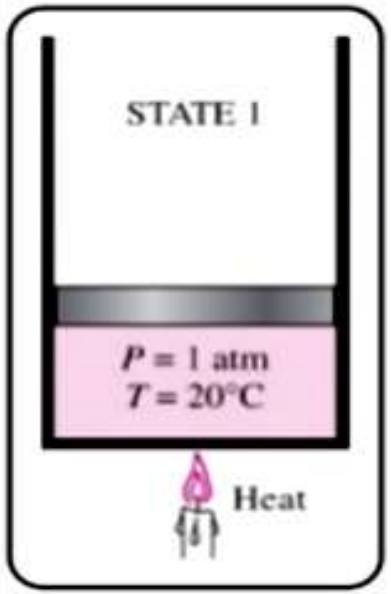
the state of chemical combination of the system does not change with time



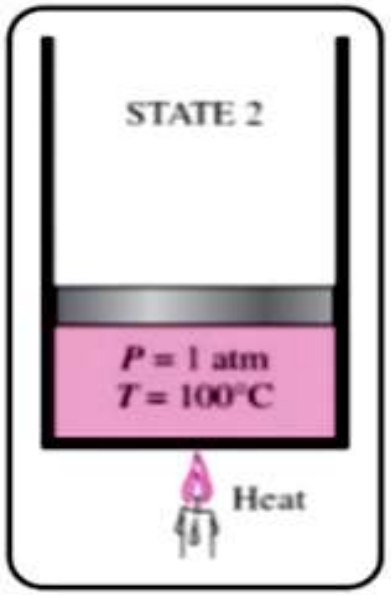
Let's do an Experiment !

In a piston-cylinder mechanism with water as a working fluid at 20°C.
Let us heat it from 20° C to 300° C and see the evolution of different phases.

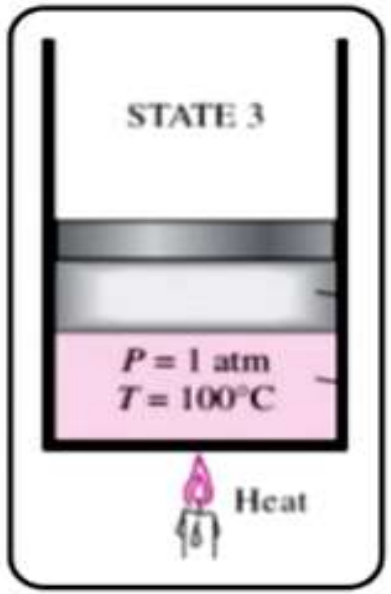
State(s) 1 - 5



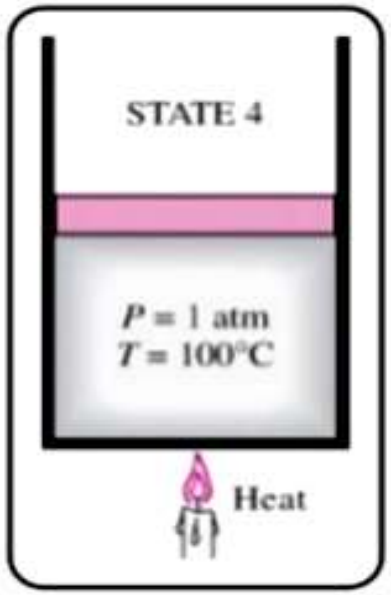
At 1 atm and 20°C, water exists in the liquid phase (*compressed liquid*).



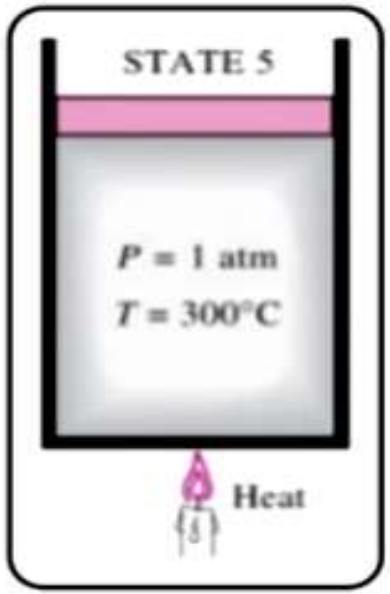
At 1 atm pressure and 100°C, water exists as a liquid that is ready to vaporise (*saturated liquid*).



As more heat is transferred, part of the saturated liquid vaporises (**saturated liquid–vapour mixture**).



At 1 atm pressure, the temperature remains constant at 100°C until the last drop of liquid is vaporised (*saturated vapour*).



As more heat is transferred, the temperature of the vapour starts to rise (*superheated vapour*).

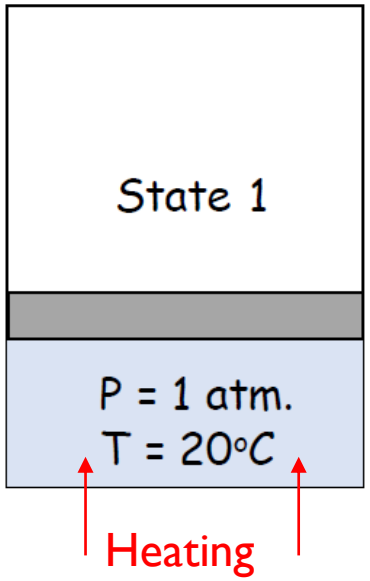
Phase Change of a Pure Substance

Let us consider the results of heating liquid water from 20°C, 1 atm. while keeping the pressure constant

- constant pressure process will be executed.
- First place liquid water in a piston-cylinder device where a fixed weight is placed on the piston to keep the pressure of the water constant at all times.
- As liquid water is heated while the pressure is held constant, the following events occur

Process 1-2:

- The temperature and specific volume will increase from the *compressed liquid*, or *subcooled liquid*, state 1, to the saturated liquid state 2
- In the compressed liquid region, the properties of the liquid are approximately equal to the properties of the saturated liquid state at the temperature



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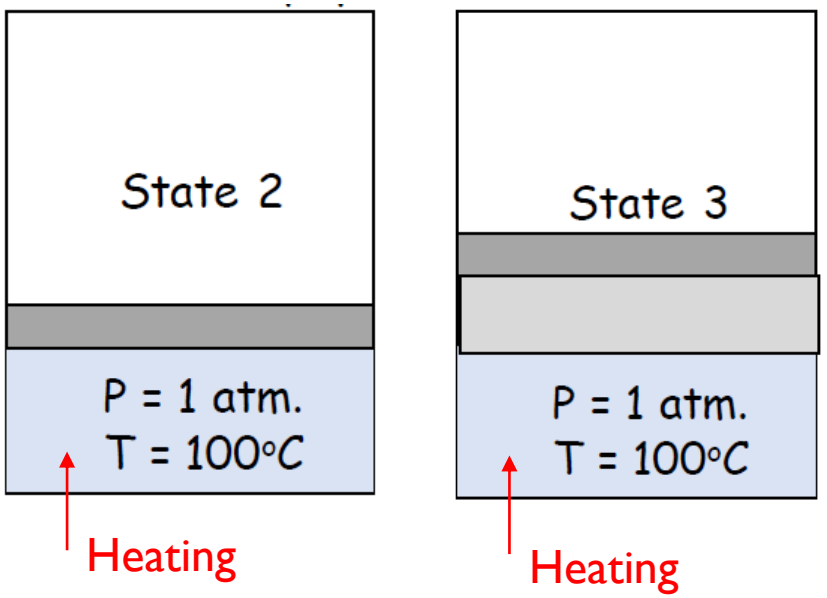
Process 2-3:

- At state 2 the liquid has reached the **temperature at which it begins to boil, called the saturation temperature**, and is said to exist as a *saturated liquid*.
- Properties at the saturated liquid state are noted by the subscript **f** and $v_2 = v_f$.
- **During the phase change both the temperature and pressure remain constant** (according to the International Temperature Scale of 1990, ITS-90, water boils at 99.975oC & 100oC when the pressure is 1 atm or 101.325 kPa).
- **At state 3 the liquid and vapor phase are in equilibrium** and any point on the line between states 2 and 3 has the same temperature and pressure.



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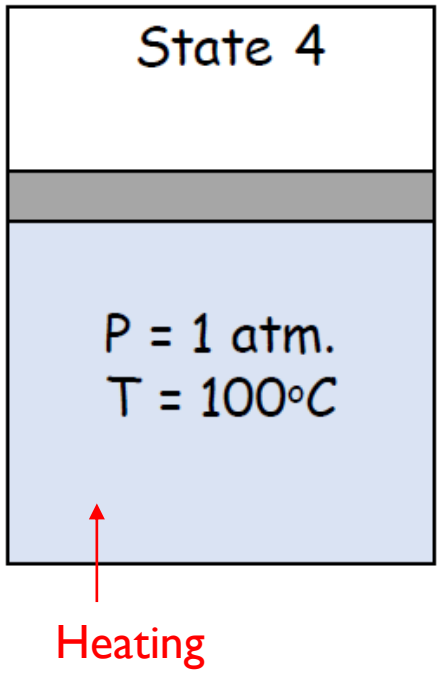
Process 3-4:

- **At state 4, a saturated vapor exists and vaporization is complete**
- The subscript **g** will always denote a saturated vapor state, $\mathbf{v_4 = v_g}$
- The saturation temperature is an independent property
- The saturation pressure is an independent property
- The saturation pressure is the pressure at which phase change will occur for a given temperature
- In the saturation region the temperature and pressure are dependent properties; if one is known, then the other is automatically known



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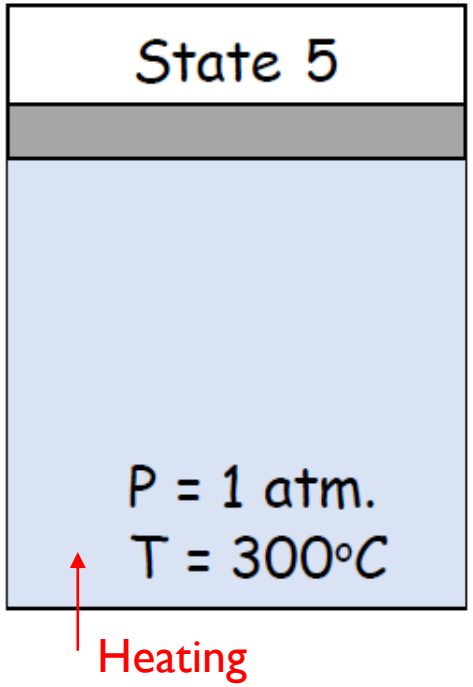
Process 4-5:

- If the constant pressure heating is continued, the temperature will begin to increase above the saturation temperature, 100°C in this example, and the volume also increases.
- **State 5 is called a *superheated state*** because temperature T_5 is greater than the saturation temperature for the pressure and the vapor is not about to condense
- Thermodynamic properties for water in the superheated region are found in the superheated steam tables



Constant Pressure Steam Generation Process

First Law applied to a process:

$$\delta q = dh - vdp$$

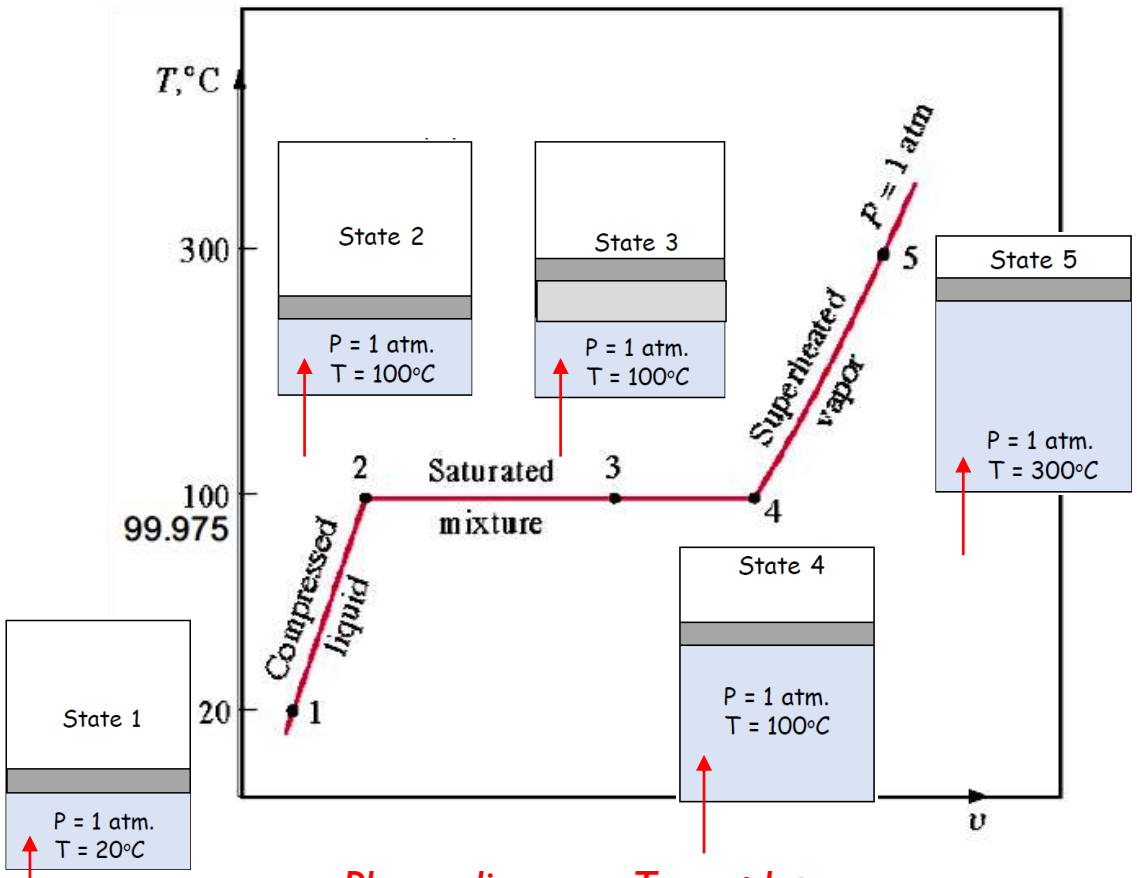
Heat supplied

Enthalpy change

Work done

For a constant pressure Steam Generation:

$$\delta q = dh - \underbrace{vdp}_{=0} = 0$$



Phase diagram :T – v plot

Note: Points 2 and 3 are at the same boiling point temperature and pressure and also that, at those conditions, the liquid and the steam are in equilibrium with each other

Important Terminologies

- **Sub-cooled/compressed liquid: Water or any liquid at the temperature below its saturation temperature at a given pressure is said to exist as Sub-cooled/compressed liquid.**

- **Saturated liquid: Water or any liquid at the saturation temperature, at which it begins the phase change from liquid to vapour, called, and is said to exist as a saturated liquid at a given pr. So, here steam quality or dryness fraction, x=0**

- **Wet steam: A mixture of water plus steam (liquid (L) plus vapor (V) i.e *L +V*) at the boiling point temperature of water at a given pressure.**

✓ ***Quality or dryness fraction:*** **the fraction of gaseous steam in a wet steam mixture :**

$$x=m_v/m,\ m=m_v + m_l$$

- **Dry steam: Steam, at the given pressure, that contains no water (also referred to as saturated steam): The quality, x = 1.**

- **Superheated steam: Dry steam, at the given pressure, that has been heated to a temperature higher than the boiling point of water at that pressure**