Module

3

Lecture

1

Asansol Engineering College
Department of Mechanical Engineering

Thermodynamics

Properties of Pure Substances

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Contents:

- Definition of Pure substance, Ideal Gases and ideal gas mixtures, Real gases and real gas mixtures,
- Compressibility charts- Properties of two phase systems - Const. temperature and Const. pressure heating of water;
- Definitions of saturated states; P-v-T surface; Use of steam tables and R134a tables;
- Saturation tables; Superheated tables; Identification of states & determination of properties,
- Mollier's chart.

Objectives:

- To understand key concepts . . . including phase and pure substance, state principle for simple compressible systems, *P*–*v*–*T* surface, saturation temperature and saturation pressure, two-phase liquid-vapor mixture, quality, enthalpy, and specific heats.
- To apply the closed system energy balance with property data.
- To learn $T-v$, $P-v$, and phase diagrams, and locate states on these diagrams.
- To retrieve property data from Tables
- To understand Mollier’s chart

Outcomes:

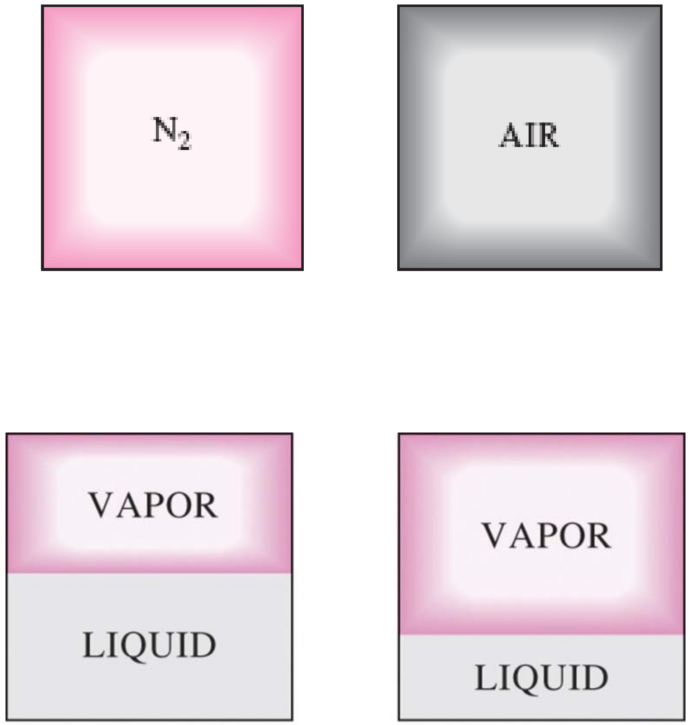
After completing this chapter, the students will be able to

- demonstrate understanding of key concepts . . . including phase and pure substance, state principle for simple compressible systems, P–v–T surface, saturation temperature and saturation pressure, two-phase liquid-vapor mixture, quality, enthalpy, and specific heats.
- apply the closed system energy balance with property data.
- sketch $T-v$, $P-v$, and phase diagrams, and locate states on these diagrams.
- retrieve property data from Tables

What is a Pure Substance?

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

- A pure substance does not have to be of a single chemical element or compound, however. A mixture of various chemical elements or compounds also qualifies as a pure substance as long as the mixture is ***homogeneous***.



(*a*) H_2O (*b*) AIR

- A pure substance can exist in more than one phase, but its chemical composition must be the same in each phase.

Examples:

- if liquid water and water vapor form a system with two phases, the system can be regarded as a pure substance because each phase has the same composition.
- A uniform mixture of gases can be regarded as a pure substance provided it remains a gas and doesn't react chemically.
- Air can be regarded as a pure substance as long as it is a mixture of gases; but if a liquid phase should form on cooling, the liquid would have a different composition than the gas phase, and the system would no longer be considered a pure substance.

Phases of a Pure Substance

- The substances exist in different phases, e.g. at room temperature and pressure, copper is solid and mercury is a liquid.

- It can exist in different phases under variations of condition.

- There are three principal phases
  - *solid*
  - *Liquid*
  - *gas*

  Each with different molecular structures.

Solid:

- The molecules in a *solid* are arranged in a three-dimensional pattern (lattice) that is repeated throughout (Fig. 3.1).
- Because of the small distances between molecules in a solid, the attractive forces of molecules on each other are large and keep the molecules at fixed positions.
- Note that the attractive forces between molecules turn to repulsive forces as the distance between the molecules approaches zero, thus preventing the molecules from piling up on top of each other.
- Even though the molecules in a solid cannot move relative to each other, they continually oscillate about their equilibrium

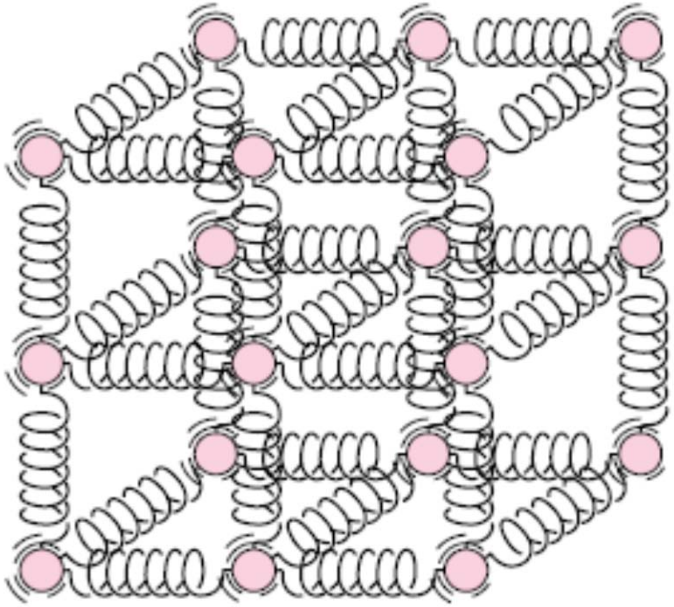
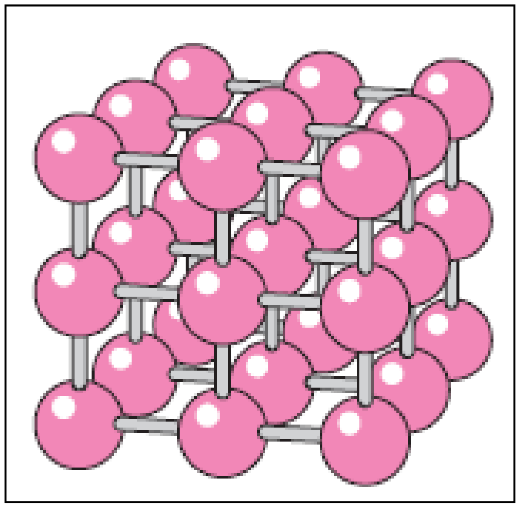


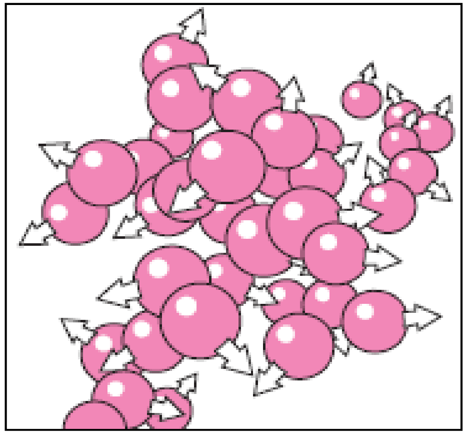
Fig. 3.1: The molecules in a solid are kept at their positions by the large springlike intermolecular forces.



Solid

Liquid:

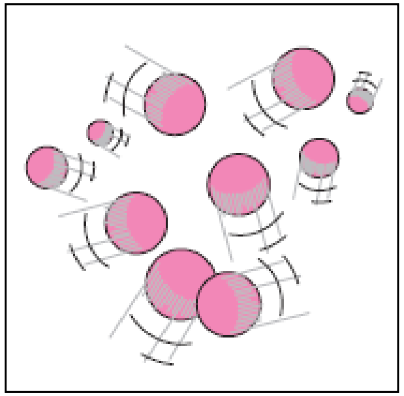
- The molecular spacing in the **liquid** phase is not much different from that of the solid phase, except the molecules are no longer at fixed positions relative to each other and they can rotate and translate freely.
- In a liquid, the intermolecular forces are weaker relative to solids, but still relatively strong compared with gases.
- The distances between molecules generally experience a slight increase as a solid turns liquid, with water being a notable exception.



Liquid

Gas:

- In the **gas** phase, the molecules are far apart from each other, and a molecular order is non existent.
- Gas molecules move about at random, continually colliding with each other and the walls of the container they are in.
- Particularly at low densities, the intermolecular forces are very small, and collisions are the only mode of interaction between the molecules.
- Molecules in the gas phase are at a considerably higher energy level than they are in the liquid or solid phases.
- Therefore, the gas must release a large amount of its energy before it can condense or freeze.



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 vapor in the boiler and the condenser of a steam power plant.
- The refrigerant turns from liquid to vapor in the freezer of a refrigerator.
- As a familiar substance, water will be used to demonstrate the basic principles involved. However, that all pure substances exhibit the same general behaviour.

Compressed Liquid and Saturated Liquid

- Consider a piston-cylinder device containing liquid water at 20°C and 1 atm pressure (state 1, Fig. 3.2). Under these conditions, water exists in the liquid phase, and it is called a *compressed liquid*, or a *subcooled liquid*, meaning that it is *not about to vaporize.*
- Heat is now transferred to the water until its temperature rises to, say, 40°C. As the temperature rises, the liquid water expands slightly, and so its specific volume increases. To accommodate this expansion, the piston will move up slightly. The pressure in the cylinder remains constant at 1 atm. during this process since it depends on the outside barometric pressure and the weight of the piston, both of which are constant. Water is still a compressed liquid at this state since it has not started to vaporize.
- As more heat is transferred, the temperature will keep rising until it reaches 100°C (state 2, Fig. 3.3). At this point water is still a liquid, but any heat addition will cause some of the liquid to vaporize. That is, a phase-change process from liquid to vapor is about to take place. A liquid that is *about to vaporize* is called a *saturated liquid*. Therefore, state 2 is a saturated liquid state.

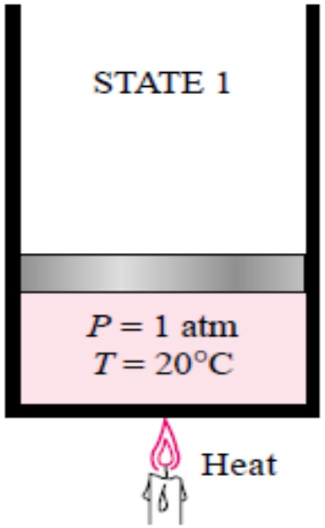


Fig. 3.2: At 1 atm and 20°C, water exists in the liquid phase (*compressed liquid*).

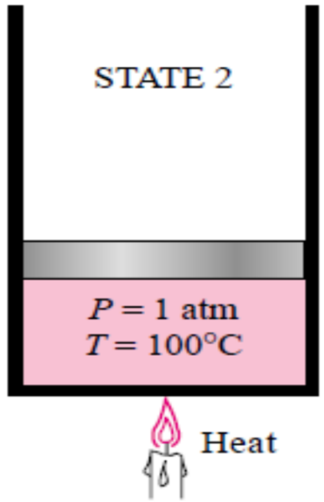


Fig. 3.3: At 1 atm pressure and 100°C, water exists as a liquid that is ready to vaporize (*saturated liquid*).

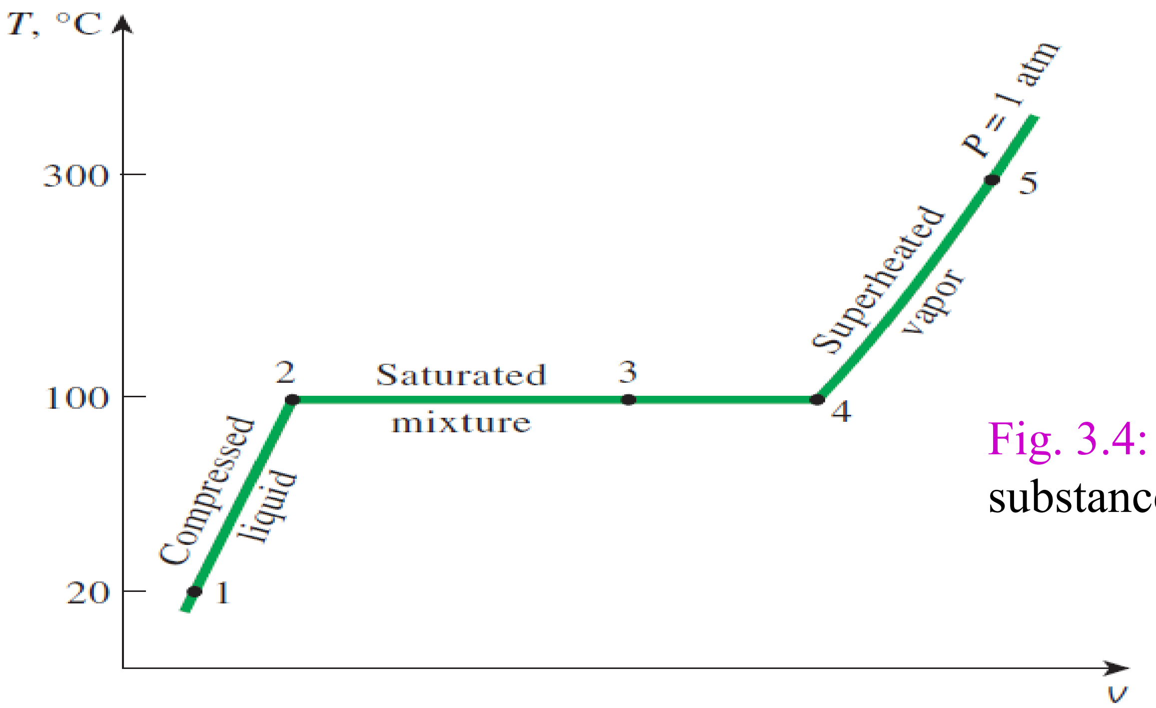


Fig. 3.4: T-v diagram for pure substance

- Once boiling starts, the temperature will stop rising until the liquid is completely vaporized. That is, the temperature will remain constant during the entire phase-change process if the pressure is held constant.
- During a boiling process, the only change we will observe is a large increase in the volume and a steady decline in the liquid level as a result of more liquid turning to vapor.
- Midway about the vaporization line (state 3, Fig. 3.5), the cylinder contains equal amounts of liquid and vapor. As we continue transferring heat, the vaporization process will continue until the last drop of liquid is vaporized (state 4, Fig. 3.6). At this point, the entire cylinder is filled with vapor that is on the borderline of the liquid phase.
- Any heat loss from this vapor will cause some of the vapor to condense (phase change from vapor to liquid). A vapor that is *about to condense* is called a *saturated vapor*. Therefore, state 4 is a saturated vapor state.
- A substance at states between 2 and 4 is often referred to as a *saturated liquid–vapor mixture* since the *liquid and vapor phases coexist* in equilibrium at these states.

Saturated Vapor and Superheated Vapor

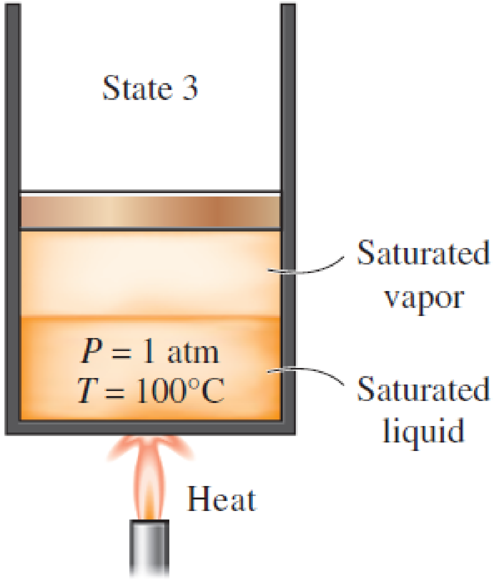


Fig. 3.5: As more heat is transferred, part of the saturated liquid vaporizes *(saturated liquid–vapor mixture)*.

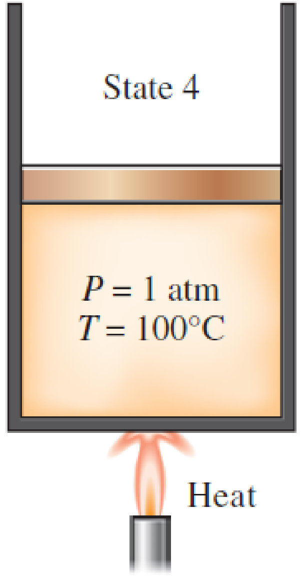


Fig. 3.6: At 1 atm pressure, the temperature remains constant at 100°C until the last drop of liquid is vaporized *(saturated vapor)*.

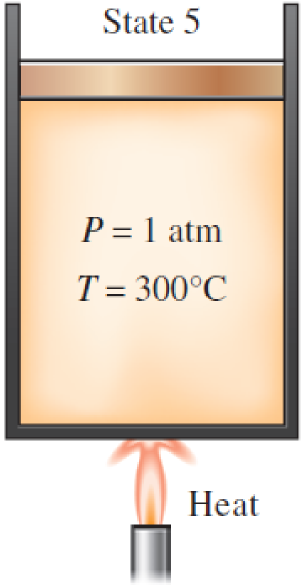


Fig. 3.7: As more heat is transferred, the temperature of the vapor starts to rise (*superheated vapor*).

- Once the phase-change process is completed, we are back to a single-phase region again (this time vapor), and further transfer of heat will result in an increase in both the temperature and the specific volume (Fig. 3.7).
- A vapor that *is not about to condense* (i.e., not a saturated vapor) is called a *superheated vapor.* Therefore, water at state 5 is a superheated vapor.

Thank You