Thermodynamics

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Lecture 44

Two Phase System - Part 1

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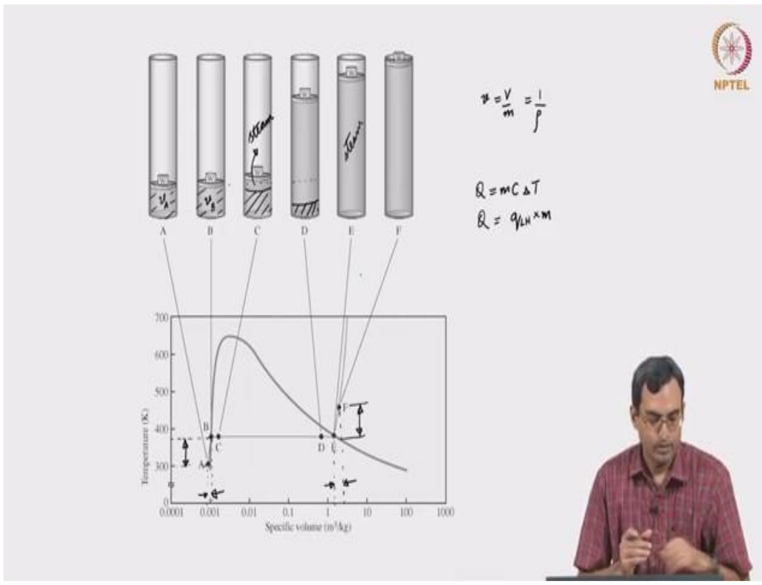

Figure 1.

Figure 1 shows a frictionless piston-cylinder arrangement containing liquid water. There is a weight w on the piston. If there is expansion or contraction in this system, it is going to happen at constant pressure (because the mass of the piston and w are constant).

We have pure water at A and we start heating it. During this process, the temperature of the water is increasing and the pressure is constant. The volume of the water will increase slightly because most substances, when heated, slightly expand. So, the volume at B is slightly more than the volume at A. The temperature at B is higher than the temperature at A. The water is still in liquid state. If we continue to heat, we reach boiling point of water at given pressure (for example, at 1 atm, the boiling point of water is 100 ℃). Let us say, at B, we have reached the boiling point. The water starts forming vapor as we continue to heat. The steam (water vapor) occupies some volume and the volume at C is larger than that at B. As we continue to heat, more and more water becomes steam. The volume keeps increasing and the water level goes down. The specific volume of steam is larger than that of water. After some time, all the water becomes steam (state E). If we continue to heat, the temperature of steam as well as its volume increases. This is how the water boils at constant pressure.

Figure 1 also shows the boiling process on a T-v diagram. At state A, the water is in liquid state. The temperature and the specific volume ($v = \frac{1}{\rho} = 0.001 \frac{m^3}{kg}$) are low. The temperature increases from state A to state B (state B is at boiling point). During this process, the volume also increases slightly. The increase in temperature is significantly larger compared to the increase in volume. The curve between states A and B on the T-v diagram is very steep. The heat supplied during the process between states A and B is called sensible heat. We have pure water at all the states between A and B. Hence, it is a liquid phase (single phase) region. At state B, we reach the boiling point. The heat added after that is used up to convert all the water into steam. This heat is called as latent heat. The temperature does not increase until all the water gets converted into steam. During the sensible heating period, the heat supplied is $Q = mC\Delta T$. However, we cannot use such equation for the latent heat. Usually, it is obtained from tables. After state B, the specific volume increases as the temperature remains constant (the pressure is also constant). From state B to state E, only the specific volume increases at constant temperature and constant pressure. Hence, all the states, B, C, D, and E, lie on a line parallel to the specific volume axis. At state B, we have pure water (saturated water) at boiling point. At state E, we have pure vapor (saturated vapor) at boiling point. At all the states between B and E, we have a mixture of liquid water and vapor (it is a two-phase region). As we continue to heat, the temperature and specific volume of the steam increases (state E to state F is a gas phase (single phase) region). As in the liquid phase region (state A to state B) the increase in temperature is significantly larger compared to that of the specific volume. However, for the same temperature difference, the increase in specific volume for the gas phase region is more compared to that of the liquid phase region. All the states A, B, C, D, E and F lie on an isobar.

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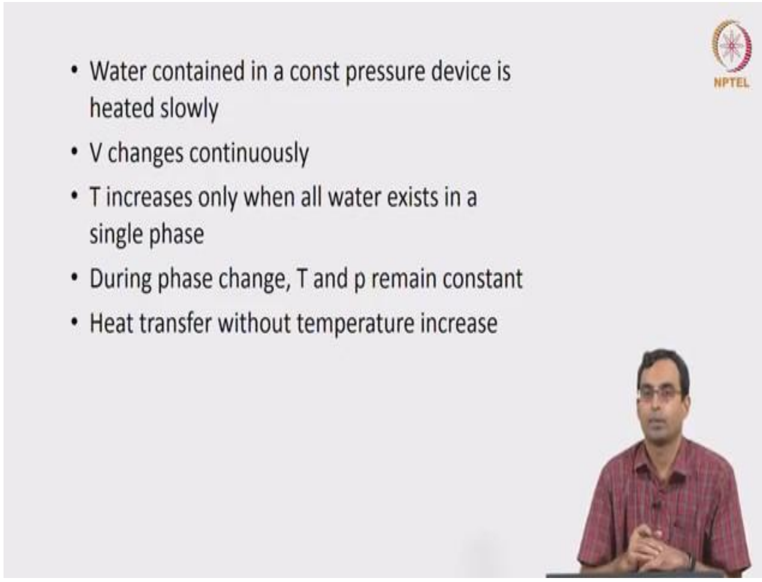

To summarize, water contained in a constant pressure device is heated slowly in the previous experiment. The volume changes continuously. Temperature increases when water is either completely in liquid phase or completely in vapor phase. During the phase change, temperature and pressure remain constant. The heat transfer happens without a temperature change when you have a mixture of liquid and vapor at constant pressure.

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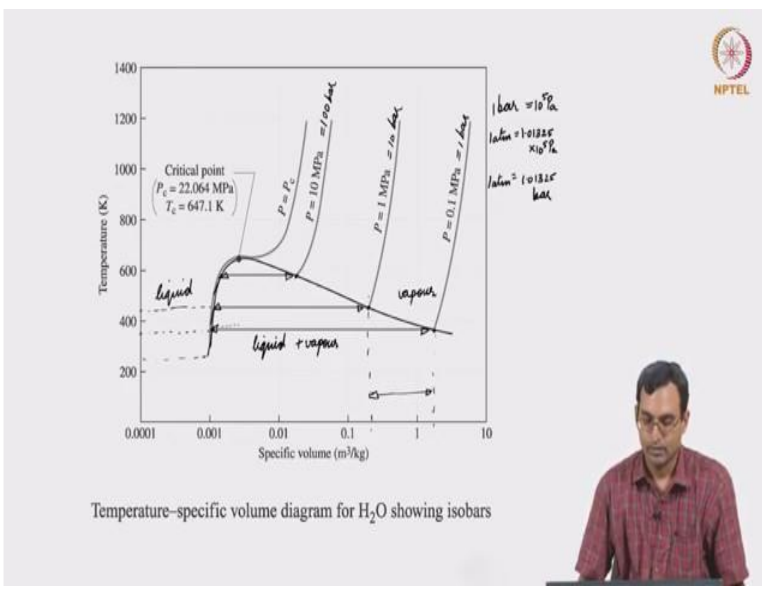

Figure 2.

Figure 2 shows different isobars on a T-v diagram. The boiling point increases with pressure. As the molecules of the liquid are forced to stay closer at higher pressure, it requires more energy to convert it into vapor. At 0.1 MPa (1 bar), the boiling point is around 373 K (100 °C). At 10 MPa (100 bar), the boiling point is around 600 K. If we join all the points where boiling starts (e.g. state B in Fig. 1), we get saturated liquid line (Fig. 2). This line separates liquid water on the left and the mixture of water and vapor on the right. Similarly, if we join all the points where boiling ends (e.g. state E in Fig .1), we get saturated vapor line. This line separates liquid and vapor region on the left and pure vapor region on the right. The saturated liquid line and saturated vapor line form liquid-vapor dome. Inside the dome, we have a mixture of liquid and vapor. At low temperatures (and low pressures), the difference between specific volumes of a pure liquid and pure vapor is large. As the temperature (and pressure) increases, this difference reduces. At some temperature and pressure this difference becomes 0. The specific volume of the liquid and the vapor is the same. The temperature, pressure and volume corresponding to this point are called critical temperature (T_c), critical pressure (p_c) and critical volume (V_c). The saturated liquid line and the saturated vapor line meet at the critical point.

The latent heat of vaporization/evaporation reduces as the temperature and pressure increases. At the critical point, the latent heat becomes 0. At pressures and temperature above p_c and T_c, we can’t distinguish between a liquid and vapor. We call it a supercritical fluid. The volume and temperature of a supercritical fluid increase with heating.

The saturated liquid line is much steeper compared to the saturated vapor line. For a given increase in pressure, the change in the specific volume of the saturated liquid is much smaller compared to that of the saturated vapor, because liquids are incompressible whereas the gases are compressible.

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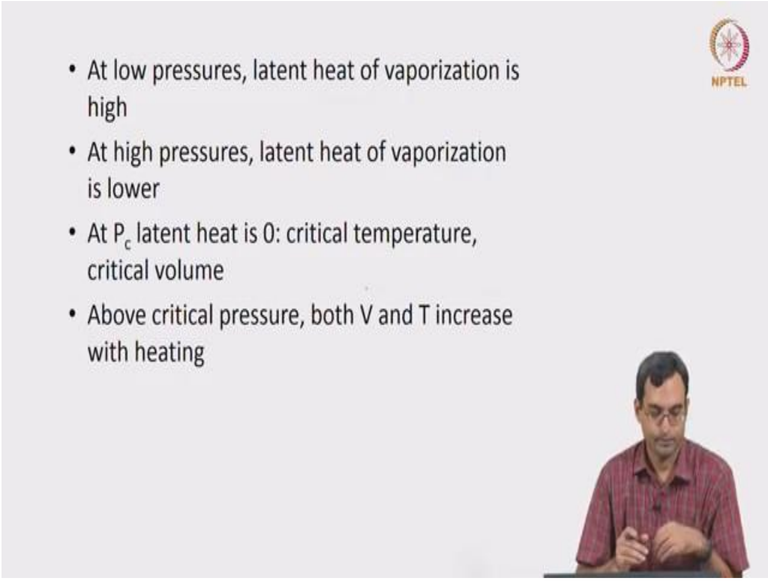

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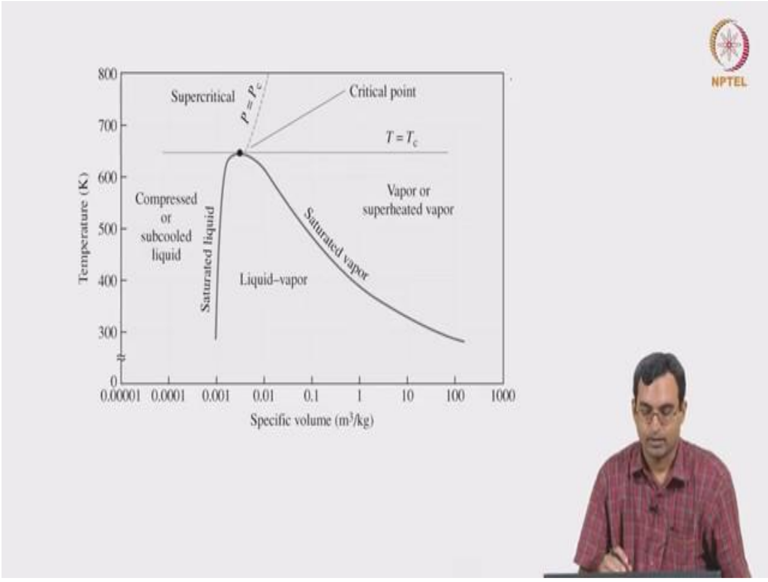

Figure 3.

Figure 3 shows all the important regions and terminologies we learnt till now on a T-v diagram. On the left of the saturated liquid line, we have compressed or subcooled liquid. On the right of saturated vapor line, we have superheated vapor. The isobar passing through the critical point is the critical isobar. At high volumes and temperature much higher than the critical point, the fluid can be treated as ideal gas. Essentially, far away from the liquid-vapor dome towards right on a T-v diagram, we can treat vapor/fluid as an ideal gas (even if we have pressure is less than the critical pressure).