# Pure Substances

Phase Change, Property Tables and Diagrams

In this chapter we consider the property values and relationships of a pure substance (such as water) which can exist in three phases - solid, liquid and gas. We will not consider the solid phase in this course.

In order to introduce the rather complex phase change interactions that occur in pure substances we consider an experiment in which we have liquid water in a piston-cylinder device at 20°C and 100kPa pressure.. Heat is added to the cylinder while the pressure is maintained constant until the temperature reaches 300°C, as shown in the following *T-v* diagram (temperature vs specific volume):
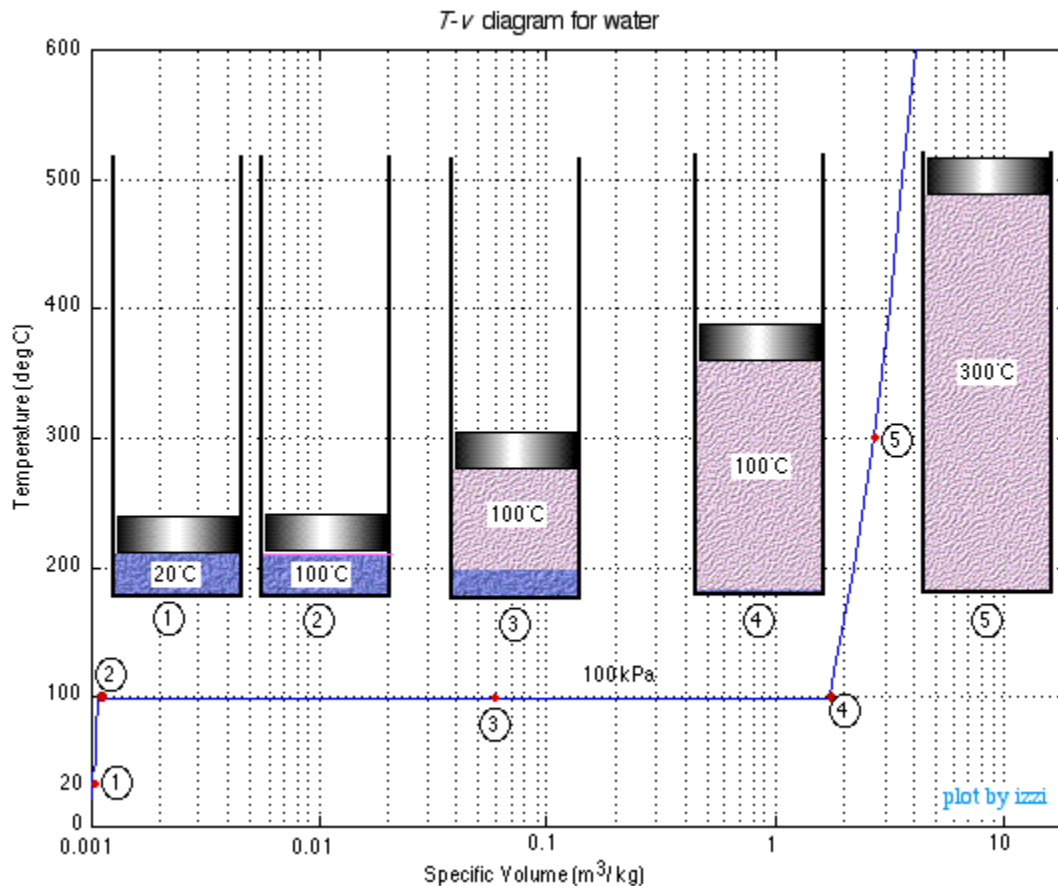

From State (1) to State (2) the water maintains its liquid phase and the specific volume increases very slightly until the temperature reaches close to 100°C (State (2) - **Saturated Liquid**). As more heat is added the water progressively changes phase from liquid to water vapor (steam) while maintaining the temperature at 100°C

(**Saturation Temperature** - T_{sat}) until there is no liquid remaining in the cylinder (State (4) - **Saturated Vapor**). If heating continues then the water vapor temperature increases ($T > T_{sat}$) and is said to be in the **Superheated** (State (5)).

Notice that during this entire process the specific volume of the water increased by more than three orders of magnitude, which made it necessary to use a logarithmic scale for the specific volume axis.

We now consider repeating this experiment at various pressures, as shown in the following *T-v* diagram:
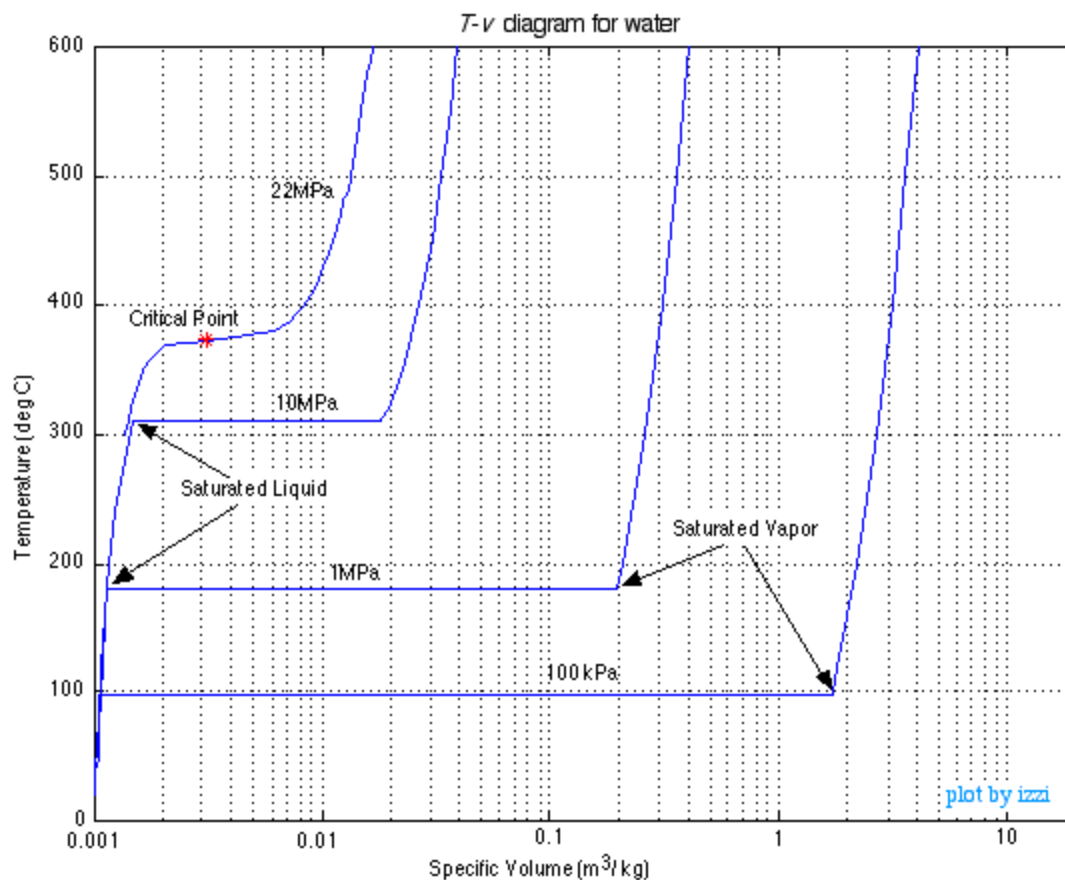
Notice that as we increase the applied pressure, the region between the saturated liquid and saturated vapor decreases until we reach the **Critical Point**, above which there is no clear distinction between the liquid and vapor states.

It is common practice to join the loci of saturated liquid and saturated vapor points as shown in the *T-v* diagram below.

T-v diagram for water
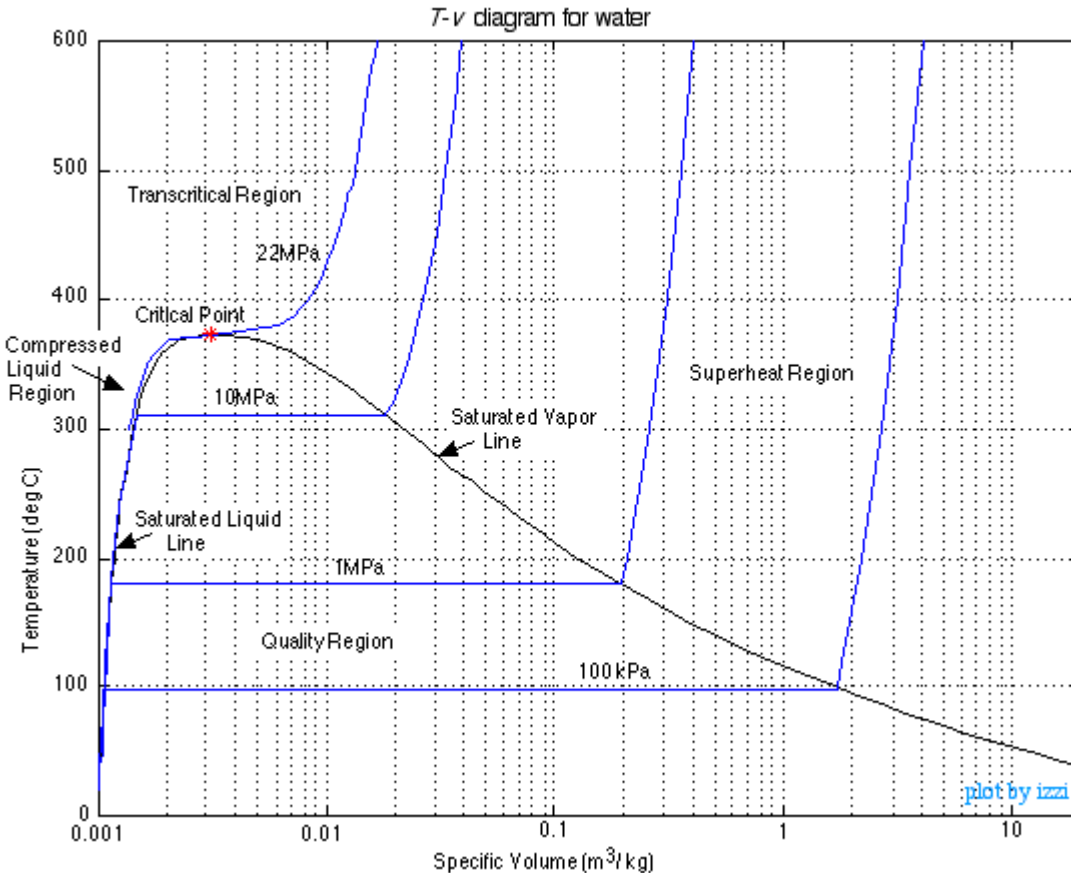
The saturation lines define the regions of interest as shown in the diagram, being the **Compressed Liquid** region, the **Quality** region enclosed by the saturation lines, and the **Superheat**region (which also includes the **Transcritical** region) to the right of the saturated vapor line and above the critical point. We will use **Property Tables** associated with the regions in order to evaluate the various properties. Notice that we have provided property tables of steam, Refrigerant R134a, and Carbon Dioxide, which we believe is destined to become the future refrigerant of common usage.

The Quality Region

The **Quality Region** (also referred to as the **Saturated Liquid-Vapor Mixture Region**) is enclosed between the saturated liquid line and the saturated vapor line, and at any point within this region the quality of the mixture (also referred to as the dryness factor) is defined as the mass of vapor divided by the total mass of the fluid, as shown in the following diagram:

T-v diagram for water
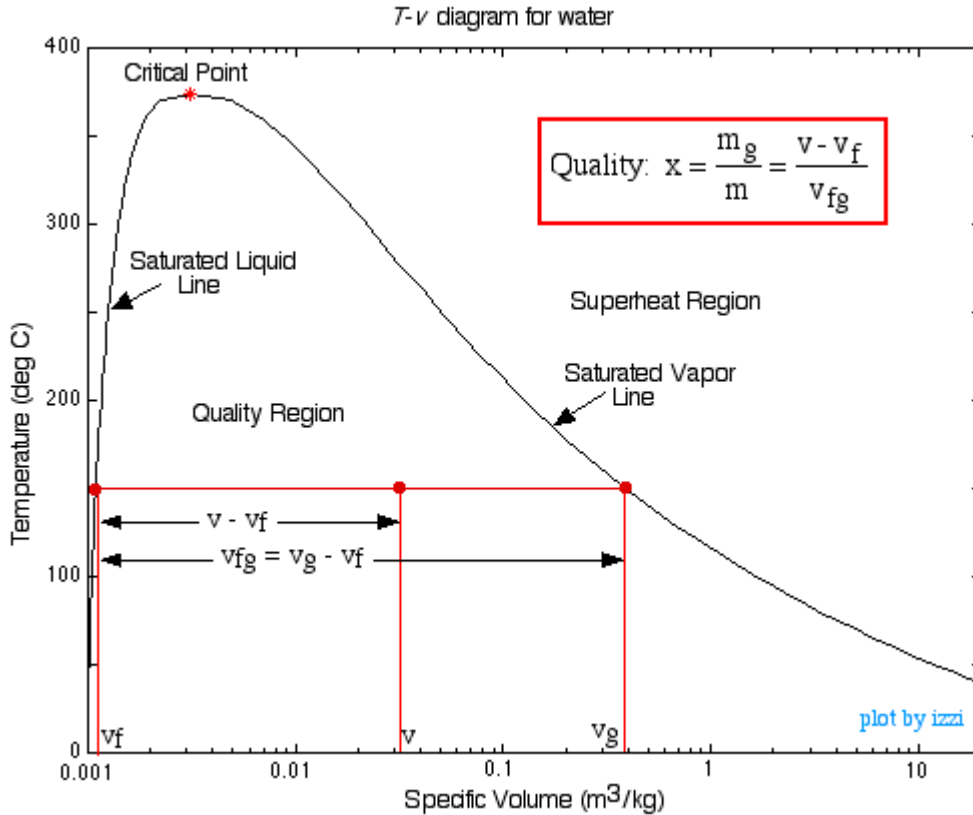
Notice that properties relating to the saturated liquid have the subscript f, and those relating to the saturated vapor have the subscript g. In order to evaluate the quality consider a volume V containing a mass m of a saturated liquid-vapor mixture.
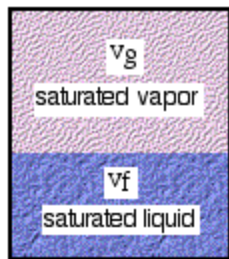
$$V = V_f + V_g$$

$$m\,v = m_f\,v_f + m_g\,v_g$$

$$m\,v = (m - m_g)\,v_f + m_g\,v_g$$

$$\text{Quality: } x = \frac{m_g}{m}$$

$$v = (1 - x)\,v_f + x\,v_g$$

$$v = v_f + x\,v_{fg}$$

$$x = \left(\frac{v - v_f}{v_{fg}}\right)$$

where: $v_{fg} = v_g - v_f$

Notice from the **steam property tables** that we have also included three new properties: internal energy u [kJ/kg], enthalpy h [kJ/kg], and entropy s [kJ/kg.K] all of which will be defined as needed in future sections. At this stage we note that the 3

equations relating quality and specific volume can also be evaluated in terms of these three additional properties.

The *P-v* Diagram for Water

The above discussion was done in terms of the *T-v* diagram, however recall from Chapter 1 when we defined the State Postulate that any two independent intensive properties can be used to completely define all other intensive state properties. It is often advantageous to use the *P-v* diagram with temperature as the parameter as in the following diagram:
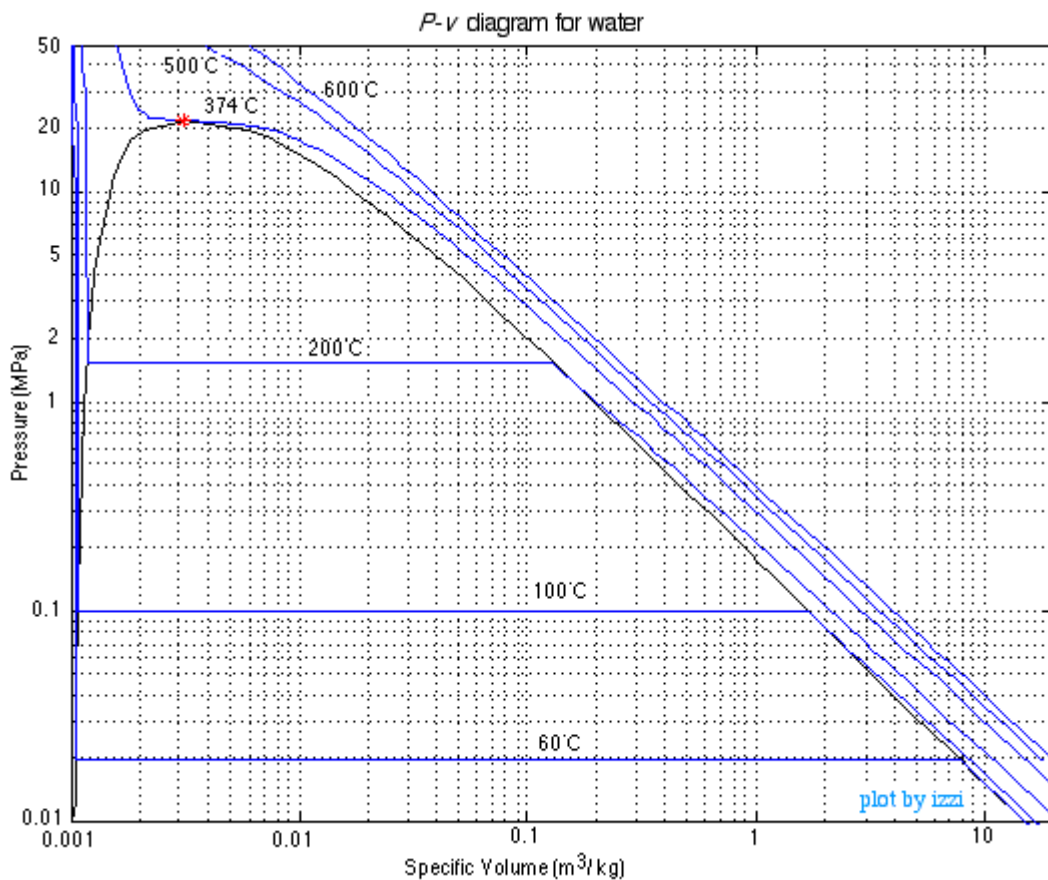
Notice that because of the extremely large range of pressure and specific volume values of interest, this can only be done on a log-log plot. This is extremely inconvenient, so both the *T-v* and the *P-v* diagrams are normally not drawn to scale, however are sketched only in order to help define the problem, which is then solved in terms of the steam tables. This approach is illustrated in the following solved problems.

Source: http://www.ohio.edu/mechanical/thermo/Intro/Chapt.1_6/Chapter2a.html