Property Plots and Tables

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Focus of Chapter

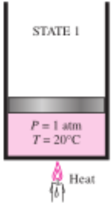
- Introduce you to "property-diagrams" and property plots of non-ideal fluids such as water, ammonia, refrigerants (Eg: R134a).
- Ideal gases (Oxygen, Nitrogen, Helium, Hydrogen, Argon, Xenon, Exhauts gases. . .) may be treated with the *ideal gas law*.
- The idea gas law is a property of state that relates the three important parameters, Pressure, volume and temperature of an ideal gas.
- The ideal gas law, however, **may not be used** for water, ammonia, refrigerants because these are not ideal. The force fields that affect these substances at the molecular level introduce certain non-linearity to their response to introduction or removal of energy.

Focus of Chapter

- There are equations of state that have been developed through meticulous experimentation and use of calculus for non-ideal fluids. (let's call them "Real" fluids)
- This led to a tabulation and graphing of the P, T and V or v for these real fluids.
- These are called property plots and need careful study.

Remember, water, ammonia, refrigerants may not be treated as an ideal gas. This list here is not comprehensive! It is always best to try and find property plots first before zeroing into using the ideal gas law.

Pivotal states in the change of phase of liquid water to water vapour

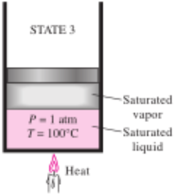


- Water is stored in a frictionless piston-cylinder arrangement. The weight of the piston and the weight of the atmosphere apply a **constant pressure** to the water. This piston cylinder arrangement is a closed system (energy transfer allowed, mass transfer/escapement not allowed).
- Energy is introduced in the form of heat.
- Say, the temperature of the water rises from 20°C to 40°C. The water expands and the piston moves to ensure constant pressure is maintained. If the water has not vaporized, **we have a compressed or subcooled liquid** state.

Pivotal states in the change of phase of liquid water to water vapour

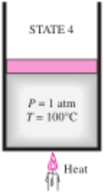
- Energy introduction is continued in the form of heat into the subcooled/compressed water.
- Say, the temperature of the water rises from 40°C to 100°C. The water expands and the piston moves to ensure **constant pressure** is maintained. If the water has not YET vaporized, **but** does so if even a smidgen of heat is introduced now **we have a saturated liquid** state.

Pivotal states in the change of phase of liquid water to water vapour



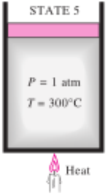
- Energy introduction, at **constant pressure**, is continued in the form of heat into the saturated liquid state of water.
- Now, vaporization takes place and phase change occurs. Some of the water will be in liquid state whilst some turns into a vapor phase. A clear **interface** between liquid and vapour is seen experimentally.
- As heat energy addition is continued, we have less liquid and more vapour.
- What is interesting is that during this step of "change of phase" the temperature remains **constant**! We have a **coexistence phase** now. It is also known as a **saturated liquid-vapour mixture**.

Pivotal states in the change of phase of liquid water to water vapour



- Energy introduction is continued at **constant pressure**, in the form of heat into the saturated liquid-vapour state.
- We arrive at a point where the **entire** cylinder is filled with vapour. Any heat removal at this stage would condense some of the liquid.
- This state is called a **saturated vapour state**.

Pivotal states in the change of phase of liquid water to water vapour

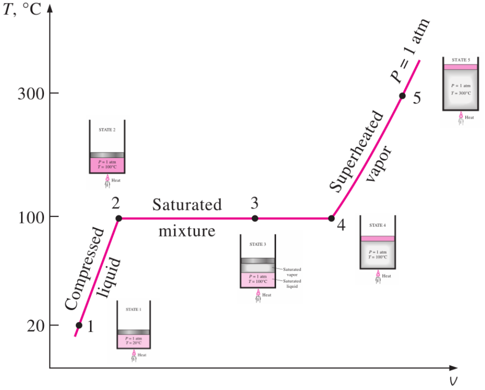


- Energy introduction is continued at **constant pressure** in the form of heat into the saturated vapour state.
- If the temperature now exceeds that of saturated vapour, we have a state in which the vapour does not condense *very easily*.
- This state is called a **superheated state**. The ease with which vapor may be able to condense is governed by the *degree of superheat*.

Some notes and summary

Pivotal states in the change of phase of liquid water to water vapour

If this process is reversed through removal of heat, we will recover the **compressed/subcooled** state of water. In thermodynamics, "water" could refer to any of the following phases: (i) compressed/Subcooled liquid (ii) Saturated liquid (iii) Saturated liquid-vapor (coexistence) (iv) Saturated vapour (v) Superheated vapour.

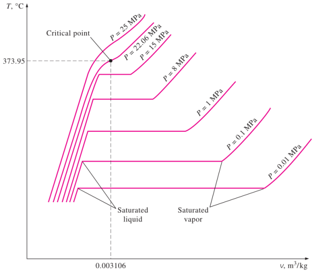


$T - v$ diagram for water at, say, P=1 Atm. It is important to state the

non-ideal fluid like water when describing it.

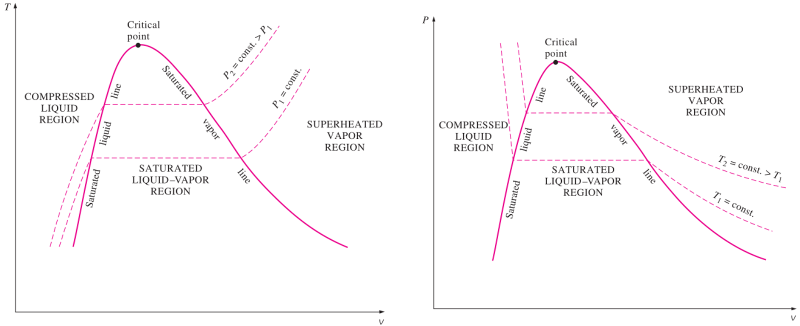
Saturation Temperature and Saturation Pressure

- In this "thought" exercise, we traced the various states of water at **constant pressure** and plotted these as a change in temperature and specific volume on a $T - v$ diagram
- If we were to do that for numerous pressures, we have a locus of points of saturated liquid and saturated vapor. Connecting these points produces the **vapour dome**.
- Saturation temperature is that temperature at which a pure substance changes phase. It is denoted by T_{sat}. The pressure at which we have saturation temperature is called saturation pressure (P_{sat}). For water, the saturation temperature (for change of phase to one that has vapour) at 1 Atm is 100°C.



$T - v$ diagram for water at several pressures. Lines draw are isobars or lines of

The tale of Two diagrams



$T - v$ and $P - v$ diagram for water at several pressures. Lines drawn are "isobars" (or lines of constant pressure) on the $T - v$ diagram while they are "isotherms" (or lines of constant temperature) on the $P - v$ diagram. The locus of saturation points is connected to form a smooth curve called the vapour dome. Under the vapour dome, we have the **coexistence** region.

Latent Heat

- A large amount of heat needs to be introduced to change the phase of a pure substance from a liquid to vapour. This energy is called **latent heat**.
- The converse is true as well: a large amount of heat is released to change the phase of a pure substance from vapour to liquid.
- We have two **"latent heats"**. Latent heat of vaporization and the latent heat of fusion. The former is for a change of phase from liquid to vapour (or g to f) while the latter is for the process of changing the phase of liquid to solid (or s to f). Latent heat of vaporization is absorbed while the latent heat of fusion is rejected.
- Under the vapour dome on the $T - v$ or $P - v$ diagram, the pressure or the temperature are respectively constant. The difference of energy states between saturated vapour and saturated liquid is the latent heat of vaporization.
- We can extend the $T - v$ or $P - v$ diagram to the solid phase too and define latent heat of fusion based on that.

The letters "f" and "g" are used to denote liquid and vapour states while "s" may be used for solids. Latent heat (h_{fg}) features prominently in the use of the first law of thermodynamics (closed or open systems) when a phase change occurs. Heat released or absorbed during a phase change process of a mass "m" is given by mh_{fg}. Again, h_{fg} has "specific" units of kJ/kg while the capital letter H_{fg} has units of kJ.

Enthalpy, Internal energy, Specific Volume

- We have already uncovered **internal energy** and **enthalpy** during our study of the ideal gas and have used these properties for closed system analysis.
- These properties exist for water as well and have been tabulated in the back of your textbook (appendix). To find the internal energy or enthalpy values at any temperature or pressure, we use these tables in the appendix. Note that saturated liquid, saturated vapour and liquid-vapour phase, all three have different values of internal energy and enthalpy.
- h_f, h_{fg}, h_g are the notations for *specific enthalpy* of saturated liquid (f), liquid-vapour (fg) and saturated vapour (g). This notation also exists for (specific) internal energy and specific volume.
- $h_{fg} = h_g - h_f$, $u_{fg} = u_g - u_f$, $v_{fg} = v_g - v_f$.

Vapour Quality

- During the vaporization process (under the vapour dome), a substance exists as part liquid and part vapour. This co-existence mixture has a property that defines its state. This property is called **vapour quality**.
- Vapour quality is defined as:

$$x = \frac{m_{\text{vapour}}}{m_{\text{total}}}$$

  Where $m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapour}}$.

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- Saturated vapour has (vapour) quality $x = 1$ because it is all vapour and no liquid: $m_{\text{liquid}} = 0$, hence $m_{\text{total}} = m_{\text{vapour}}$.
- The coexistence region (f-g region) has vapour quality $0 \leq x \leq 1$.

At this point, we move on to a "numerical problem based approach" in further understanding phase transition and the use of thermodynamic tables.