THERMODYNAMIC PROPERTIES

THE STATE POSTULATE...

FOR A SIMPLE COMPRESSIBLE SUBSTANCE MEANS THAT TWO INDEPENDENT, INTENSIVE PROPERTIES FIXES THE STATE.

- FOR OUR PURPOSES, WE DIVIDE SUBSTANCES INTO THREE CLASSES:

INCOMPRESSIBLE STUFF

- MOST LIQUIDS & SOLIDS
- EQUATIONS USED TO FIND PROPERTIES
- SEE "THE INCOMPRESSIBLE MODEL *UNLEASHED*"

REAL STUFF

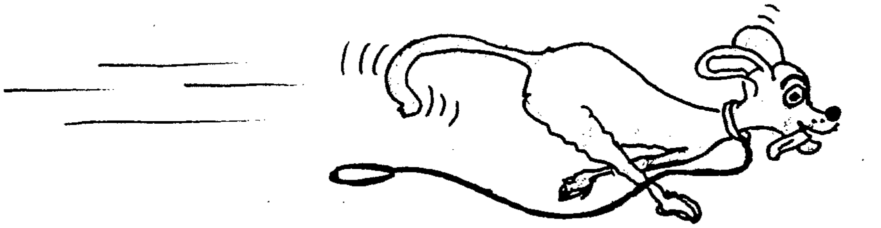
- USED WHEN <u>PHASE CHANGE IS POSSIBLE</u>
- STUFF LIKE STEAM, R-134a
- USE TABLES TO FIND PROPERTIES
- SEE "AN ALGORITHM TO..."

IDEAL GAS (STUFF)

- VALID FOR GASES AT "LOW" PRESSURES
- STUFF LIKE O_2, N_2, AIR, HE.
- EQUATIONS <u>AND</u> TABLES USED
- SEE "IDEAL GASES... BURRRP!"

THE INCOMPRESSIBLE MODEL

UNLEASHED →

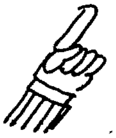


★ **BASIC ASSUMPTION** ⇨ $\rho = \text{CONST}$

THIS MEANS → (USING THE GIBB'S EQN. AND SOME OTHER PROPERTY RELATIONS)

		IF $C \approx \text{CONST}$
SPECIFIC INTERNAL ENERGY ...	$du = c\,dT$ ...	$u_2 - u_1 = c_{AV}(T_2 - T_1)$
SPECIFIC ENTHALPY ...	$d\check{h} = du + v\,dP$ $= c\,dT + v\,dP$ ...	$h_2 - h_1 = c_{AV}(T_2 - T_1) + v(P_2 - P$ $= c_{AV}(T_2 - T_1) + \dfrac{P_2 - P_1}{\rho}$
SPECIFIC ENTROPY ...	$ds = \dfrac{c}{T}\,dT$ ...	$s_2 - s_1 = c_{AV} \ln\left(\dfrac{T_2}{T_1}\right)$

MUST USE ABSOLUTE TEMPERATURE!



NOTE: FOR INCOMPRESSIBLE STUFF,

$$C_p = C_v = C.$$

IDEAL GASES...

- THE EQUATION YOU KNOW FROM CHEM:

$$P\forall = N R_u T \leftarrow \text{ABSOLUTE TEMP}$$

ABSOLUTE PRESSURE

NUMBER OF MOLES

UNIVERSAL I.G. CONSTANT = 8.314 $\frac{\text{kJ}}{\text{kmol-K}}$

- OTHER ONES (WE LIKE BETTER)
  - $P\forall = mRT$
  - $Pv = RT$
  - $P = \rho RT$

I.G. GAS CONSTANT = R_u/M

MOLAR MASS

- u & h
  - FUNCTIONS OF TEMPERATURE ONLY
  - $du = c_v\,dT$
  - $dh = c_p\,dT$

WHERE $c_v \equiv \left.\frac{\partial u}{\partial T}\right)_v$ &

$c_p \equiv \left.\frac{\partial h}{\partial T}\right)_p$

- ENTROPY (s)
  - NEED TWO PROPERTIES TO FIND IT (ACTUALLY, CHANGES IN..)

- IF SPEC. HEATS ARE CONSTANT*:

$$u_2 - u_1 = c_v(T_2 - T_1)$$
$$h_2 - h_1 = c_p(T_2 - T_1)$$
$$s_2 - s_1 = c_v \ln(T_2/T_1) + R\ln(v_2/v_1)$$
-OR-
$$s_2 - s_1 = c_p \ln(T_2/T_1) - R\ln(P_2/P_1)$$

- IF c_p & c_v ARE VARIABLE

$$u_2 - u_1 = u(T_2) - u(T_1)$$
$$h_2 - h_1 = h(T_2) - h(T_1)$$
$$s_2 - s_1 = s^\circ(T_2) - s^\circ(T_1) - R\ln(P_2/P_1$$

MUST USE TABLES HERE.

* WHICH SPECIFIC HEAT TO USE IS A HEATED TOPIC. (GET IT? *HEATED*?)

Finding Thermodynamic Properties for a Pure, Simple Compressible Substance — *A Simple Algorithm* for Liquid-Vapor Systems

Case I: Given *P* and *T*

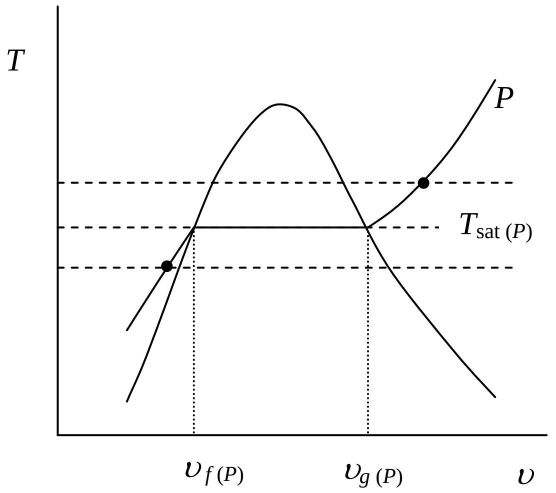
(1) Determine the phase of the substance (and hence what set of tables you should consult).

(1a) Go to one of the liquid-vapor Saturation Tables.

(1b) Compare the given P and T against the saturation values reported in the table.

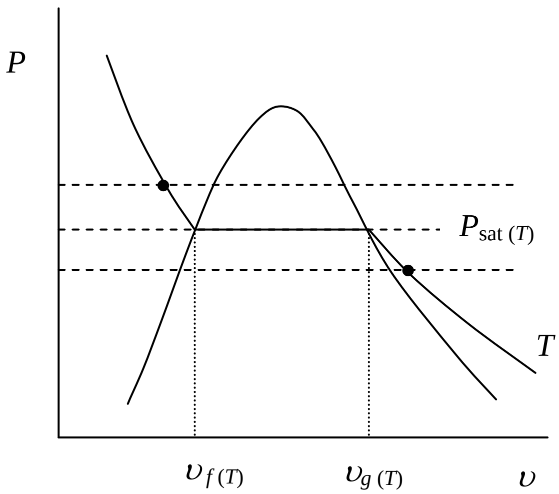
In the Pressure Saturation Table, find the saturation temperature at the given pressure, $T_{\mathrm{sat}(P)}$.

if $T > T_{\mathrm{sat}(P)}$ then *superheated vapor*
if $T < T_{\mathrm{sat}(P)}$ the *compressed (subcooled) liquid*



In the Temperature Saturation Table, find the saturation pressure at the give temperature, $P_{\mathrm{sat}(T)}$.

if $P > P_{\mathrm{sat}(T)}$ then *compressed (subcooled) liquid*
if $P < P_{\mathrm{sat}(T)}$ then *superheated vapor*



(2) Go to the appropriate single-phase table and enter the table using *P* and *T*. If the values of P and T do not coincide with the given values (as usually happens in *real* applications) you must *linearly interpolate* within the table to find the desired values.

<u>Note</u>: Compressed Liquid Approximation. If you find the substance is a *compressed (subcooled) liquid* and you do not have a compressed-liquid table <u>or</u> the pressure is between the saturation value and the lowest value in the compressed-liquid table, you may find it easier (and almost as accurate) to apply the **compressed-liquid approximation** to estimate the values in the compressed-liquid table using the saturation-table values as follows:

$$u_{(T,P)} \cong u_{f(T)} \quad \text{[specific internal energy]}$$

$$\upsilon_{(T,P)} \cong \upsilon_{f(T)} \quad \text{[specific volume]}$$

$$s_{(T,P)} \cong s_{f(T)} \quad \text{[specific entropy]}$$

$$h_{(T,P)} \equiv u + P\upsilon \cong u_{f(T)} + P\,\upsilon_{f(T)} = h_{f(T)} + \{\,P - P_{\mathrm{sat}(T)}\,\}\,\upsilon_{f(T)} \quad \text{[specific enthalpy]}$$

Because $h_{(T,P)} = h_{f(T)}$ is only true if $P \cong P_{\mathrm{sat}}$ *and* the error in using this approximation under conditions where $P \neq P_{\mathrm{sat}}$ depends on the specific problem, *it is always more accurate to use the full approximation that includes the pressure correction!*

Case II: Given P (or T) and υ (or u, h, s or x)

(1) Determine the phase of the substance (and hence what set of tables you should consult).

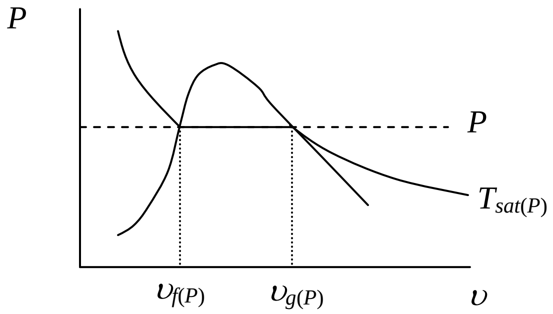
(1a) Go to one of the liquid-vapor Saturation Tables.

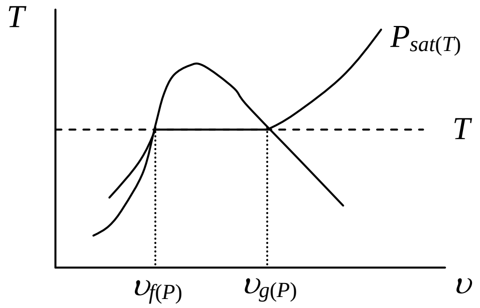
(1b) Find the saturated liquid and saturated vapor values for the specific volume : $\upsilon_{f\,(P)}$ and $\upsilon_{g\,(P)}$.

Note: If you are given quality x then you immediately know that it is either a saturated liquid, a saturated liquid-vapor mixture, or a saturated vapor and you can go directly to step (2).

(1c) Compare the given value of υ against the saturation values to find the phase (and the appropriate table):

$\upsilon < \upsilon_{f\,(P)}$	*compressed (subcooled) liquid*
$\upsilon = \upsilon_{f\,(P)}$	*saturated liquid*
$\upsilon_{f(P)} < \upsilon < \upsilon_{g(P)}$	*saturated liquid-vapor mixture*
$\upsilon = \upsilon_{g\,(P)}$	*saturated vapor*
$\upsilon > \upsilon_{g\,(P)}$	*superheated vapor*





(2) Go to the appropriate table and enter the table using the values of P and υ. Linear interpolation may be required if values do not match table entries.

Compressed Liquid: $\upsilon < \upsilon_{f\,(P)}$ [Quality is undefined.]

- If compressed-liquid approximation is used, let $\upsilon_{f\,(T)} = \upsilon$ to find temperature. Then use approximation to find other properties. (Since $\upsilon_{f(T)}$ is a *very* weak function of temperature, this approach is very inaccurate. Much more accurate to look for another property like s or u which is a strong function of temperature.)

Saturated Liquid: $\upsilon = \upsilon_{f\,(P)}$ [Quality: $x = 0$ or 0%]

- All properties equal to those for a saturated liquid.

Saturated Liquid-Vapor Mixture: $\upsilon_{f(P)} < \upsilon < \upsilon_{g\,(P)}$ [Quality: $0 < x < 1$ or $0\% < x < 100\%$]

- $T = T_{sat(P)}$, the saturation temperature at pressure P
- Calculate quality before finding any other properties: $x = (\upsilon - \upsilon_f) / (\upsilon_g - \upsilon_f)$
- Then use quality to find other intensive properties, e.g. $u = u_f + x\,(u_g - u_f)$

Saturated Vapor: $\upsilon = \upsilon_{g\,(P)}$ [Quality: $x = 1$ or 100%]

- All properties equal to those for a saturated vapor.

Superheated Vapor: $\upsilon > \upsilon_{g\,(P)}$ [Quality is undefined.]

- Enter the superheated vapor table with P and υ. Because υ often falls between the tabular values, it is often required to linearly interpolate to find the correct temperature which can then be used to find the other values. Sometimes it is necessary to do a *double linear interpolation*.

Note: If you are given temperature instead of pressure use the same process as above starting with temperature saturation table.