

In order to understand what happens during phase change; or "How the pressure remains constant (as well as Temp), still volume changes." In fact not only volume, internal energy also changes as quality of steam is constantly changing. ( $u = u_g x + u_{ol}(1-x)$ )

→ To answer the above query, we have to keep in mind that liq + vap (or in general steam) is a real fluid. If we dig more, we can derive that for any fluid, change in internal energy ( $\Delta u$ ) is given by,

$$\rightarrow du = C_v dT + \left( T \left( \frac{\beta}{\alpha} \right) - p \right) dv$$

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★ we will see derivation in future classes

$\beta$  &  $\alpha$  are physical properties of real fluid.

$\alpha$  coefficient of expansion

$$\beta = \frac{1}{V} \left( \frac{\partial V}{\partial T} \right)_{P=\text{constant}}$$

$\alpha$  isothermal compressibility

$$\alpha = -\frac{1}{V} \left( \frac{\partial V}{\partial P} \right)_{\text{constant } T}$$

for an ideal gas  $\beta = \frac{1}{T}$  ,  $\alpha = \frac{1}{P}$

Hence  $du = C_v dT$  (Thus for an ideal gas.  $du = 0$  if  $T$  is constant)



However if we consider a real fluid, even at constant T & P

we have  $du = c_v dT + \left( T \frac{\beta}{\alpha} - p \right) dv$   
 $\Rightarrow du = \left( T \frac{\beta}{\alpha} - p \right) dv$

Thus during phase change, for a real fluid, both volume & internal energy can change even if P & T are constant.

~~Now~~ Now we notice that although T is not changing during phase change, still internal energy (u) is changing. We also know T (temp) is manifestation of avg. kinetic energy of molecules, thus at constant T, change in u is only possible by changing intermolecular potential energy.

what we learn: [internal energy of a fluid = kinetic energy of molecules + potential energy (intermolecular)]  
 $\beta$  &  $\alpha$  are manifestation of intermolecular potential energy in some limited sense.

[just to get more clarity on this consider a real fluid following van der Waals eqn. for which  $p = \frac{RT}{v-b} - \frac{a}{v^2} \Rightarrow T \left( \frac{\partial p}{\partial T} \right)_v = \frac{RT}{v-b}$   
 $du = \left( T \left( \frac{\partial p}{\partial T} \right)_v - p \right) dv + c_v dT = c_v dT + \frac{a}{v^2}$



Thus for van der Waals fluid,

$$du = C_v dT + \frac{a}{v^2} dv$$

So at constant T,  $du = \frac{a}{v^2} dv$

(we all know from our basic knowledge that "a" accounts for intermolecular attraction, in other words intermolecular potential energy),

★ Thus, so far we established that for a real fluid,  $u$  &  $v$  both can change, even at constant T & P

Now if we consider phase change process, we know pressure is constant.

Now consider a positive change in volume (increase in quality)

It means we are moving towards right on phase line. Further  $\Delta u$  will be also positive, & as sat. vapor phase contribution will increase as  $x$  increases.



Let us discuss/revisit Class illustration 5:

The only way to reach from initial stage (i) (10 kPa,  $x=0.9$ )

to final stage (f) (30 bar,  $560^\circ\text{C}$ ) is, first following the phase change line to sat. vapor point, followed by vapor compression till f.

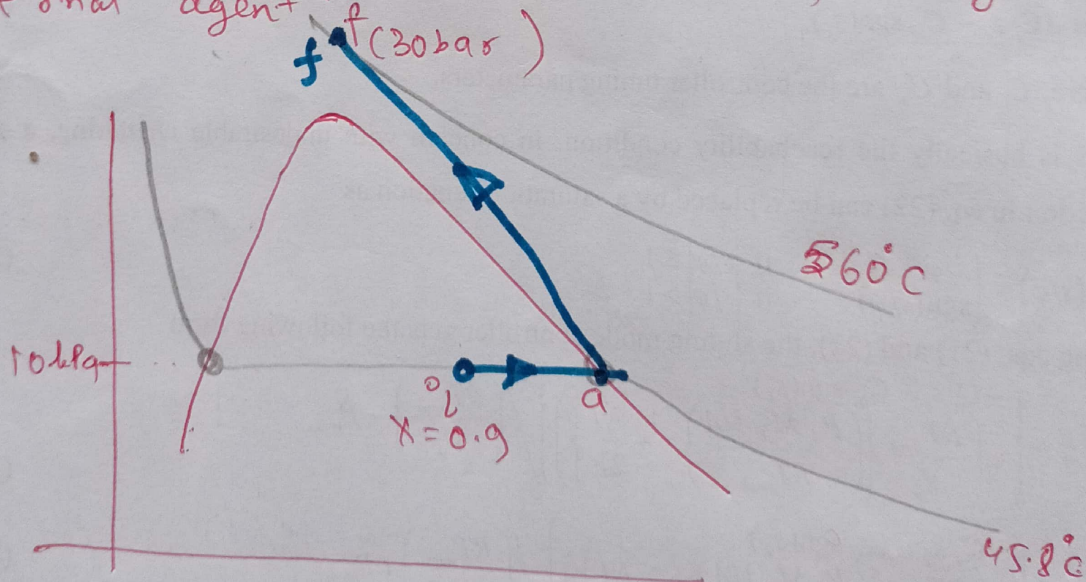
if we see net work done by system,

$$W_{\text{by system}} = W_{i \rightarrow a} + W_{a \rightarrow f}$$

(expansion)      (compression)  
+ive                      -ive

Net effect (-ive)

Q  $W_{\text{by system}} = -\text{ive}$ , which implies work is being done on system/fluid by external agent.



You can see. (area under curve  $i \rightarrow a$ ) < (area under curve  $a \rightarrow f$ )

expansion work < compression work

Hence Net work is done by external agent.