Basic Principles and Calculations in Chemical Engineering
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Lecture # 21
Enthalpy balances without reaction

Welcome to massive open online course on basic principles and calculations in chemical engineering. So, we are discussing about energy balances on nonreactive processes as a module 7. In the previous lecture we have discussed about the mechanical energy balance in this lecture will try to you know discuss more about that energy balances with nonreactive processes.

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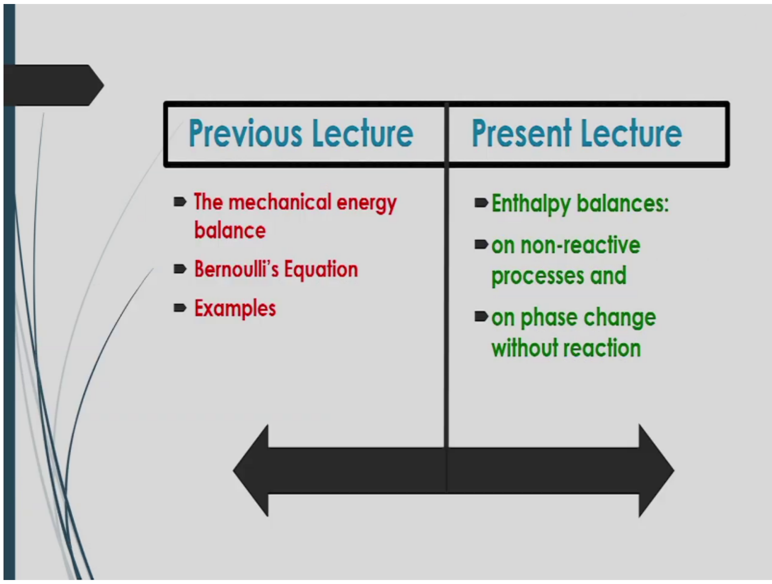

Previous Lecture	Present Lecture
The mechanical energy balance Bernoulli's Equation Examples	Enthalpy balances: on non-reactive processes and on phase change without reaction

Especially for enthalpy balance without you know reaction also, we will discuss more about that the enthalpy balances when there will be a you know change of phase without any reaction there.

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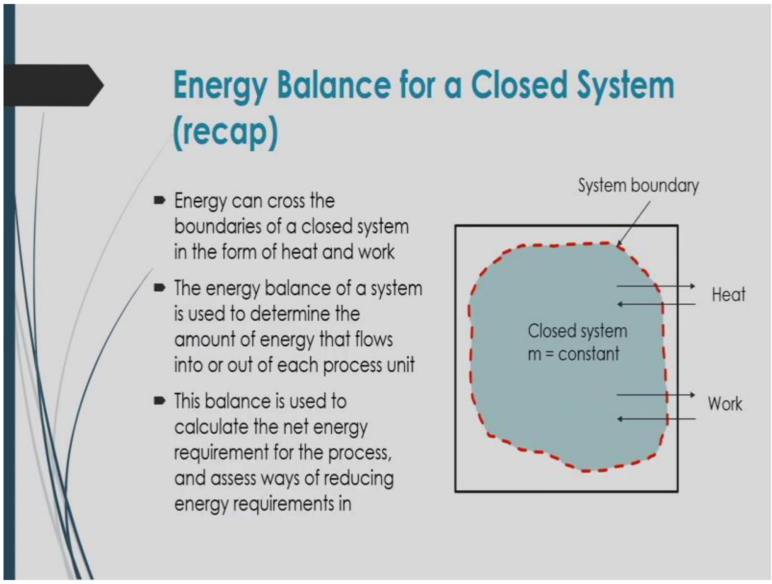

Energy Balance for a Closed System (recap)

- Energy can cross the boundaries of a closed system in the form of heat and work
- The energy balance of a system is used to determine the amount of energy that flows into or out of each process unit
- This balance is used to calculate the net energy requirement for the process, and assess ways of reducing energy requirements in

So, what is the energy balance for a closed system that already we have discussed in our you know earlier lectures in that case energy can cross the boundary of a closed system in the form of heat and work the energy balance of a system that is used to determine the amount of energy that flows into or out of the system for our particular process, unique and this is because, actually, that energy of anybody to be supplied to the system, that we change its internal energy.

And how that you know, that internal energy will, you know, changes you know, that, system environment and then accordingly how that system will be you know done work to the surroundings or to the fluid or to other you know that you know process unit for a particular you know operation. Now, this balance is used to calculate that Net energy requirement for the process and assess of reducing energy requirement in a particular you know system.

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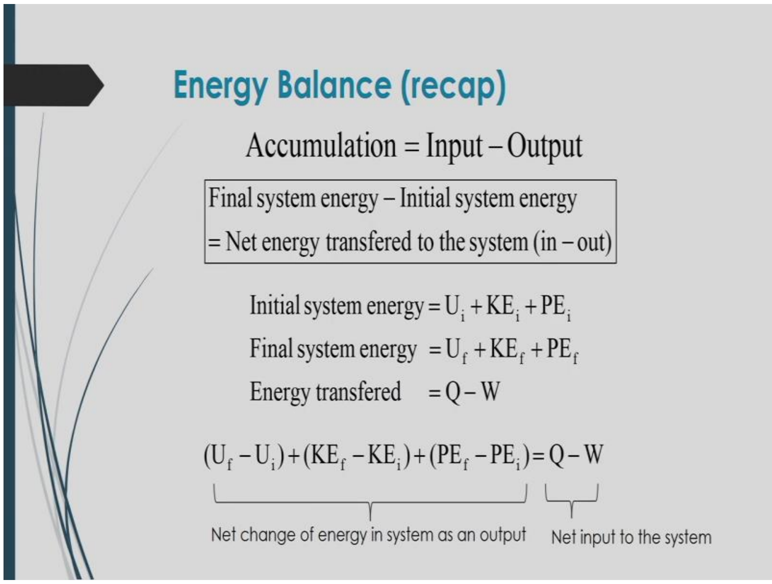

Energy Balance (recap)

$$\text{Accumulation} = \text{Input} - \text{Output}$$

$$\boxed{\begin{array}{l}\text{Final system energy} - \text{Initial system energy}\\ = \text{Net energy transfered to the system (in} - \text{out)}\end{array}}$$

$$\text{Initial system energy} = U_i + KE_i + PE_i$$

$$\text{Final system energy} = U_f + KE_f + PE_f$$

$$\text{Energy transfered} = Q - W$$

$$\underbrace{(U_f - U_i) + (KE_f - KE_i) + (PE_f - PE_i)}_{\text{Net change of energy in system as an output}} = \underbrace{Q - W}_{\text{Net input to the system}}$$

We know that energy balance equation that is accumulation that is caused through input minus output and particular system what is the you know, final system energy and what is the, you know, initial system energy and this change of our final initial system and it will give you that Net energy transport to the system or net energy transfer to the system will change this you know energy system energy from it is initial to final.

Now, in that case we also you know told about that initial system energy is basically the you know summation of internal energy, kinetic energy and potential energy. And similarly, final system and it also will be as some of you know that internal energy, kinetic energy and potential energy and to get this you know change of this you know initial to final you know system energy that some energy to be supplied and based on which you will see there will be some, you know work to be done by the system.

So, net energy will be you know that some amount that is represented by you know, our heat energy minus, you know, flow energy there. So, basically the difference of these 2 energy that is U f - U i are that is internal energy change plus you know kinetic energy change plus potential energy change that will be equal to Q - W. So, by this equation we can say that net change of energy in the system as an output that will be equals to net input to the system.

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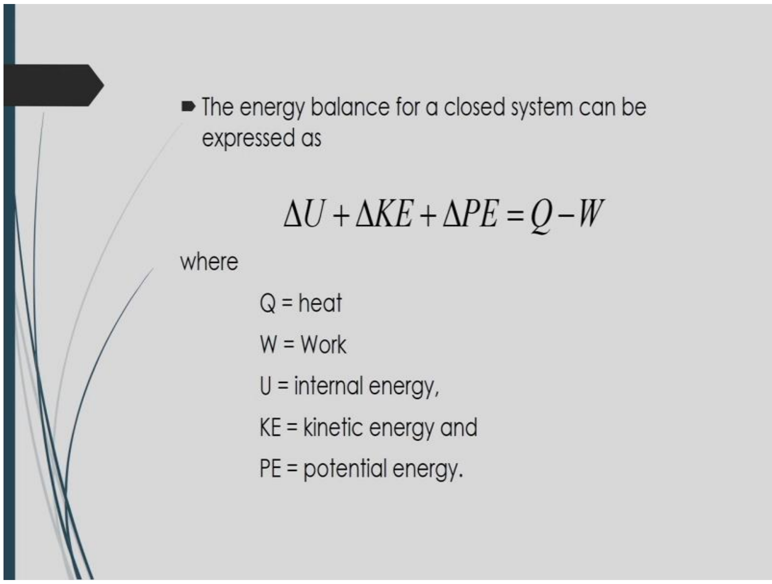

- The energy balance for a closed system can be expressed as

$$\Delta U + \Delta KE + \Delta PE = Q - W$$

where

Q = heat

W = Work

U = internal energy,

KE = kinetic energy and

PE = potential energy.

Then this energy balance for a closed system can be expressed by this equation given in the slides that already we have discussed.

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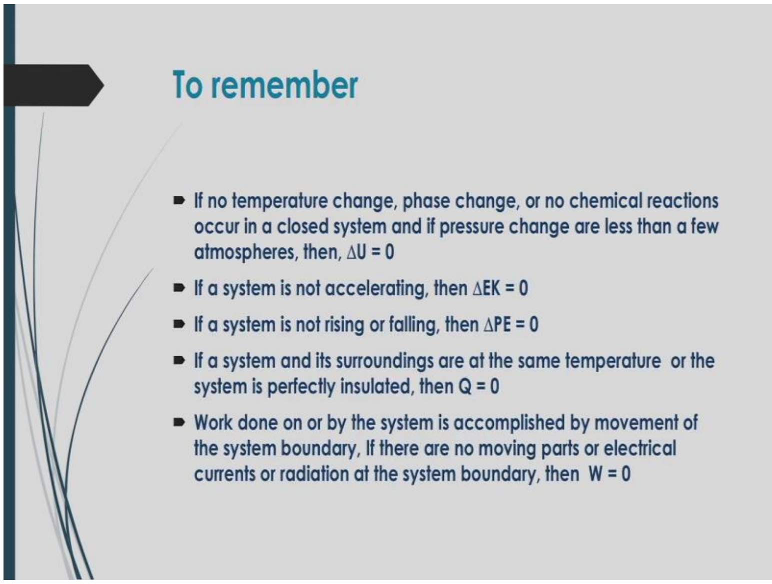

To remember

- If no temperature change, phase change, or no chemical reactions occur in a closed system and if pressure change are less than a few atmospheres, then, $\Delta U = 0$
- If a system is not accelerating, then $\Delta EK = 0$
- If a system is not rising or falling, then $\Delta PE = 0$
- If a system and its surroundings are at the same temperature or the system is perfectly insulated, then Q = 0
- Work done on or by the system is accomplished by movement of the system boundary, If there are no moving parts or electrical currents or radiation at the system boundary, then W = 0

And also we you know suggested to you know remember that, if no temperature change, if there is no phase change or no chemical reactions occur in a closed system and if the pressure change are less than a few atmospheres, then we can say that internal energy change will be close to zero. Now, if your system is not accelerating, then we can say that the kinetic energy will be equal to zero and, if a system is not rising or falling, then you can see that potential energy is equal to zero.

Now, if your system and its surroundings are at the same temperature or the system is perfectly, you can see that insulated in that case Q will be equal to zero that is supplied to the system with it is zero and work done on or by the system will be accomplished by the movement of the system boundary. And if there are no moving parts or you can see that electrical currents or other form of energy at the system boundary will not work, then you can simply write that W will equal to be zero there.

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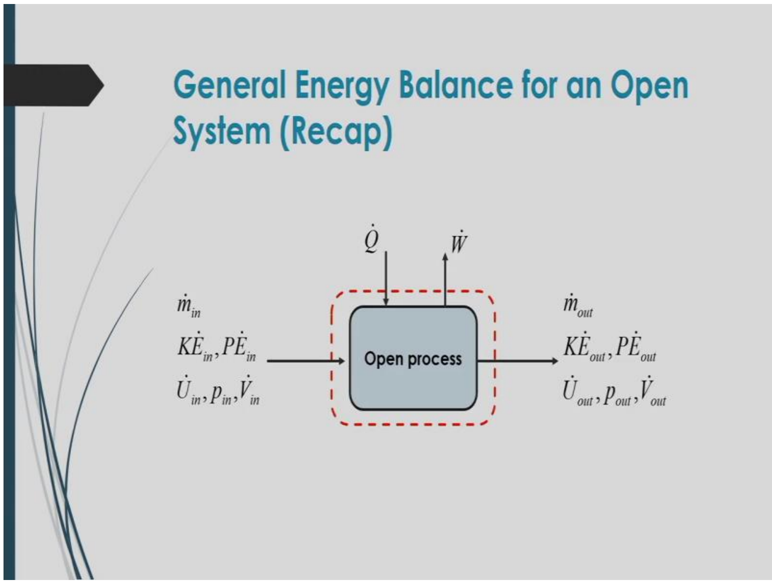

General Energy Balance for an Open System (Recap)

$\dot{Q}$ $\dot{W}$

$\dot{m}_{in}$
$\dot{KE}_{in}, \dot{PE}_{in}$
$\dot{U}_{in}, p_{in}, \dot{V}_{in}$

Open process

$\dot{m}_{out}$
$\dot{KE}_{out}, \dot{PE}_{out}$
$\dot{U}_{out}, p_{out}, \dot{V}_{out}$

And based on that we can also write that energy balance equation for an open system here it is given in the previous lectures also we have described this you know energy balance equation.

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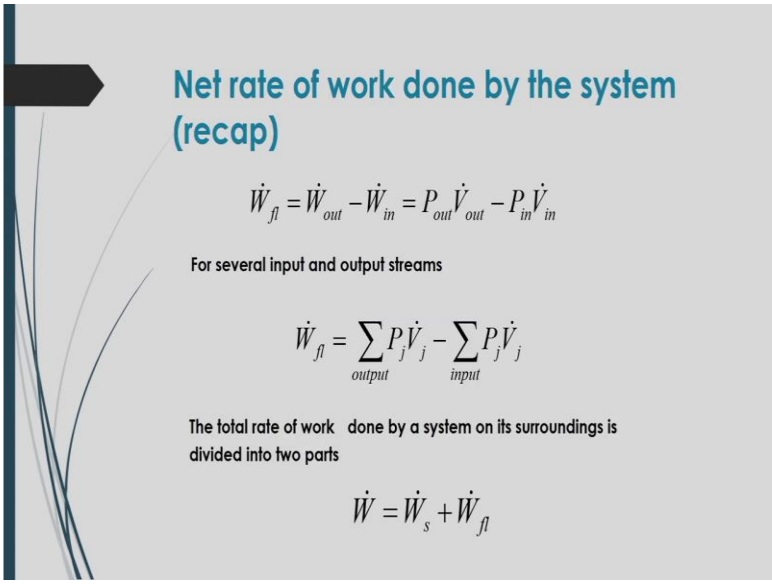

Net rate of work done by the system (recap)

$$\dot{W}_{fl} = \dot{W}_{out} - \dot{W}_{in} = P_{out}\dot{V}_{out} - P_{in}\dot{V}_{in}$$

For several input and output streams

$$\dot{W}_{fl} = \sum_{output} P_j \dot{V}_j - \sum_{input} P_j \dot{V}_j$$

The total rate of work done by a system on its surroundings is divided into two parts

$$\dot{W} = \dot{W}_s + \dot{W}_{fl}$$

And for that, you know net rate of work done by the system that is regarded by this you know that summation of that work because to shaft work and also flow work there.

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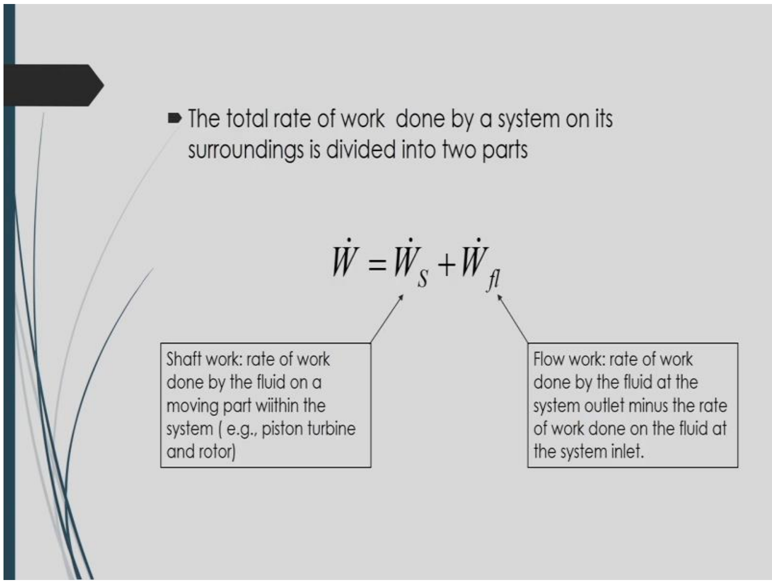

- The total rate of work done by a system on its surroundings is divided into two parts

$$\dot{W} = \dot{W}_S + \dot{W}_{fl}$$

Shaft work: rate of work done by the fluid on a moving part wiithin the system (e.g., piston turbine and rotor)

Flow work: rate of work done by the fluid at the system outlet minus the rate of work done on the fluid at the system inlet.

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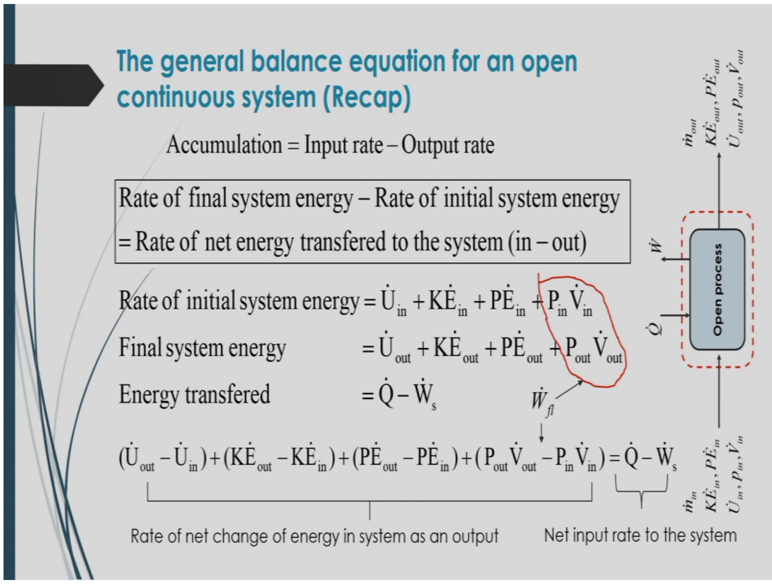

The general balance equation for an open continuous system (Recap)

$$\text{Accumulation} = \text{Input rate} - \text{Output rate}$$

$$\boxed{\begin{aligned}&\text{Rate of final system energy} - \text{Rate of initial system energy}\\&= \text{Rate of net energy transfered to the system (in} - \text{out)}\end{aligned}}$$

$$\text{Rate of initial system energy} = \dot{U}_{in} + \dot{KE}_{in} + \dot{PE}_{in} + P_{in}\dot{V}_{in}$$

$$\text{Final system energy} = \dot{U}_{out} + \dot{KE}_{out} + \dot{PE}_{out} + P_{out}\dot{V}_{out}$$

$$\text{Energy transfered} = \dot{Q} - \dot{W}_s \qquad \dot{W}_{fl}$$

$$\underbrace{(\dot{U}_{out} - \dot{U}_{in}) + (\dot{KE}_{out} - \dot{KE}_{in}) + (\dot{PE}_{out} - \dot{PE}_{in}) + (P_{out}\dot{V}_{out} - P_{in}\dot{V}_{in})}_{\text{Rate of net change of energy in system as an output}} = \underbrace{\dot{Q} - \dot{W}_s}_{\text{Net input rate to the system}}$$

And you will see that, based on that, you know shaft work and flow work, the general energy balance equation can be written by this equation here as shown in the slide. So, please go to the slides also here how to represent that you know general energy balance equation in terms of you know, change up internal energy change your kinetic energy, change your potential energy and also change of flow work they are in the system and also want to be the input and output in the system.

Because of that net energy supply of you know heat or by you know work done by your to the system. So, finally we can write this you know, General energy balance equation even in continuous form as the rate there.

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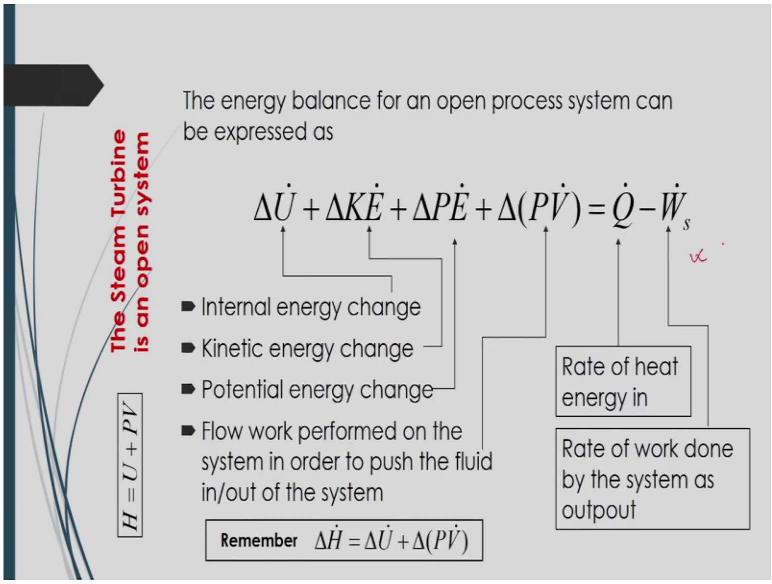

The Steam Turbine is an open system

$H = U + PV$

The energy balance for an open process system can be expressed as

$$\Delta\dot{U}+\Delta\dot{KE}+\Delta\dot{PE}+\Delta(P\dot{V})=\dot{Q}-\dot{W}_s$$

- Internal energy change
- Kinetic energy change
- Potential energy change
- Flow work performed on the system in order to push the fluid in/out of the system

Rate of heat energy in

Rate of work done by the system as outpout

Remember $\Delta\dot{H}=\Delta\dot{U}+\Delta(P\dot{V})$

And in concise form we can write in terms of difference we can write this equation as delta U dot plus delta KE dot plus delta PE dot plus delta PV dot that will be equal to Q dot minus W dot. Here, dot means rate and delta U means, basically internal energy change delta K dot means basically kinetic energy change in rates and delta PV is basically the flow of work that is performed on the system in order to push the fluid in or out of the system

and Q dot is the rate of heat energy in to the system and W dot is generally rate of work done by the system as an output and summation of these internal energy and this you know rate of work done by the system or to work that is performed on the system in order to push the fluid in or out of the system will be regarded as enthalpy of the system, which is denoted by H. So, delta H would be equal to basically that summation of that internal energy change and you know, flow work of change here.

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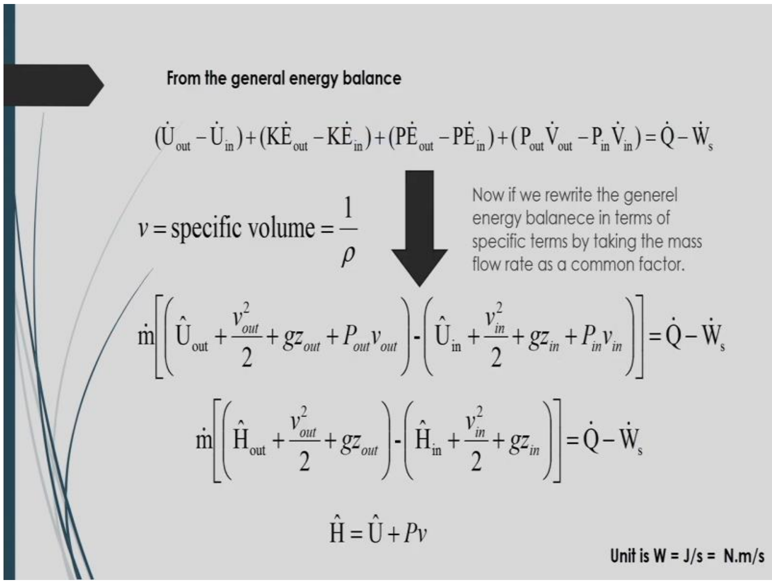

From the general energy balance

$$(\dot{U}_{out} - \dot{U}_{in}) + (K\dot{E}_{out} - K\dot{E}_{in}) + (P\dot{E}_{out} - P\dot{E}_{in}) + (P_{out}\dot{V}_{out} - P_{in}\dot{V}_{in}) = \dot{Q} - \dot{W}_s$$

$$v = \text{specific volume} = \frac{1}{\rho}$$

Now if we rewrite the generel energy balanece in terms of specific terms by taking the mass flow rate as a common factor.

$$\dot{m}\left[\left(\hat{U}_{out} + \frac{v_{out}^2}{2} + gz_{out} + P_{out}v_{out}\right) - \left(\hat{U}_{in} + \frac{v_{in}^2}{2} + gz_{in} + P_{in}v_{in}\right)\right] = \dot{Q} - \dot{W}_s$$

$$\dot{m}\left[\left(\hat{H}_{out} + \frac{v_{out}^2}{2} + gz_{out}\right) - \left(\hat{H}_{in} + \frac{v_{in}^2}{2} + gz_{in}\right)\right] = \dot{Q} - \dot{W}_s$$

$$\hat{H} = \hat{U} + Pv$$

Unit is W = J/s = N.m/s

Now, from the general energy balance equation, we can represent that equation in terms of you know specific terms by taking the you know mass flow rate as a common factor there. And then finally, we can write this equation based on this, you know mass flow rate, and also specific terms there and in this case here correction is that V and U here is basically U and this is new is here this is U and here new is basically 1 by row is defined the specific volume and this new is U that is velocity at different composition, and they are in inlet and outlet condition.

We can say so, finally, we can get this, you know equation has final form of equation here as that you know their energy balance equation based on that enthalpy for enthalpy is defined as your H will equal to U plus P v, P there.

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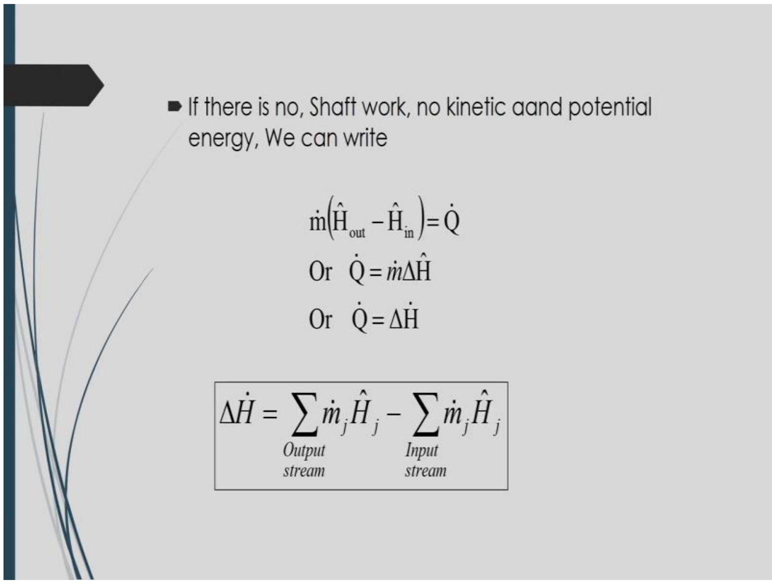

- If there is no, Shaft work, no kinetic aand potential energy, We can write

$$\dot{m}\left(\hat{H}_{out} - \hat{H}_{in}\right) = \dot{Q}$$

$$\text{Or} \quad \dot{Q} = \dot{m}\Delta\hat{H}$$

$$\text{Or} \quad \dot{Q} = \Delta\dot{H}$$

$$\boxed{\Delta\dot{H} = \sum_{\substack{Output\\stream}} \dot{m}_j\hat{H}_j - \sum_{\substack{Input\\stream}} \dot{m}_j\hat{H}_j}$$

And they saw if there is no shaft work no kinetic and potential energy then we can write here, simply this equation from that general energy balance equation that is Q dot will be equal to m dot into delta H dot and then we can write that enthalpy change will equal to here, if you are having that enthalpy change at inlet and outlet condition then you can simply write that a difference in the enthalpy based on this equation.

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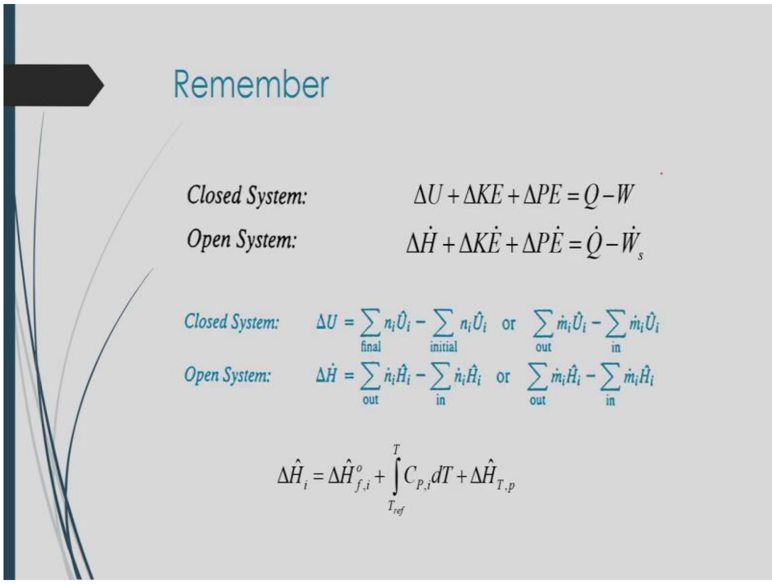

Remember

Closed System: $\Delta U + \Delta KE + \Delta PE = Q - W$

Open System: $\Delta\dot{H} + \Delta\dot{KE} + \Delta\dot{PE} = \dot{Q} - \dot{W}_s$

Closed System: $\Delta U = \sum_{final} n_i\hat{U}_i - \sum_{initial} n_i\hat{U}_i$ or $\sum_{out} \dot{m}_i\hat{U}_i - \sum_{in} \dot{m}_i\hat{U}_i$

Open System: $\Delta\dot{H} = \sum_{out} \dot{n}_i\hat{H}_i - \sum_{in} \dot{n}_i\hat{H}_i$ or $\sum_{out} \dot{m}_i\hat{H}_i - \sum_{in} \dot{m}_i\hat{H}_i$

$$\Delta\hat{H}_i = \Delta\hat{H}^o_{f,i} + \int_{T_{ref}}^{T} C_{P,i}\,dT + \Delta\hat{H}_{T,p}$$

Also you have to remember that for the closed system, what should the energy balance equation for the open system what should be the energy balance equation and in terms of you know that internal energy change for the closed system we can write this here because they are kinetic energy and potential energy will be you know negligible. So, the equation will be coming as only in terms of you know internal energy and enthalpy there and if there is a you know, temperature change from its reference point or if you are hitting the system from its temperature 1 to temperature 2, we can say that there will be a enthalpy change based on that, you know, temperature change.

And also what is, you know, specific heat capacity for that substance at particular temperature, because this specific heat capacity depends on the temperature, the air. So, accordingly if you are having that constant specific heat capacity there you can easily calculate what should be the enthalpy change on the based on that temperature difference and if you are having that specific heat capacity changing with you know temperature.

Then of course, you have to consider that integral form of enthalpy change based on this you know, temperature change. Again if you are having that there will be you know change of phase liquid to vapour. So, there will be a certain change of you know energy or enthalpy that enthalpy will be called as you know, heat of vaporization or heat up you know, melting point or you can see that heat of sublimation like this. So, that heat you know or enthalpy because of that needs to be considered.

And also suppose, if you are considering the enthalpy change at a particular temperature range, they are of course, you have to consider what should be the heat you know or enthalpy change because of its formation. So, that is called you know, heat of formation of that component. So, to do any you know energy balance for the inlet and outlet components of the system to calculate that enthalpy at a particular temperature. What you have to do that you have to calculate that enthalpy change because of the temperature, because of that phase change and also because of that formation of that component there.

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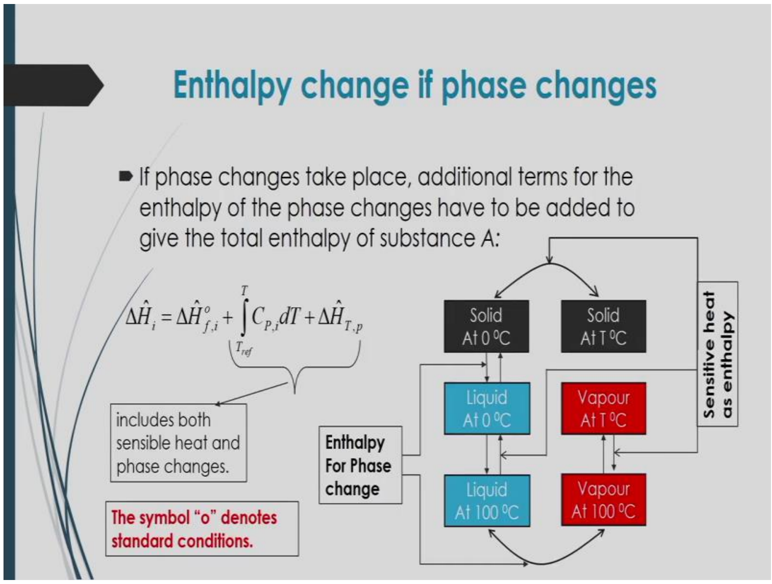

Enthalpy change if phase changes

- If phase changes take place, additional terms for the enthalpy of the phase changes have to be added to give the total enthalpy of substance A:

$$\Delta\hat{H}_i = \Delta\hat{H}^o_{f,i} + \underbrace{\int_{T_{ref}}^{T} C_{P,i}\,dT + \Delta\hat{H}_{T,p}}$$

includes both sensible heat and phase changes.

The symbol “o” denotes standard conditions.

Now, let us see that, you know enthalpy changes, there is a phase changes. Now, in that case, you have to consider that additional terms for the enthalpy of the phase change with those, you know, energy change of, you know, for your process. And in that case, the total enthalpy of that substance, if you are considering any substance say. So, we can write the era you know that the enthalpy change will be equal to here, heat formation of that particular component i or A and the enthalpy change because of that, you know, temperature change.

That will be regarded as sensible heat or sensible enthalpy you can say and also enthalpy change because of that phase change. So, these are 2 terms here, as soon here in the slide that these 2 terms basically includes the both sensitive heat up a change and this terms is basically the enthalpy change due to its formation and this here in this terms or basically represents the standard condition, that being said, you know, zero degrees Celsius.

And you know, that one atmospheric there, suppose, there is a you know, a phase change of the suppose water from solid state to you know, vapor phase, so, at zero degrees Celsius, you will see that solid liquid will try to, you know, mainly to the liquid phase. So, there will be a temperature is constant. So, at that constant temperature, the solid water will be converting to the liquid water after that, you know that this liquid will be you know heated up 100 degrees Celsius till it boils.

What happened here during that constant temperature of zero degrees Celsius, when this solid water will be melting so, there will be a change of enthalpy will be called as you know it is called that melting you know enthalpy or you can see that latent hat you know melting after that whenever liquid will be you know heated up 100 degrees Celsius there will be a change of temperature. There will be a change of temperature from 0 to 100 degrees Celsius and because of which you will see there will be a changeup enthalpy or heat and that is called you know sensible heat or sensible enthalpy.

And that enthalpy can be calculated based on that you know temperature difference and also bought to be the specific heat capacity of that water and if it is changing with temperature, then you have to you know calculated by integrating that multiplication of specific heat capacity of the water and you know that temperature difference and up to that, when you bought that liquid will be converting into a vapour at that particular constant temperature of 100 degrees Celsius you will see there will be again change of enthalpy that change of enthalpy will be called us latent heat up, you know, on vapourization or latent heat of vaporization.

And after that, this you know vapour at 100 degrees Celsius to be you know heated up again to a certain temperature T. So, for that again you have to calculate that you know sensible heat based on that you know specific heat capacity and that temperature difference after that if you want to you know convert that you know vapour into directly to solve it then you know what will be the you know energy required that energy required will be you know that, you know will be the summation of that you know to convert from solid to that direct vapour said that will be called solid vapour.

So, in this way we can see that there will be an enthalpy change because of that phase change as well as you know temperature change as well as its formation. So, all those you know, enthalpy change to be considered for a particular component whenever you are going to you know consider heat at an outlet you know components or inlet components they are for that process and also for the you know energy balance for that particular process.

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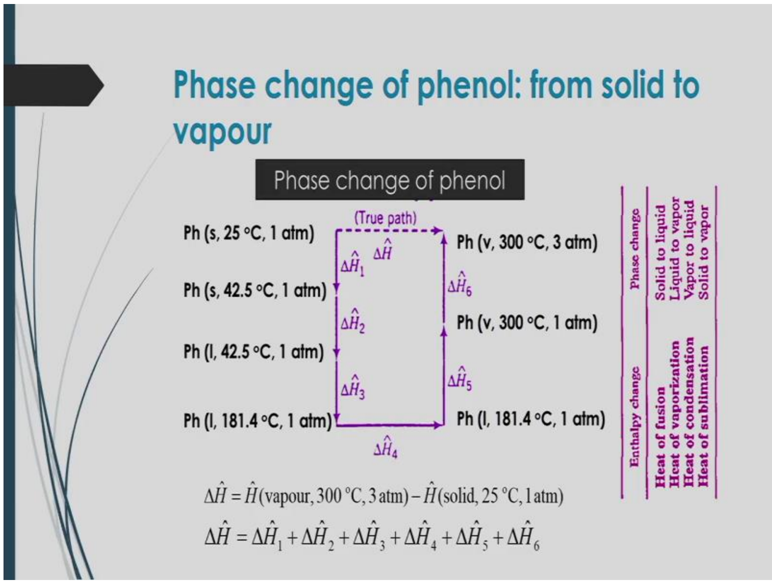

Phase change of phenol: from solid to vapour

Phase change of phenol

Phase change	Enthalpy change
Solid to liquid	Heat of fusion
Liquid to vapor	Heat of vaporization
Vapor to liquid	Heat of condensation
Solid to vapor	Heat of sublimation

$$\Delta\hat{H} = \hat{H}(\text{vapour}, 300\,^{\circ}\text{C}, 3\,\text{atm}) - \hat{H}(\text{solid}, 25\,^{\circ}\text{C}, 1\,\text{atm})$$

$$\Delta\hat{H} = \Delta\hat{H}_1 + \Delta\hat{H}_2 + \Delta\hat{H}_3 + \Delta\hat{H}_4 + \Delta\hat{H}_5 + \Delta\hat{H}_6$$

Now, let us have another example of that phase change here for phase change of your phenol will see that the phenol will be a solid phase at 25 degrees Celsius at one atmospheric pressure. Again if you heated up to 25 degrees Celsius there will be a sensible heat for that solid phenol and there is some heat requirement or enthalpy change will be there that will be regarded as delta H one per unit moles or mass you can say.

And similarly, when you bought this solid phenol will be converting to liquid phase particular constant temperature of 42.5 degrees Celsius at one atmospheric pressure you will see there will be you know, latent heat change that will be change of enthalpy which is regarded as delta H 2 here hat per unit mass. Similarly, liquid you know enthalpy to be you know heated up to you know it is boiling point of 181.4 degrees Celsius by you know that heat up amount it is you know sensible heat because of this temperature difference.

And then, it will be you know, heated up to you know, 300 degrees Celsius after converting it phase change from you know liquid to vapor to that changing of liquid to vapor of this phenol phase, you have to you know, consider that latent heat of vaporization and after that you have to heat it up to a certain and other temperature from its boiling point up to 300 degrees Celsius like here. So, in this case it will be you know delta H 5.

Similarly, you can change these you know vapour phase of phenol x at 300 degrees Celsius at atmospheric condition to higher pressure also at the same temperature for that also you need to have some you know enthalpy change that can be regarded as delta H 6. So, to convert these you know, solid this phenol to it is vapour from 25 degrees Celsius to 300 degrees Celsius temperature and a pressure from one atmospheric to you know 3 atmospheric pressure for that total amount of enthalpy will be required.

That total enthalpy change will be equal to delta H 1 plus delta H 2 plus delta H 3 plus delta H 4 plus delta H 5 plus delta H 6 respectively here as given in the, you know, slide there. So, you are having that how that enthalpy change will be there because of that phase change. Now, this enthalpy change, because of that phase change will be you know, at constant temperature there in that case, you know, that, there are different types of enthalpy change it is called heat of fusion, where solids will be converting into liquid, heat of vaporization.

When liquids to be converting into vapor heat of condensation that means, vapor will be converting to you know that liquid phase and heat of sublimation that case solids to be directly converting to the vapour. So, that will that will be called as heat of sublimation there.

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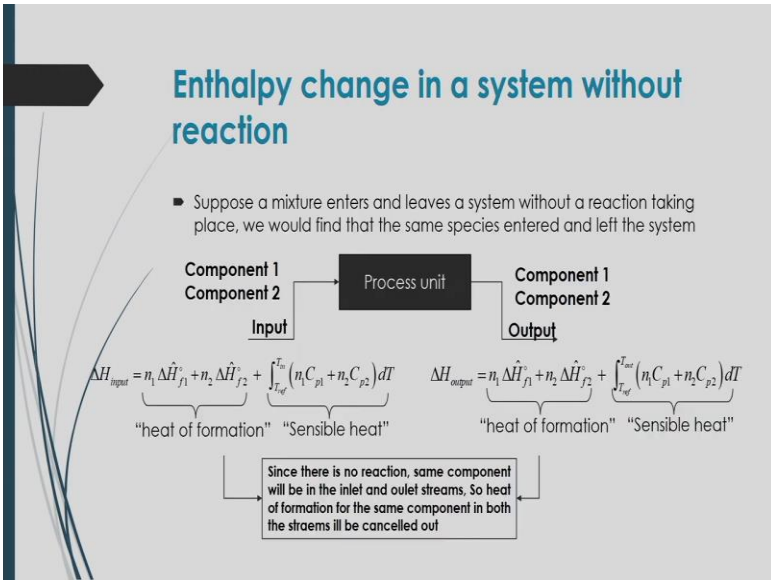

Enthalpy change in a system without reaction

- Suppose a mixture enters and leaves a system without a reaction taking place, we would find that the same species entered and left the system

$$\Delta H_{input} = \underbrace{n_1 \Delta\hat{H}^{\circ}_{f1} + n_2 \Delta\hat{H}^{\circ}_{f2}}_{\text{"heat of formation"}} + \underbrace{\int_{T_{ref}}^{T_{in}} (n_1 C_{p1} + n_2 C_{p2}) dT}_{\text{"Sensible heat"}}$$

$$\Delta H_{output} = \underbrace{n_1 \Delta\hat{H}^{\circ}_{f1} + n_2 \Delta\hat{H}^{\circ}_{f2}}_{\text{"heat of formation"}} + \underbrace{\int_{T_{ref}}^{T_{out}} (n_1 C_{p1} + n_2 C_{p2}) dT}_{\text{"Sensible heat"}}$$

Since there is no reaction, same component will be in the inlet and oulet streams, So heat of formation for the same component in both the straems ill be cancelled out

Another thing that suppose if you have being a process unique without you, you know reaction there will be some process going on and for that at the inlet condition some components like component 1 component 2 component 3 like there are several components will be coming into the process unit and after processing you will see that that components will be you know, coming out as a component 1 and 2 again after having some you know, change maybe because of that phase change maybe because of you know, some other you know, physical you know, state of that component change, or maybe you know that, you know that mixture change also they are being you know that, that some change of properties.

So, there will be some input, there will be some output for that components, because of some, you know, that change your phase, you know, enthalpy now, you have to calculate that enthalpy change for those components which are coming into the system and which are coming out from the system based on that, if is there any temperature change if is there any phase change or not so, far that you have to first consider what will be the you know enthalpy change because of its formation you know in the inlet condition for all components.

Similarly, what should be the heat of formation for all components in the outlet condition again what should be the summation of sensible heat because of that temperature if is there any heat is supplied to the system because of heat that there will be a certain change of sensible heat, because of its temperature difference, then you have to summing up all the sensible heat for all components in the inlet and outlet streams.

Again, if you are seeing that there is a change of temperature from one to another in Celsius that in between there will be a change of those components, then they are also you have to consider that enthalpy change because of enthalpy change. So, according to that the enthalpy change in the input that will be able to heat up formation for all components in the input, sensible heat summation of all components for all those, you know sensible heat they are similar at the outlet condition.

Also summation of all you know, heat formation for all components and summation of all sensible heats because of that temporary change and also if is there any feature that you have to consider. So, accordingly we can have this change of interpreted the input change of enthalpy and the output and what do we have entropy change between these input and output just simply you have to subtract it, then you will get that what the enthalpy change for this particular process in this case one interesting point that if you are having the same components in the input and output streams.

You see that heat of formation for all those components will be same, because heat of formation for any components will not be changed anywhere in the system. So, in this case, you can neglect this heat of formation at the inlet and outlet condition if you are having the same components and the inlet and outlet streams. So, we can say that since there is no reaction, same component will be in the inlet and outlet streams. So, heat of formation for the same component in both the streams will be cancelled out. So, only you know that enthalpy change will be because of that sensible heat because of that temperature change, because of that a phase change.

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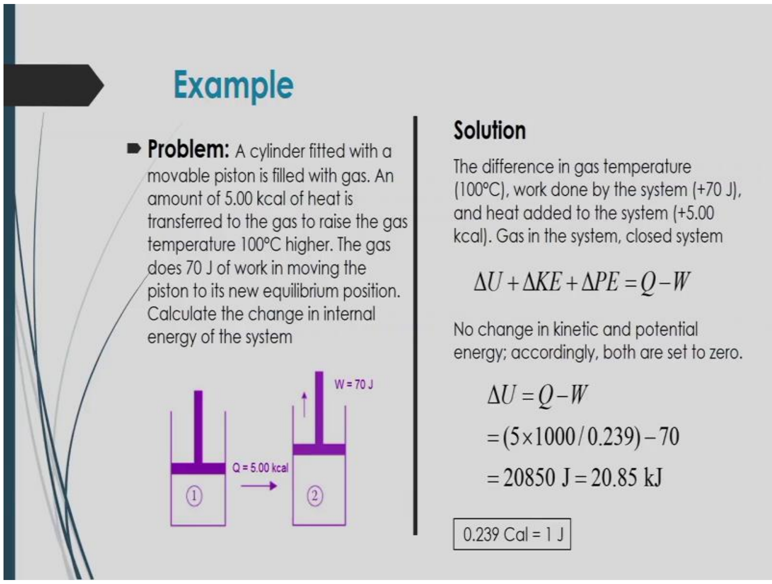

Example

- **Problem:** A cylinder fitted with a movable piston is filled with gas. An amount of 5.00 kcal of heat is transferred to the gas to raise the gas temperature 100°C higher. The gas does 70 J of work in moving the piston to its new equilibrium position. Calculate the change in internal energy of the system

Solution

The difference in gas temperature (100°C), work done by the system (+70 J), and heat added to the system (+5.00 kcal). Gas in the system, closed system

$$\Delta U + \Delta KE + \Delta PE = Q - W$$

No change in kinetic and potential energy; accordingly, both are set to zero.

$$\Delta U = Q - W$$
$$= (5 \times 1000 / 0.239) - 70$$
$$= 20850\ \text{J} = 20.85\ \text{kJ}$$

$\boxed{0.239\ \text{Cal} = 1\ \text{J}}$

Now, let us do an example particular this you know energy balance equation and how it can be used for this you know internal energy change, let us consider a cylinder which is filled with a you know movable piston with a gas and amount of you know 5 kilocalorie of heat is you know transferred to the gas to raise the gas temperature of 100 degrees Celsius higher the gas does 70 joules of work in moving the piston to its new equilibrium position.

As per figure shown in the slide, in this case, you have to calculate how that internal energy change will give you these you know new equilibrium position of this piston and what will be the amount of that internal energy they are in the system. So, in this case, we can say that there is a difference in gas temperature that is, you know 100 degrees Celsius and we are done by the system is you know 70 joule. And heat to the system is here it is given 5 kilo calorie.

So, according to this closed system concept, and based on that energy balance equation we can write delta U plus delta KE plus delta PE that will be given Q minus W here summation of internal energy, kinetic energy potential energy that will actually will be close to the net energy supplied to the system. In this case, since there is no change in kinetic and potential energies accordingly we can say that delta KE and delta PE that will be close to zero.

And if you set this zero here in this equation, then you can write here delta U will be equal to Q minus W. So, after substitution of this value of Q and W as given in the problem then we can write delta U will be equal to 20850 joule that is 20.585 kilojoule. In this case you have to convert this, you know calorie to joule by this conversion factor, remember this, if all units are in joule, then you have to convert this calorie to joule here according to the problem.

So, finally, we are getting that internal energy change of will be 20.85 kilojoule based on this temperature rise 200 degree Celsius just because of that 70 joule work done for moving this piece down to its new equilibrium position and also because of this temperature that are to be that high kilocalorie of heat is transport to the gas. So, based on which we can calculate what internal energy change.

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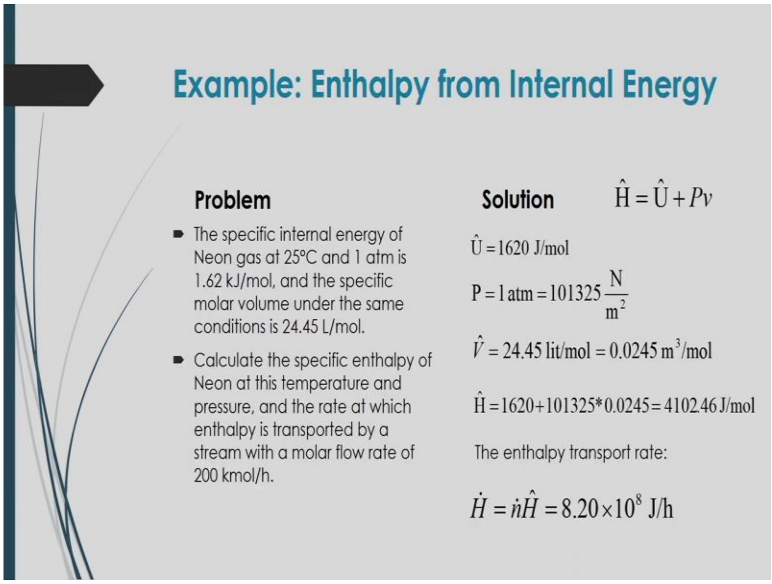

Example: Enthalpy from Internal Energy

Problem

- The specific internal energy of Neon gas at 25°C and 1 atm is 1.62 kJ/mol, and the specific molar volume under the same conditions is 24.45 L/mol.
- Calculate the specific enthalpy of Neon at this temperature and pressure, and the rate at which enthalpy is transported by a stream with a molar flow rate of 200 kmol/h.

Solution $\hat{H} = \hat{U} + Pv$

$\hat{U} = 1620 \text{ J/mol}$

$P = 1 \text{ atm} = 101325 \frac{N}{m^2}$

$\hat{V} = 24.45 \text{ lit/mol} = 0.0245 \text{ m}^3\text{/mol}$

$\hat{H} = 1620 + 101325 * 0.0245 = 4102.46 \text{ J/mol}$

The enthalpy transport rate:

$\dot{H} = \dot{n}\hat{H} = 8.20 \times 10^8 \text{ J/h}$

Similarly, another example you can do to calculate this enthalpy from the internal energy like in this case, if you know that a specific internal energy of suppose neon gas at 25 degree Celsius and 1 atmosphere is 1.62 kilojoules per mole and the specific molar volume under the same conditions is given us 24.45 liter per mole. So, in that case, you have to calculate what should be the specific enthalpy of the neon gas at this temperature and pressure and the rate at which that enthalpy is transferred by your stream with the molar flow rate of 200 kilometres per hour.

So, what exactly you need to find out here, this specific enthalpy and for that, you know that this specific enthalpy is basically summation of internal energy plus you know, flow energy, that internal energy it is if you are considering that a specific rate then here to be that specific rate of internal energy here specific rate of flow energy.

So, here specific internal energy is given to you pressure is given to you here you know, specific volume is here 24.45 liter per mole era, this is 0.0245 meter per mole here this is nothing but a specific volume. This is nothing but we had we can write as H hat is basically after substitution can be calculated based on that equation here it will come finally, 4102.46 joules per mole. So, the enthalpy transport rate we can write it is a you know specific enthalpy that means the energy per mole.

So to that total enthalpy transport rate you have to multiply it by molecular or molar flow rate there, this molar flow rate is given here in H dot that is here 200 kilomole per hour. So, accordingly, we can have this total enthalpy transport rate will be equal to 8.20 into 10 to the power of joule per hour.

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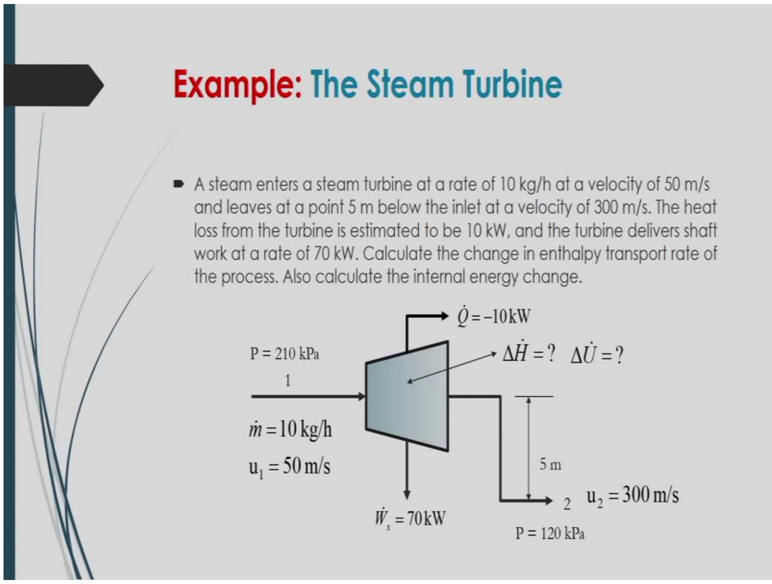

Example: The Steam Turbine

- A steam enters a steam turbine at a rate of 10 kg/h at a velocity of 50 m/s and leaves at a point 5 m below the inlet at a velocity of 300 m/s. The heat loss from the turbine is estimated to be 10 kW, and the turbine delivers shaft work at a rate of 70 kW. Calculate the change in enthalpy transport rate of the process. Also calculate the internal energy change.

Now, let us do another example, for steam turbine in this case also, you know, you have to calculate what should be that change in enthalpy transport rate of the process and also calculate the internal energy change when a steam enters this steam turbine at a rate of you know 10 kg per hour at a velocity of 50 meter per second and it leaves at 8.5 meter below the inlet active velocity of 300 meter per second the heat loss from the turbine is estimated to be you know 10 kilo watt and the turbine delivers some shaft work at a rate of you know 70 kilowatt. In this case, you have to calculate what should be the change in enthalpy transport rate of the process and also what should be the internal energy change.

So, here see that, at the inlet condition of this turbine, as shown here in the slide, that P is given here. At this point one mass flow rate is given velocity at this point is given and at this point 2 it is that level at point 2 is 5 meter below that you know inlet you know stream and pressure at this condition at the point to it is given 120 kilopascal were as velocity is 300 meter per second. Here the heat loss from the turbine it is given 10 kilowatt and also turbine delivers work at the rate of 70 kilowatt so, based on this what should be your enthalpy change and internal change.

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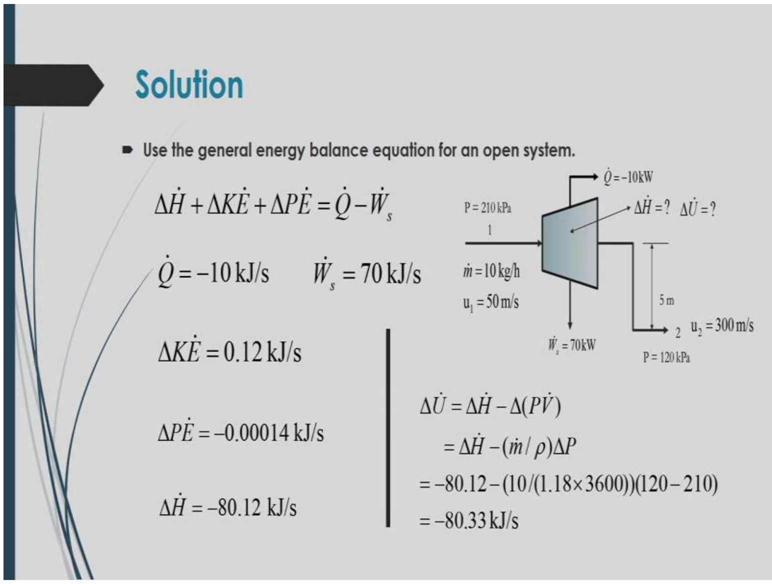

Solution

- Use the general energy balance equation for an open system.

$$\Delta\dot{H} + \Delta\dot{KE} + \Delta\dot{PE} = \dot{Q} - \dot{W}_s$$

$$\dot{Q} = -10\,\text{kJ/s} \qquad \dot{W}_s = 70\,\text{kJ/s}$$

$$\Delta\dot{KE} = 0.12\,\text{kJ/s}$$

$$\Delta\dot{PE} = -0.00014\,\text{kJ/s}$$

$$\Delta\dot{H} = -80.12\,\text{kJ/s}$$

$$\begin{aligned}\Delta\dot{U} &= \Delta\dot{H} - \Delta(P\dot{V}) \\ &= \Delta\dot{H} - (\dot{m}/\rho)\Delta P \\ &= -80.12 - (10/(1.18\times3600))(120-210) \\ &= -80.33\,\text{kJ/s}\end{aligned}$$

As for that general energy balance equation for that open system we can write this change of enthalpy plus kinetic energy plus potential energy that will be equal to Q dot minus W dot here Q dot is given to W dot is given to you kinetic energy can be calculated from the velocity of differences to you know streams in inlet and outlet and what would the kinetic energy change that is half you squared from that you can calculate similarly potential energy.

You can calculate, then enthalpy change after substitution of that value in this equation of general energy balance equation you can have, so, it is finally coming as minus 80.12 kilojoule per second. So, based on this enthalpy change you can calculate what should be the, you know internal energy change, because this internal energy change is basically that how much you know enthalpy is exceeded from this flow energy that will be regarded as your internal energy.

So, it will be basically that delta H minus delta PV dot so after substitution of that, here, we can have this value up here in V dot basically m dot by row and delta P is here and then finally, we can get a substitution of those you know variables and then you can get to minus 80.33 kilojoule per second. So, this is your internal energy. So, turbine based on this, you know problem that changing that internal energy of this amount and change of enthalpy will be of this amount there.

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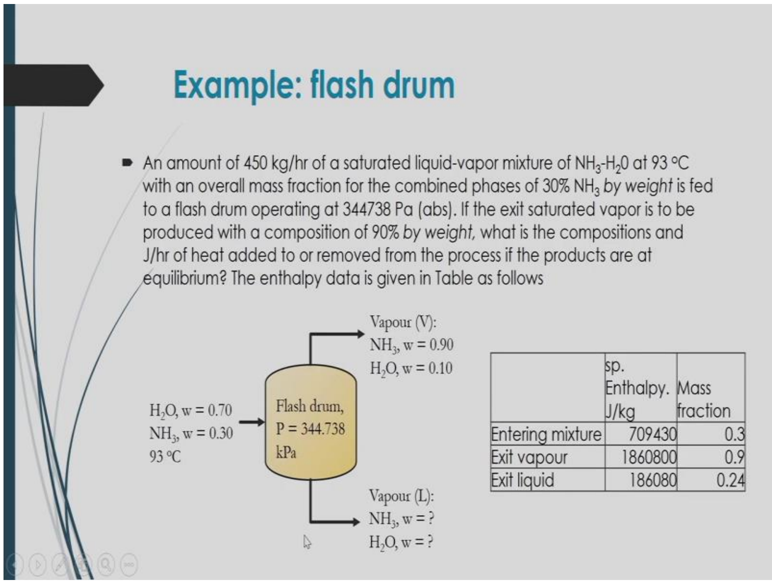

Example: flash drum

- An amount of 450 kg/hr of a saturated liquid-vapor mixture of NH_3-H_20 at 93 °C with an overall mass fraction for the combined phases of 30% NH_3 *by weight* is fed to a flash drum operating at 344738 Pa (abs). If the exit saturated vapor is to be produced with a composition of 90% *by weight*, what is the compositions and J/hr of heat added to or removed from the process if the products are at equilibrium? The enthalpy data is given in Table as follows

	sp. Enthalpy. J/kg	Mass fraction
Entering mixture	709430	0.3
Exit vapour	1860800	0.9
Exit liquid	186080	0.24

Let us do another example of you know applying this you know, energy balance equation for flash you know drum that case in the flash drum and among amount of 450 kg per hour of saturated liquid vapor mixture of ammonia water at 93 degrees Celsius with an overall mass fraction of like you know 30% ammonia and remaining 70% water is operated at you know 344.738 kilo Pascal absolute pressure now, exit saturated vapor is to be produced with a composition of 90% of you know water vapor by weight.

And remaining is you know that 90% of you know that ammonia and 10% of water that you know vapour stream from that you know flash drum then what is the composition and also you have to find out what should be the heat added to or removed based on the calculation from the process if the products are at equilibrium. So, in this case the liquid era liquid will be coming from this you know bottom part with the composition of you know, that liquid ammonia and liquid water you know will be coming as a certain fraction that you have to find out.

In this case you need to have that you know specific enthalpy of that components in the entering mixture, the specific enthalpy of that mixture is this given and mass production is given here exists to be a mass production is given and also enthalpies given their and liquid that enthalpy specific enterprise given and mass production is given there so, according to that you have to calculate this you know composition and heat added or removed from the system.

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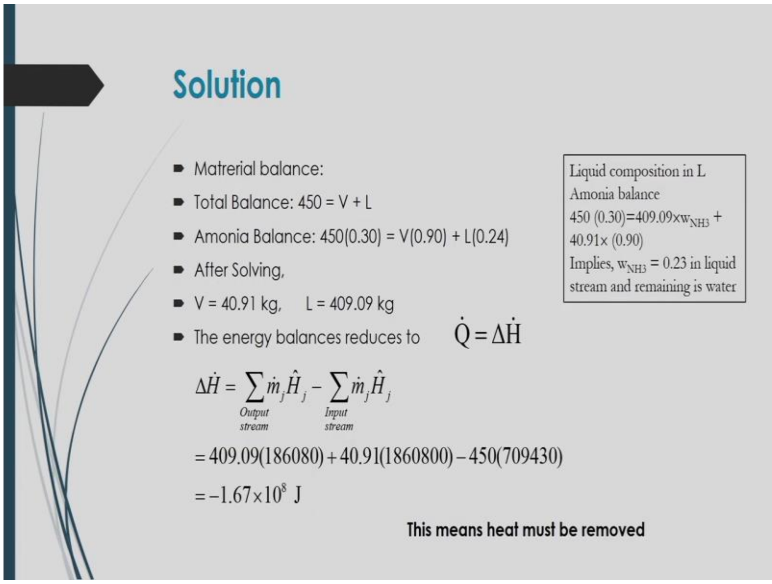

Solution

- Matrerial balance:
- Total Balance: 450 = V + L
- Amonia Balance: 450(0.30) = V(0.90) + L(0.24)
- After Solving,
- V = 40.91 kg, L = 409.09 kg
- The energy balances reduces to $\dot{Q} = \Delta\dot{H}$

$$\Delta\dot{H} = \sum_{\substack{Output\\stream}} \dot{m}_j\hat{H}_j - \sum_{\substack{Input\\stream}} \dot{m}_j\hat{H}_j$$

$$= 409.09(186080) + 40.91(1860800) - 450(709430)$$

$$= -1.67\times10^{8}\ \text{J}$$

This means heat must be removed

Liquid composition in L
Amonia balance
450 (0.30)=409.09×w_{NH3} +
40.91× (0.90)
Implies, w_{NH3} = 0.23 in liquid
stream and remaining is water

Now, material balance will give you that as per total balance 450 that will be equal to V plus L and if you do the ammonia balance there, it will come as 450 into 0.30 that will be equal to V into 0.90 plus L into 0.24 and after solving you will get that amount of vapour from the flash drum and amount of liquid from the liquid drum. And then as per that energy balance we should be reducing here Q dot will be equal to delta is H dot now, this delta H dot is basically the enthalpy change from its you know, output stream and input streams by summing up all that you know enthalpy change for all components there.

So, according to that up the substitution of all you know that we lose here, we can finally get this enthalpy changes minus 1.67 into 10 into the power of 8 joule. So, please go through this you know calculation again then finally, you get this you know this mass of energy they are since it is negative, so, we can say that heat must be removed from the system for the liquid composition after material balance, what is that ammonia from the ammonia balance we can have this this liquid composition after substitution of those, you know composition in the vapour and liquid phase.

Here since the liquid phase this amonia liquid is you know, unknown so, you are assuming here that the fraction of amonia balance is W. So, after substitution of that, we are having these sub volume fraction of ammonia in the liquid phases .23. So, remaining portion will be as you know what that it will be you know that around 69.69 there for water. So, in this way, how that energy balance equation can be applied to calculate that you know enthalpy change, if you are having multiple components in the inlet and outlet system.

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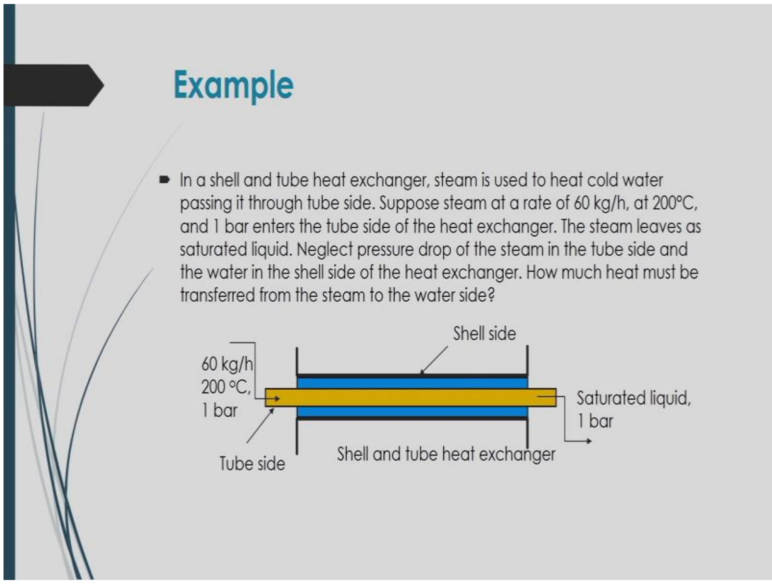

Example

- In a shell and tube heat exchanger, steam is used to heat cold water passing it through tube side. Suppose steam at a rate of 60 kg/h, at 200°C, and 1 bar enters the tube side of the heat exchanger. The steam leaves as saturated liquid. Neglect pressure drop of the steam in the tube side and the water in the shell side of the heat exchanger. How much heat must be transferred from the steam to the water side?

Another example, suppose, in a shell and tube heat exchanger steam is used to heat cold water passing it through the tube side here, you will see that shell and tube heat exchanger the outside it is you know that shell side this is tube side from the tube side some you know that liquid will be passing maybe you know hot water to be passing or hot liquid to be passing to heat up that you know cold liquid which is in shell side or vice versa also it can be done.

So, suppose a steam at a rate of 60 kg per hour at 200 degrees Celsius and one bar enters the tube side of the heat exchanger. Now the steam leaves rated liquid here from the outlet neglect the pressure drop of the steam in the tube side and the water in the shield side of the heat exchanger. Now, based on this, how must it must be transferred from the steam to heat of this water in shell side? So, here this is cold liquid you have to heat it up by supplying that steam in the you know tube side that case, how much heat is to be transport that you have to calculate.

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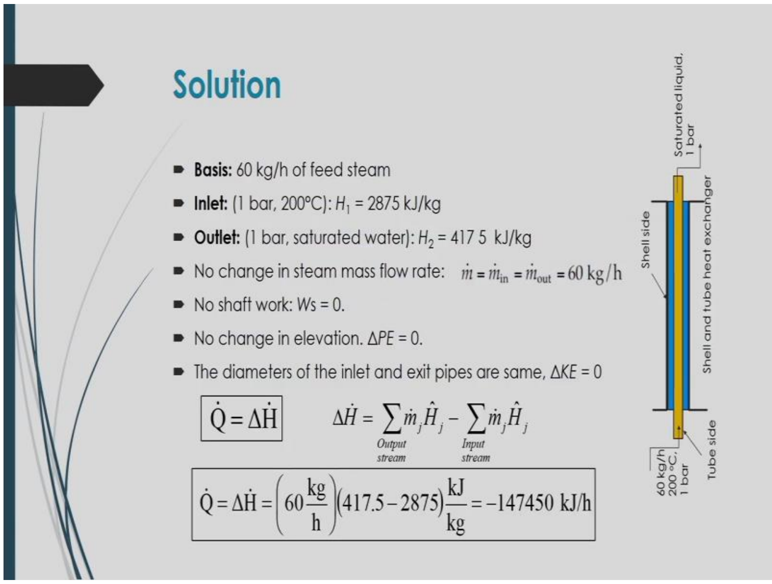

Solution

- **Basis:** 60 kg/h of feed steam
- **Inlet:** (1 bar, 200°C): $H_1 = 2875$ kJ/kg
- **Outlet:** (1 bar, saturated water): $H_2 = 417\ 5$ kJ/kg
- No change in steam mass flow rate: $\dot{m} = \dot{m}_{in} = \dot{m}_{out} = 60\ \text{kg/h}$
- No shaft work: $Ws = 0$.
- No change in elevation. $\Delta PE = 0$.
- The diameters of the inlet and exit pipes are same, $\Delta KE = 0$

$$\boxed{\dot{Q} = \Delta\dot{H}} \qquad \Delta\dot{H} = \sum_{\substack{\text{Output}\\ \text{stream}}} \dot{m}_j \hat{H}_j - \sum_{\substack{\text{Input}\\ \text{stream}}} \dot{m}_j \hat{H}_j$$

$$\boxed{\dot{Q} = \Delta\dot{H} = \left(60\frac{\text{kg}}{\text{h}}\right)(417.5 - 2875)\frac{\text{kJ}}{\text{kg}} = -147450\ \text{kJ/h}}$$

So, it can be done based on that energy balance equation now, in this case 60 kg per hour that is a steam is supplying and inlet condition is one bar and 200 degrees Celsius enthalpy is this condition is 2875 you can calculate or you can have it from you know that psychometrics or that we have you know discussed in earlier lecture there so, based on that psychometric set at this, you know temperature and pressure you can calculate what should be the you know enthalpies there or you can calculate it from a you know, other way from that you know temperature change.

Therefore, to the you know enthalpy there at outlet also since it is a saturated water one bar again you can have this enthalpy from this you know psychometric chart and no change in steam mass flow rate in the inlet and outlet condition. So, you can write what is the mass flow rate in inlet and what the mass flow rate in outlet that will be equal and that is basically 60 kg per hour is given and here no shaft work is done. No pump no other things is used to you know supply to the you know system or system does not work as a shaft work there and no change in innovation.

Since this is horizontally placed. So, there is no you know change in elevation. So, potential energy it will be zero. And also you can see that since the diameter of that inlet that takes in uniform at the inlet and outlet side. So, we can say that there will be no change of velocity of that steam. So, we can say that kinetic energy change will be zero. So, after considering that, no shaft work no potential energy no kinetic energy based on which you can finally, get this you know energy balance equation into a simplified form of Q dot will be equal to delta H dot this delta H dot basically that what will be the total enthalpy in the output stream and total enthalpy in the inlet streams.

So, based on that deviation to give you that enthalpy change of this particular processes. So, that can be calculated after substitution of that mass flow rate here m dot j here at the inlet, the same as the simply 16 into 2875 and outlet that is 60 into 417.5. So, after you know calculation we can get this enthalpy change as you know minus 147450 kilojoule per hour. So, this is basically that heat is supplied or heat is you know transport from this you know due to the shell side.

Since it is coming negative, we can say that the heat is applied it is our transport from this tube side to the shell side. So, based on this example, we can then assess this energy balance equation and we can understand this energy balance equation more, you know precisely.

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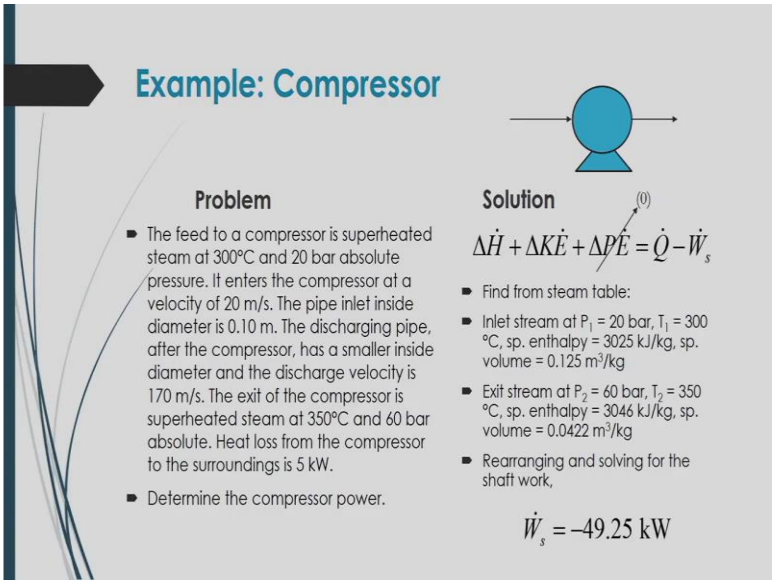

Example: Compressor

Problem

- The feed to a compressor is superheated steam at 300°C and 20 bar absolute pressure. It enters the compressor at a velocity of 20 m/s. The pipe inlet inside diameter is 0.10 m. The discharging pipe, after the compressor, has a smaller inside diameter and the discharge velocity is 170 m/s. The exit of the compressor is superheated steam at 350°C and 60 bar absolute. Heat loss from the compressor to the surroundings is 5 kW.
- Determine the compressor power.

Solution

$$\Delta\dot{H}+\Delta\dot{KE}+\cancelto{(0)}{\Delta\dot{PE}}=\dot{Q}-\dot{W}_s$$

- Find from steam table:
- Inlet stream at P_1 = 20 bar, T_1 = 300 °C, sp. enthalpy = 3025 kJ/kg, sp. volume = 0.125 m^3/kg
- Exit stream at P_2 = 60 bar, T_2 = 350 °C, sp. enthalpy = 3046 kJ/kg, sp. volume = 0.0422 m^3/kg
- Rearranging and solving for the shaft work,

$$\dot{W}_s = -49.25\ \text{kW}$$

And then you can apply this you know enthalpy balance equation or energy balance equation, but the compressor also there also you will see that if suppose if you want to use a compressor you know by heating up certain you know steam that is super heated at 300 degrees Celsius and at 200 bar absolute pressure you will see that when this this steam interests this compressor at a velocity of 20 meter per second and to this pipe of diameter of .1 meter and the discharging pipe hotter that compressor has a smaller diameter.

And the distance velocities suppose, increased up to 170 meters per second and the exit of that compressor is superheated steam at 350 degree Celsius and the pressure at 60 bar absolute under this condition there will be a certain heat loss from the compressor to the surrounding and it is seen that it is approximately 5 kilowatt. Now, in this case you have to calculate with a compressor power.

So, this is a simple that air enthalpy change will be there, because of that temperature change from 300 to 315 Celsius, kinetic energy change will be there because of that velocity change at the inlet and outlet condition outlet now, you know of this compressor there will be no change or potential energy because of that alignment of this inlet and outlet pipe in the same level and you know that heat loss that is you know, because of this compressor that heat loss to the surrounding.

So, we can have this Q dot here as a negative value and also we can see that there will be some power will be done by this you know compressor. So, what should be that, you know compressor power that you have to find out So, you can write this energy balance equation here enthalpy change kinetic energy change Q dot and W dot will be used.

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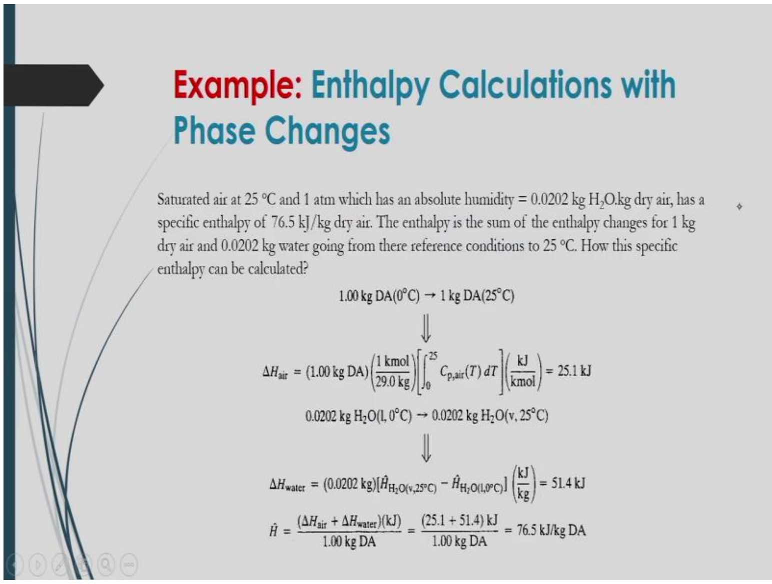

Example: Enthalpy Calculations with Phase Changes

Saturated air at 25 °C and 1 atm which has an absolute humidity = 0.0202 kg H_2O.kg dry air, has a specific enthalpy of 76.5 kJ/kg dry air. The enthalpy is the sum of the enthalpy changes for 1 kg dry air and 0.0202 kg water going from there reference conditions to 25 °C. How this specific enthalpy can be calculated?

$$1.00\text{ kg DA}(0^\circ\text{C}) \rightarrow 1\text{ kg DA}(25^\circ\text{C})$$

$$\Downarrow$$

$$\Delta H_{\text{air}} = (1.00\text{ kg DA})\left(\frac{1\text{ kmol}}{29.0\text{ kg}}\right)\left[\int_0^{25} C_{p,\text{air}}(T)\,dT\right]\left(\frac{\text{kJ}}{\text{kmol}}\right) = 25.1\text{ kJ}$$

$$0.0202\text{ kg }H_2O(\text{l}, 0^\circ\text{C}) \rightarrow 0.0202\text{ kg }H_2O(\text{v}, 25^\circ\text{C})$$

$$\Downarrow$$

$$\Delta H_{\text{water}} = (0.0202\text{ kg})[\hat{H}_{H_2O(\text{v},25^\circ\text{C})} - \hat{H}_{H_2O(\text{l},0^\circ\text{C})}]\left(\frac{\text{kJ}}{\text{kg}}\right) = 51.4\text{ kJ}$$

$$\hat{H} = \frac{(\Delta H_{\text{air}} + \Delta H_{\text{water}})(\text{kJ})}{1.00\text{ kg DA}} = \frac{(25.1 + 51.4)\text{ kJ}}{1.00\text{ kg DA}} = 76.5\text{ kJ/kg DA}$$

For this calculation for us this potential energy because to zero now, from the steam table you can directly calculate at a certain pressure and temperature what should be a specific enthalpy and also what to be the specific volume and from the exit stream also at a certain temperature and pressure, possibly the specific enthalpy and the specific Volume. Now, rearranging and solving for this a shaft to our from this energy balance equation we can have this W s dot will be equal to minus 49.25 kilowatts.

So, this is you know compressor power which is worked on the system worked by this compressor to you know heat because of this energy change and to be lost the atmosphere. Let us have an example when there will be enthalpy change because of that a change. Now if you have that saturated air at 25 degrees Celsius and one atmospheric pressure, who says an absolute humidity here 0.0202 kg of water by kg dry air in this case has a specific enthalpy 76.5 kilojoules per kg dry air.

The enthalpy is the sum of enthalpy changes for 1 kg dry air and 0.0202 kg water that goes from their reference condition to 25 degree Celsius. Now, how this specific enthalpy can calculate there now, in this case, 1 kg dry air and it is saturated at 25 degrees Celsius dryer in this case this the dry air enthalpy change you can calculate based on that you know temperature difference and from this specific heat capacity based on this equation and will come 25.1 kilojoule.

And you will see that this water and moisture content of these 2.0202 kg and that is that liquid condition at zero degree Celsius. It will be converting to you know vapor at 25 degrees Celsius of the same amount of that water. Now for this what will be the you know enthalpy change that enthalpy add that 25 degrees Celsius for the vapour of that water and enthalpy of water at that liquid state of zero degree Celsius and you know difference of that in enthalpy change.

You will get that total enthalpy change of water based on this you know temperature change and after that you will see that what will be the specific you know, enthalpy change after substitution of this value up enthalpy change of air and enthalpy change of the water per unit you know mass of dry air, then it will be coming up finally as 76.5 kilojoule per kg of dry air. So, this is your you know 1 kg of dry air will give you the enthalpy change of 76.5 kilojoule.

When this liquid you know water will be, you know changing it is state to vapor at 25 degree Celsius now enthalpy change for water at one atmosphere showing the phase transition in this figure it is shown that the x axis is temperature, based on this temperature, you will see that how enthalpy will be changing at a different you know phase change condition like for heat of fusion at this condition at a temperature up to 73 you know Kelvin at constant temperature we change our heat that is called heat of fusion.

Again if you change the temperature from 273 to here 373 that is at its boiling point there will be a change of you know enthalpy of your sensible heat and again add that you know boiling point temperature of water you will see that the water will be becoming before vapour and at a you know that enthalpy change of vaporization. So, this vaporization can be you know represented by this you know figure here as shown in the slide in this case very interesting that no accurate simple way to estimate heat or fusion, you will see experimentally.

So, the heat of fusion of many elements and compounds can be roughly estimated by this equation here as part you know, email, that is text book. They are, I have suggested to you know, follow that textbook. So, there it is given that that enthalpy change because of this fusion at a constant temperature that can be close to constant. It will be 2 to 3, 4 elements and to be 5 to 7 or inorganic compounds and to be 9 to 11 for organic compounds. And in this case T f is basically melting point and this delta H f hat which is that will be molar heat of fusion their calorie per gram.

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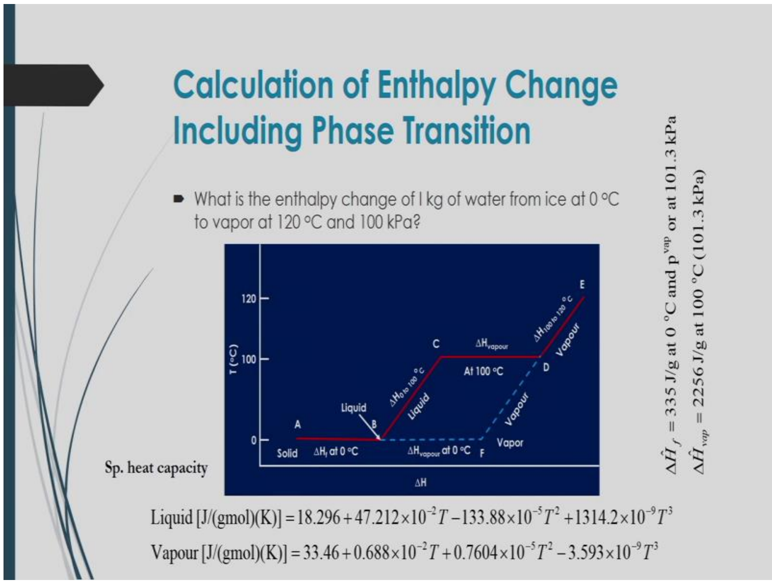

Calculation of Enthalpy Change Including Phase Transition

- What is the enthalpy change of l kg of water from ice at 0 °C to vapor at 120 °C and 100 kPa?

Sp. heat capacity

$\Delta\hat{H}_f = 335$ J/g at 0 °C and p^{vap} or at 101.3 kPa

$\Delta\hat{H}_{vap} = 2256$ J/g at 100 °C (101.3 kPa)

$$\text{Liquid [J/(gmol)(K)]} = 18.296 + 47.212\times10^{-2}T - 133.88\times10^{-5}T^2 + 1314.2\times10^{-9}T^3$$

$$\text{Vapour [J/(gmol)(K)]} = 33.46 + 0.688\times10^{-2}T + 0.7604\times10^{-5}T^2 - 3.593\times10^{-9}T^3$$

Similarly, calculation of enthalpy change including phase transition here, it is represented by this you know figure as shown in the slide, you will see that how you know temperature change will give you that different enthalpy change that we have already discussed for you know that phenol and water here for water it is shown that how enthalpy change at each different you know temperature and how to be changing whenever temperature is constant.

They are you know solid water will be converting to you know that liquid water and then liquid to you know, a higher temperature and up to its boiling point after the from the boiling point to be vaporized, and then at that vaporization condition, you can you know, keep the constant at a certain you know boiling point that at its boiling point and then you know from that boiling point you can rise the temperature up to a certain temperature as part of your you know consideration.

So, accordingly that liquid solid will be you know that are solid will be converting to liquid liquid to vapor and vapor then even higher you know superheated vapor there according to that temperature change and because of that vapour change, there will be you know certain change of enthalpy that can be represented by this diagram here. Now, when you know there will be sensitive heat change because of the temperatures are you know change that you have to consider the specific heat capacity that may be a function of temperature.

So, for that, you know, temperature dependent specific heat capacity, can be you know calculated for basically for what are you can calculate it by this equation and similarly for vapour you can calculate by this equation. So, accordingly you can get to these you know that sensible heat based on the specific heat and the temperature difference also a heat fusion also can be you know considered here and also heat vaporization can be, you know calculated or can be, you know, used based on this balance here given in the slide.

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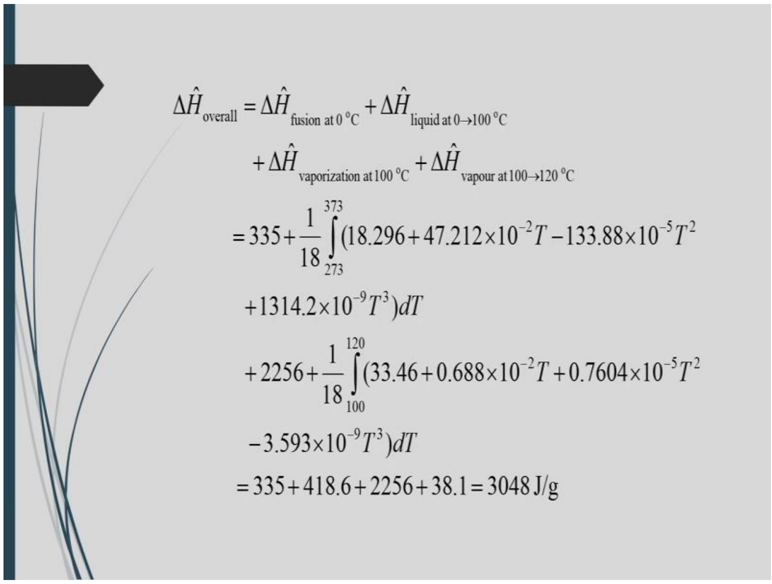

$$\Delta\hat{H}_{\text{overall}} = \Delta\hat{H}_{\text{fusion at } 0\,^{\circ}\text{C}} + \Delta\hat{H}_{\text{liquid at } 0\to 100\,^{\circ}\text{C}}$$

$$+\Delta\hat{H}_{\text{vaporization at } 100\,^{\circ}\text{C}} + \Delta\hat{H}_{\text{vapour at } 100\to 120\,^{\circ}\text{C}}$$

$$= 335 + \frac{1}{18}\int_{273}^{373}(18.296 + 47.212\times10^{-2}T - 133.88\times10^{-5}T^{2}$$

$$+1314.2\times10^{-9}T^{3})dT$$

$$+2256 + \frac{1}{18}\int_{100}^{120}(33.46 + 0.688\times10^{-2}T + 0.7604\times10^{-5}T^{2}$$

$$-3.593\times10^{-9}T^{3})dT$$

$$= 335 + 418.6 + 2256 + 38.1 = 3048\ \text{J/g}$$

And then up to substitution of these values of fusion at zero degrees Celsius liquid at 0 to 100 degrees Celsius, that enthalpy change and entropy change for vaporization at 100 degree Celsius and also entropy change because of the temperatures are arising from these you know, boiling point to that certain temperature and after substitution of that specific heat capacity as a function of temperature here, and finally, you can get this value of 3048 joule.

So, per gram of you know water, if you change it is you know solid to its vapour up to 120 degrees Celsius, you need to have that enthalpy or heat it will be equal to 3048 joule per gram, I think you have understood the problem solving based on that, you know energy balance equation without reaction based on the enthalpy change and how to calculate the entropy change based on that temperature variation, how to calculate the enthalpy change based on you know, a change.

How to calculate the internal energy based on that pressure change how to calculate the internal energy based on enthalpy change, how to you know solve those, you know, problem of you know, like turbine or you know that other examples that is given here in this lecture, it will be, I think helpful for better understanding of that enthalpy balance for that, and I would suggest you to follow this text to you know solve more problems up example, that is given in the textbook.

So, next lecture, we will discuss more about that energy balance, they are with multiple streams without reaction would be considering. And so, thank you for giving your kind attention to the lecture.