Basic Principles and Calculations in Chemical Engineering

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Lecture # 18

Laws and properties of thermodynamics

Welcome to massive open online course on basic principles and calculations in chemical engineering. We are discussing about energy and it forms under module 6 or in this module, we will discuss today about the laws and properties of thermodynamics.

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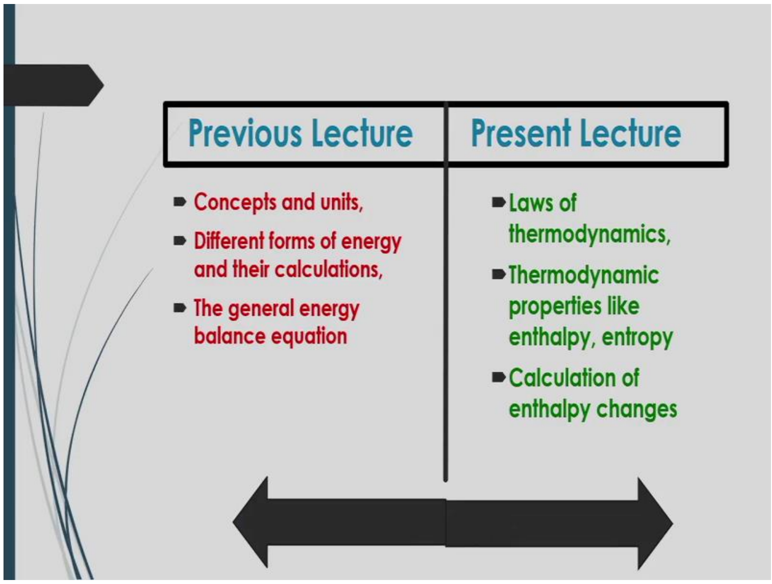

Previous Lecture	Present Lecture
Concepts and units,	Laws of thermodynamics,
Different forms of energy and their calculations,	Thermodynamic properties like enthalpy, entropy
The general energy balance equation	Calculation of enthalpy changes

In the previous lecture we have described regarding concepts and units of that energy and also what are the different forms of energy and also how it can be calculated that given some you know idea and also described that different forms of energy and also we have given the general energy balance equation and how that energy balance equation can be you know used to you know assess that process for an energy analyze.

This will also give more examples on that, you know calculation based on that general energy balance equation, you know successive you know, lecture series. Now in this lecture will try to even know something more about that energy and its forms in this case that, thermodynamics, and it is law and also different properties of law that thermodynamics like enthalpy, entropy and how those entropy and enthalpy can be calculated will be discussed here.

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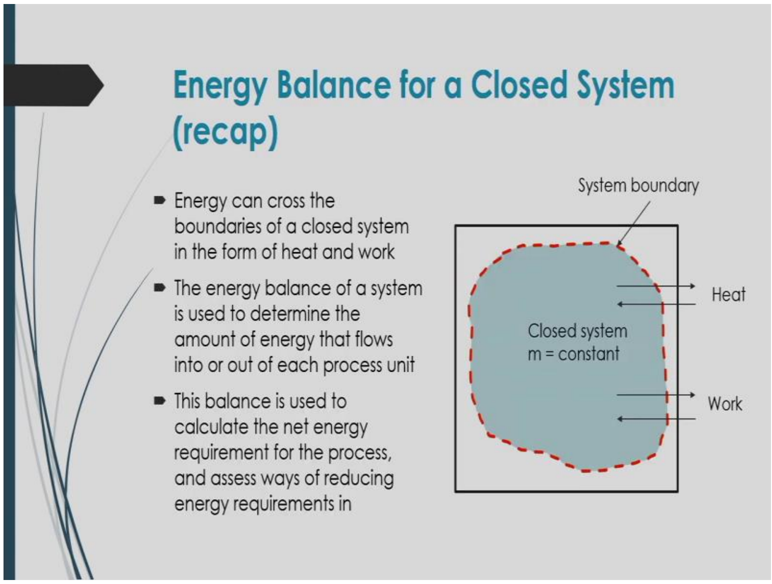

Energy Balance for a Closed System (recap)

- 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

As we know that that energy balance equation for any closed systems you know to represent each.

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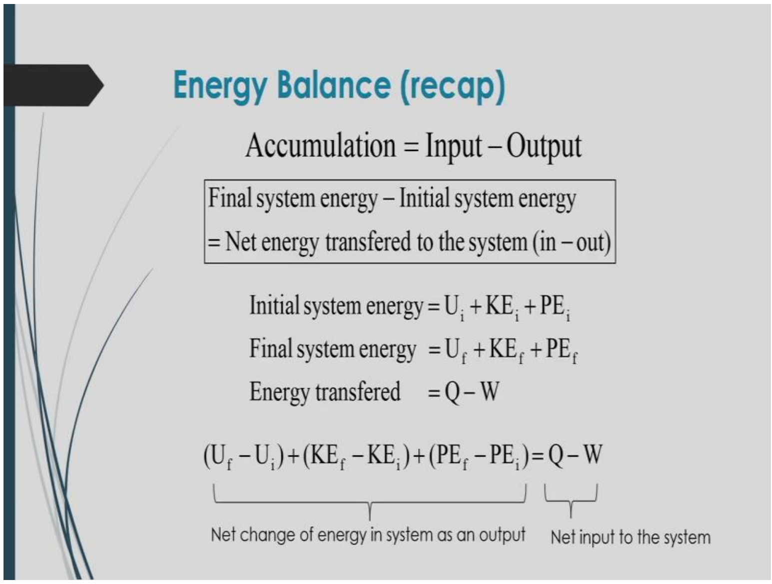

Energy Balance (recap)

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

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

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

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

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

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

We are having this you know energy balance equation like accumulation that we input minus output and because of that you know heat input or work output or work input by or heat output based on these there will be a you know change of you know internal energy and also you know other you know system energy change and based on which you can see that how much energy would be accumulated based on this input or output of the energy of heat.

And you know work by energy transferred so, in that case the system and it will be changed from initial to final stage and because of this you know energy transferred this a change of this, you know final system energy from its initial system energy can be represented by this general energy balance equation here as shown in the slides.

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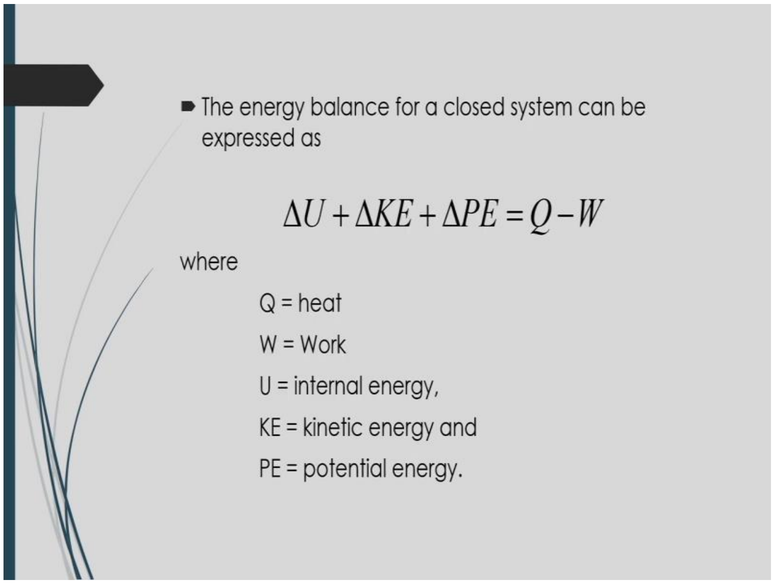

- The energy balance for a closed system can be expressed as

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

where

Q = heat

W = Work

U = internal energy,

KE = kinetic energy and

PE = potential energy.

And we can you know that, express this equation in this difference form here like this delta U that is a difference in internal energy and difference in kinetic energy and difference in potential energy. And these changes will be equals to that, you know, heating input or output or lot of done by the system there and here you can see that this heat energy or that work that is done by the system or on the system that will change this different system energy like you know that internal energy, kinetic energy and potential energy they are so, based on who is who can you represent is a general form of equation.

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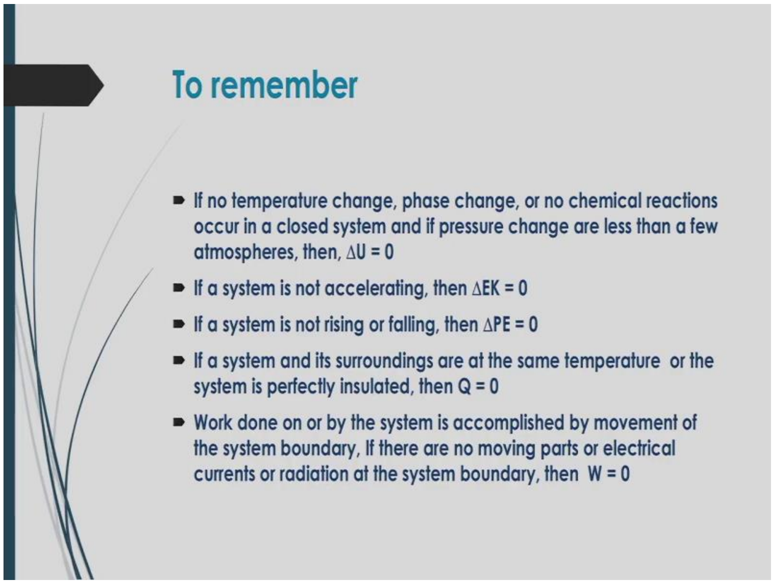

To remember

- 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 $W = 0$

So, in this case you have to remember that, if there is no temperature change, even phase change also it is not there are no chemical reactions occur in a closed system and if pressure change our less than if you atmosphere in that case we can see that that internal energy will be negligible or almost zero. Now, if your system is not accelerating, in that case kinetic energy you know, that will be close to zero. And if your system is not rising or falling, we can say that there will be no potential energy change.

And also if your system and its surroundings are at the same temperature or the system is perfectly insulated, then we can say that there is no heat you know supply to the air or to be coming out from the system and work done on or by the system is generally accomplished by you know movement of the system boundary and in that case, there are no moving parts or electrical currents or radiation of energy of this type at the system boundary, then you can see that this work will be equal to 0.

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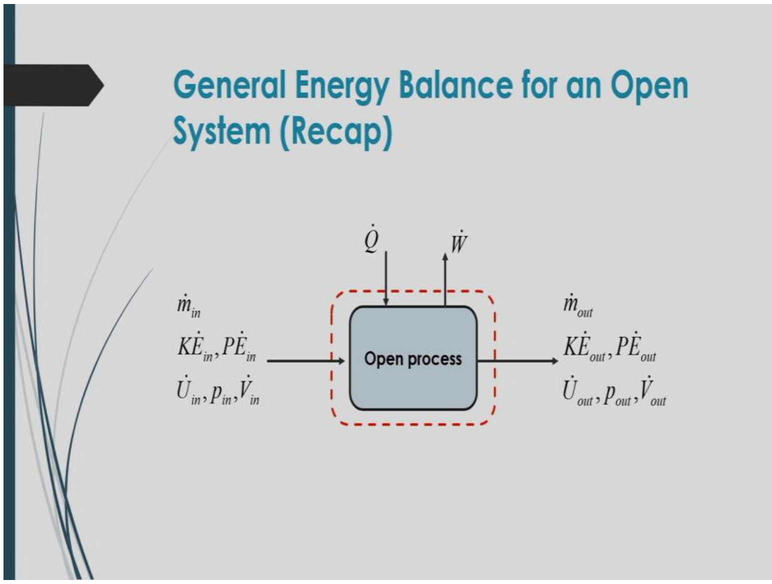

General Energy Balance for an Open System (Recap)

$\dot{Q}$

$\dot{W}$

$\dot{m}_{in}$

$K\dot{E}_{in}, P\dot{E}_{in}$

$\dot{U}_{in}, p_{in}, \dot{V}_{in}$

Open process

$\dot{m}_{out}$

$K\dot{E}_{out}, P\dot{E}_{out}$

$\dot{U}_{out}, p_{out}, \dot{V}_{out}$

So, if we express that general energy balance for an open system can have this you know, energy input and energy you know what can output for us here in the initial state that the kinetic energy potential energy and what will be the internal energy also how this pressure they are in the inlet change and also you know volume of that in the condition. Similarly, at that outlet condition what are those you know system variables are there as an energy.

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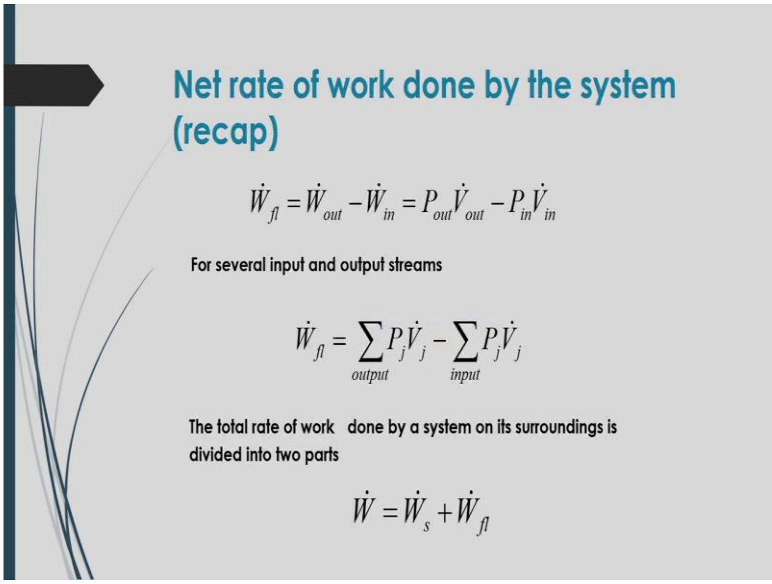

Net rate of work done by the system (recap)

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

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

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

So, based on which we can write this you know.

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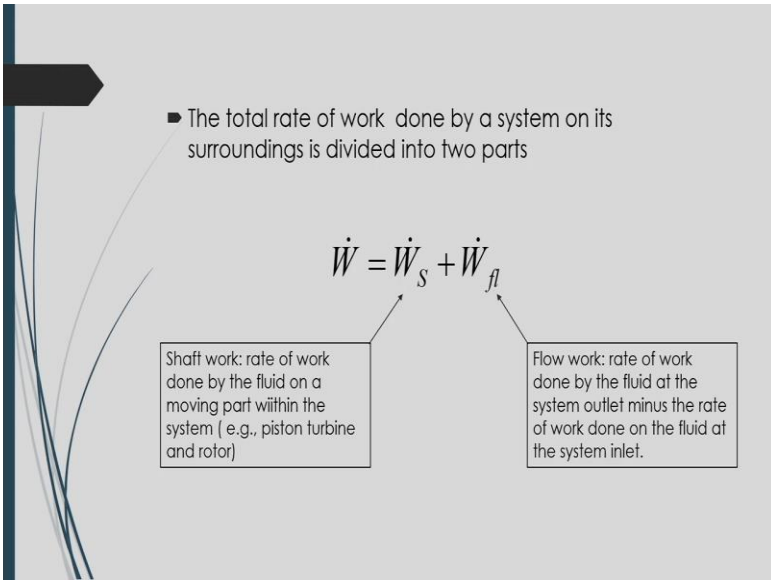

- The total rate of work done by a system on its surroundings is divided into two parts

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

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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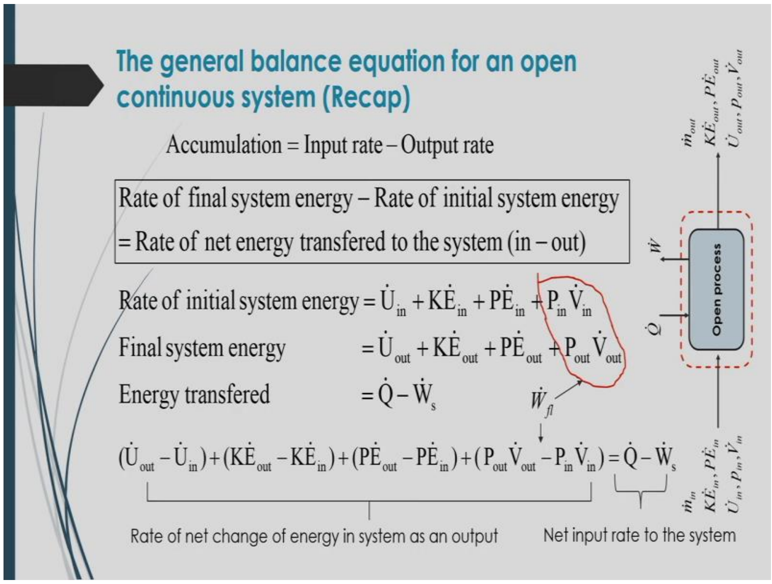

The general balance equation for an open continuous system (Recap)

Accumulation = Input rate – Output rate

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

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

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

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

$\dot{W}_{fl}$

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

Final form of general energy balance here so, this will be your change your potential energy change of kinetic energy, change your potential energy here this, you know that this no work done by the fluid system here that will be represented by this P out V out minus P in into V in then it will be close to here as general balance equation given. So, this is you know that final forms of general energy balance equation for an open continuous system.

So, in this case here to final system energy minus rate of initial system energy that will be close to rate of energy transfer to the system. Now, this rate of initial system energy can be represented by these terms and the final system energy can be represented by these terms and energy transfer that will be q dot minus w dot, this Ws dot is basically that shaft work and this P1 you know P in V in and also the outlet P out V out the difference of this you know that we are done by this changing of volume or pressure by this you know quick flow it will be regarded as that work done by the fluid and in this case this you know that were done by the shaft and work done by the fluid you know flow then it can be regarded as total work energy as w.

So, that is why we can you know that here that W will be equal to Ws plus W fl here in this case Ws dot is shaft to work that done by the fluid on a moving part within the system example like piston turbine and rotor. Similarly W fl here this is a flow work that is rate of work done by the fleet at the system outlet minus the rate of work done on the fluid the system in inlet. So, this summation of this you know shaft work and the flow work will be you know, regarded as the total work done by the system.

This you know that the difference in that you know heat energy supplied all this work done by the system what is the difference that difference will give you that change of internal energy kinetic energy and potential energy and also we can say that that will be added to that you know that changing flow was so, input rate to the system will change the rate of change of energy in the system as an output there.

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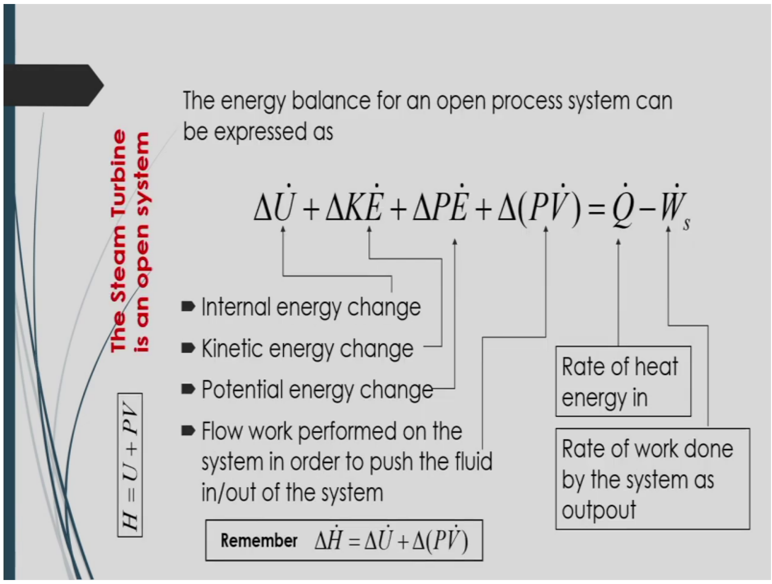

The Steam Turbine is an open system

$H = U + PV$

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

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

- 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

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

Rate of heat energy in

Rate of work done by the system as outpout

Now, the energy balance for an open process system can also be actually expressed by this equation here in terms of you know different forms there so, delta U dot plus delta KE dot plus delta PE dot plus delta PV dot that will be equal to Q dot minus Ws dot.

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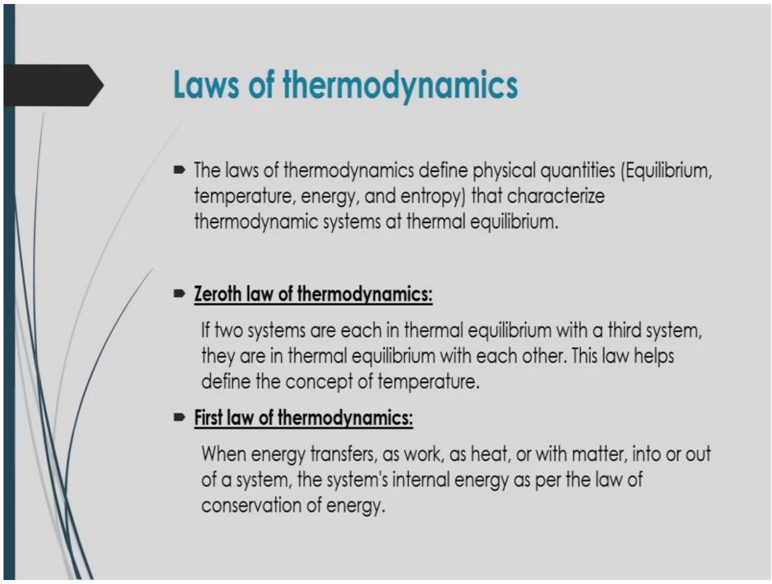

Laws of thermodynamics

- The laws of thermodynamics define physical quantities (Equilibrium, temperature, energy, and entropy) that characterize thermodynamic systems at thermal equilibrium.
- **Zeroth law of thermodynamics:**

  If two systems are each in thermal equilibrium with a third system, they are in thermal equilibrium with each other. This law helps define the concept of temperature.
- **First law of thermodynamics:**

  When energy transfers, as work, as heat, or with matter, into or out of a system, the system's internal energy as per the law of conservation of energy.

So in this case, we can say that this delta U dot is the internal energy change, delta KE dot is, kinetic energy change and delta PE dot is potential energy change and delta PV dot the work performed on the system in order to push the fluid in or out of the system. And here Q dot is the rate of heat energy in and Ws dot is the rate of work done by the system as output and you have to remember that this summation of this internal energy change and this an pro work performed on the system will be close to or will be regarded as enthalpy of the system.

So, this enthalpy change will be you know defined as delta U dot plus or you know delta PV dot. So, this this delta H dot is called enthalpy change. So, the enthalpy that will be to call to then internal energy plus that pressure into volume, we can see that the steam turbine is an open system where you can apply this you know energy balance equation to solve this problem even other problems also, you can apply this general balance equation.

We will do some problems in our next lectures there with this you know, energy balance equation. So, before going to you know, use this energy balance equation for a particular chemical engineering process you need. We have to know some, you know thermodynamic properties and it is a law because here this internal energy enthalpy change all those are basically thermodynamic properties. So, these are how these thermodynamic properties are defined and how to calculate we have to learn first.

Then we can use these you know these thermodynamic properties of like this internal energy, how enthalpy change and also how potential energy kinetic energy, all those things are change based on that will be able to you know do the energy balance for a particular process. So, let us know something about that laws of thermodynamics, here the laws of thermodynamics define actually which physical quantities like equilibrium temperature and achieve and entropy that characterize thermodynamics system set you know thermal equilibrium.

So, there are you know different laws of thermodynamics that well you know, give that you know, idea of that physical quantities in terms of equilibrium temperature energy entropy, which will characterize this thermodynamic system. In this case, we can see the law of thermodynamics, first law of thermodynamics second law of thermodynamics like this. Now, what is that zeroth law of thermodynamics here according to this, you know law, it is said that the 2 systems is in equilibrium thermally with the third system then you can say they are in thermal equilibrium with each other.

So, this law helps to define the concept of temperature actually so, this temperature will you know higher temperature will try to you know distribute in saturated with that it will equal it will make all you know that equilibrium of this 2 temperature of higher to lower. So, based on which you can say that if suppose 2 systems are in contact with each other in a thermal equilibrium condition with third one, then of course, this third system will scout will come try to come in a thermal equilibrium.

So, that they are in equilibrium with each other. So, this is called zeroth law of thermodynamics, but first law of thermodynamics gives you know that concept of you know conservation of energy in that case when energy transfers as work as heat or with matter into or out of the system, then systems internal energy as per the law of conservation of energy will be you know they are accordingly. So, when energy transfers as work as heat or with matter into or out of the system, the system internal energy will change accordingly to give you that, you know total energy of the system without you know destroying.

So, that is why this first law thermodynamics will give you that how much energy will be formed internal energy will be forms based on the you know that work done on the system or work done by the system or heat energy will be supplied or that energy may be you know transferred by the metals. So, based on which you can see that how that system will be changing its energy.

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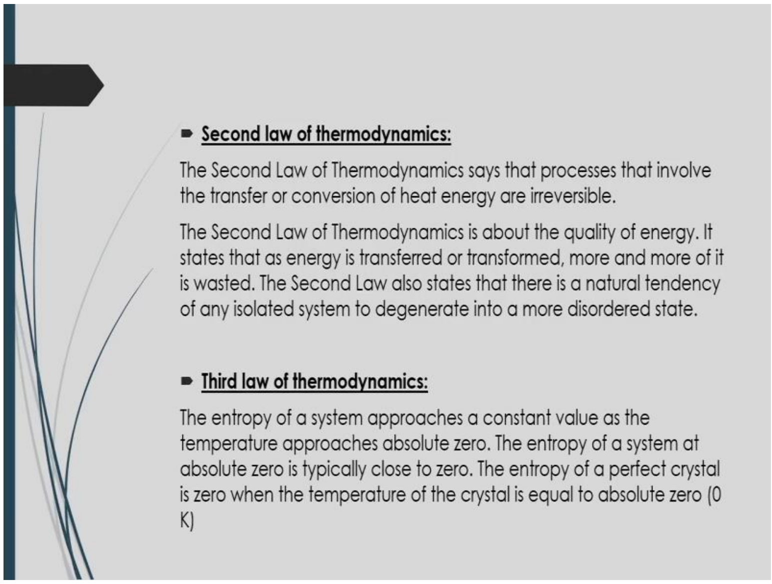

- **Second law of thermodynamics:**

The Second Law of Thermodynamics says that processes that involve the transfer or conversion of heat energy are irreversible.

The Second Law of Thermodynamics is about the quality of energy. It states that as energy is transferred or transformed, more and more of it is wasted. The Second Law also states that there is a natural tendency of any isolated system to degenerate into a more disordered state.

- **Third law of thermodynamics:**

The entropy of a system approaches a constant value as the temperature approaches absolute zero. The entropy of a system at absolute zero is typically close to zero. The entropy of a perfect crystal is zero when the temperature of the crystal is equal to absolute zero (0 K)

And also the second law of thermodynamics says that processes that involve the transport or conversion of the heat energy that will be you know, irreversible and it is about the quality of the energy and it states that that energy which is transferred or transformed and more and more of it is generally being wasted. And according to the second law, it is also you know, say that there is a mutual tendency of any isolated system to actually degenerate into a more disordered state.

So, we can say that, according to these second law of thermodynamics, that whatever transfer or conversion of that heat energy will be there, you cannot make it to you know, reversible or to its original state. So, it is called the irreversible process. And in the case of you know that third law of thermodynamics, you know that there will be a change of entropy because of that, you know, our conversion would, you know, heat energy into each other forms like internal energy change or potential energy kinetic energy change there.

You will see that this phenomena of changing this state of this system that will you know a process a constant value as the temperature approaches absolute zero. So, all these you know that whatever internal energy will be changed by, you know, supplying that heat energy from the surroundings to the system. And in that case, this internal energy portability change that actually, depending on the temperature change.

So, anybody we are talking about the, you know, some characteristics which are being changed in terms of that internal energy or you can see that some you know environment will be changing who should be called as the entropy that depends on the temperature. Now, you will see that if there is an you know in equilibrium condition of the temperature distribution in inside the system you will see there will be a certain characteristics of the system that will be represented by the entropy.

Now, that entropy will you know be to absolute zero or in temporary setup process that up to absolute zero that you will see that the entropy of the system will recess to a constant value. So, there is you know that this is a something is qualitative, you know, thinks that some you know the characteristics of that, you know systems will change and it will reach to a constant value when this temperature will reset to its absolute zero.

Now, this entropy of the system at absolute zero is typically close to zero. And in that case the entropy of the perfect crystal is regarded as zero and the temperature of the crystal is equal to the absolute zero for the pure substances like few crystals in that case this entropy will be zero at its you know absolute zero whereas, in other cases you will see that at its absolute zero temperature, this entropy will resist to a certain value that is a constant value, you cannot actually get that absolute zero entropy.

They are because of that any systems of real system you can say that that may not you know, have extemporary converted into absolute zero because they are anyway they are restarted you know that you know frictional energy movement of that are molecules will give you certain heat energy there. So, at that cases, you will see that this temperature is going to or approximately close to zero that you can see that this entropy will be you noticing it is constant value and how does entropy actually quantitatively can be estimated.

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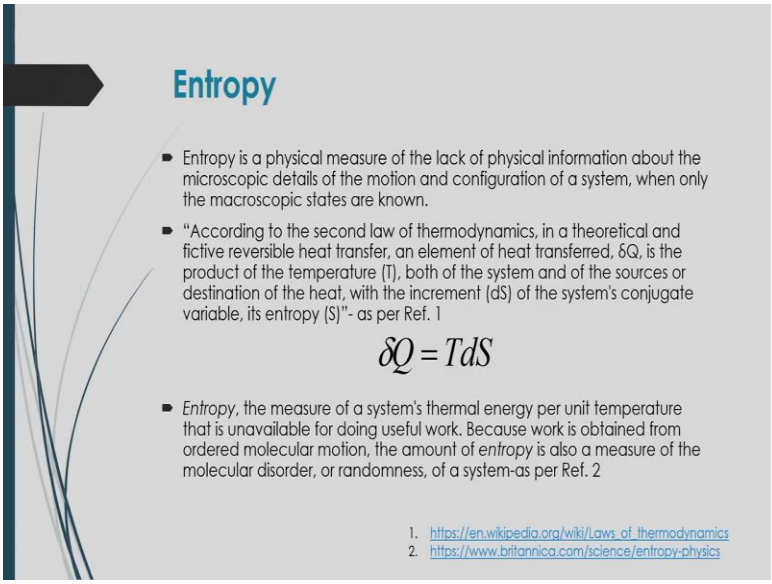

Entropy

- Entropy is a physical measure of the lack of physical information about the microscopic details of the motion and configuration of a system, when only the macroscopic states are known.
- "According to the second law of thermodynamics, in a theoretical and fictive reversible heat transfer, an element of heat transferred, δQ, is the product of the temperature (T), both of the system and of the sources or destination of the heat, with the increment (dS) of the system's conjugate variable, its entropy (S)"- as per Ref. 1

$$\delta Q = TdS$$

- *Entropy*, the measure of a system's thermal energy per unit temperature that is unavailable for doing useful work. Because work is obtained from ordered molecular motion, the amount of *entropy* is also a measure of the molecular disorder, or randomness, of a system-as per Ref. 2

1. https://en.wikipedia.org/wiki/Laws_of_thermodynamics
2. https://www.britannica.com/science/entropy-physics

So, in this case, here one, you know that mathematical you know, representation here shown here, that, how do you entropy change can be calculated, if you are changing your, you know, heat energy for a small amount you will see at a particular temperature, you will see that at that temperature that entropy change will be, you know, defined by that change your heat upon at its temperature. So, we can see that entropy is basically a physical measure of the lack of physical information that is called characteristics, how that system will change about the microscopic details of the motion and configuration of the system.

When only the macroscopic you know states are known to you. So, we can observe that there is a change of that entropy only by change of that macroscopic you know states whereas, this entropy basically happens when there will be a microscopic change of this physical activities, they are or you can see that some characteristics they are and like you know that if suppose, there is a motion of that particles even if you are you know changing the configuration of the system.

So, they are then microscopically you can say that because of this microscopic change of this motion or system configuration you will see that there will be a change of entropy and that entropy you cannot actually measure by that microscopic change, but only you can realize it by the macroscopic state change of that you know system. So, according to that second law of thermodynamics or you know that laws or you can say thermodynamic PVR in a theoretical and you know, fictive reversible heat transport.

We can say that an element of heat transferred that is delta Q is the product of the temperature are both the system and the sources of our destination of the heat with increment delta is of the systems that conjugate variables and this is called that entropy. So, as part the saw you know concept the mathematical representation of this you know entropy can be you know expressed as you know delta Q because to T into ds also this entropy can be a you know measure of systems thermal energy per unit temperature that is, you know unable for doing useful work there.

Because in this case this work is obtained from the order of that you know order or you can see regular fashion of that molecular motion and also this can be a measure of that you know, molecular disorder or you know, randomness of the system there. So, this basically a you know that, how that systems you know environment will be changing based on that you know heat energy supplied at a particular temperature and this may change of you know, molecular order or disorder or fashion or you can see some configuration of the systems. So, based on who is this entropy can be you know measured.

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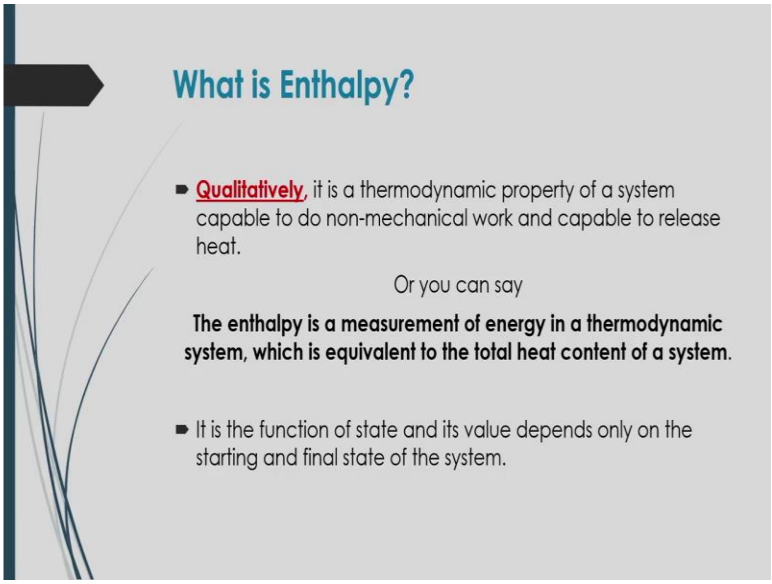

What is Enthalpy?

- **Qualitatively**, it is a thermodynamic property of a system capable to do non-mechanical work and capable to release heat.

Or you can say

The enthalpy is a measurement of energy in a thermodynamic system, which is equivalent to the total heat content of a system.

- It is the function of state and its value depends only on the starting and final state of the system.

Another important thermodynamic properties you can see for that energy consideration is the enthalpy it is generally that you know, how much you know internal energy will be changed there and also if you know supply or if you apply some pressure and because of it there any you know that the volume of that you know systems will change, you will see there will be you know change of you know system energy because of that applying or that heat energy there. So, that you know change of that, you know systems, you know energy in terms of internal energy and also system energy.

They are, we can define this term and an improved quality as an enthalpy now, this enthalpy can be actually known as qualitatively and also quantitatively also qualitatively, we can say that it is a thermodynamic property of a system that will be capable to do non-mechanical work and capable to release some heat or you can say that the enthalpy is a measurement of energy in the thermodynamic system, which is equivalent to the total heat content of your system. So, it is a function of state and its value depends only on the starting and final states of the system.

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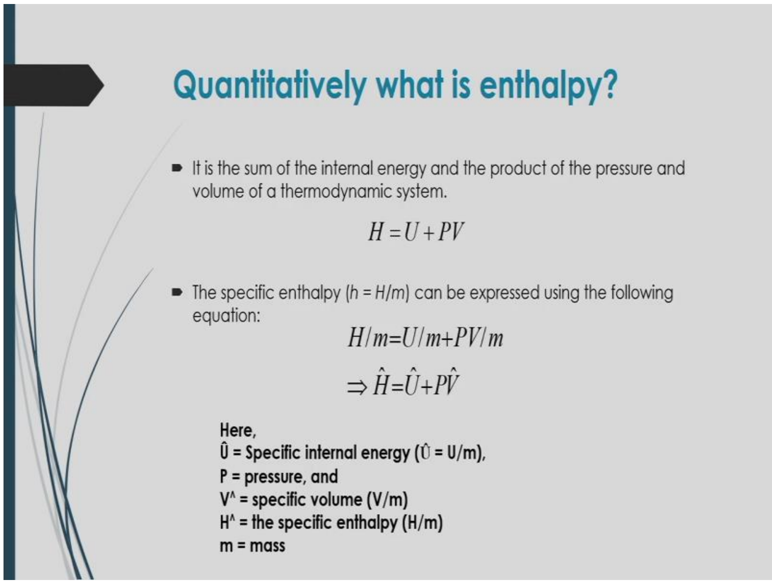

Quantitatively what is enthalpy?

- It is the sum of the internal energy and the product of the pressure and volume of a thermodynamic system.

$$H = U + PV$$

- The specific enthalpy ($h = H/m$) can be expressed using the following equation:

$$H/m = U/m + PV/m$$

$$\Rightarrow \hat{H} = \hat{U} + P\hat{V}$$

Here,
Û = Specific internal energy (Û = U/m),
P = pressure, and
V^ = specific volume (V/m)
H^ = the specific enthalpy (H/m)
m = mass

And quantitatively, we can define this enthalpy as the sum of the internal energy and the product of the pressure and volume of then you know thermodynamic system. This is basically the summation of internal energy and the flow energy there. So, this enthalpy you know can be denoted by H and it can be done it can be defined by this equation given in the slides here H is in enthalpy and U is the specific internal energy and PV is the pressure and specific volume has a specific enthalpy can be defined as here as or it can be denoted by H hat.

So, H hat will be H by m that means, per unit mass what will be the enthalpy there it could, it can be you know regarded as specific enthalpy so, this is specific enthalpy can be defined H by m as per the equation H by m will be equal to U by m for this equation here. So, H by m will be equal to U by m plus PV by m. So, H by m is basically that specific enthalpy and this U by m can be you know denoted by you had it is called specific internal energy and PV by m that you can regard it as being to be PV hat and this for you know specific volume of the system. So, we can then represent this, this specific enthalpy by this equation here.

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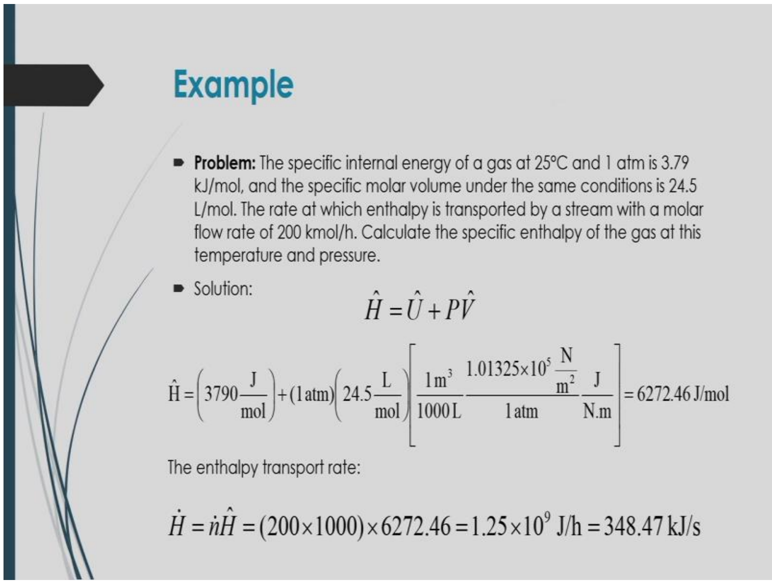

Example

- **Problem:** The specific internal energy of a gas at 25°C and 1 atm is 3.79 kJ/mol, and the specific molar volume under the same conditions is 24.5 L/mol. The rate at which enthalpy is transported by a stream with a molar flow rate of 200 kmol/h. Calculate the specific enthalpy of the gas at this temperature and pressure.
- Solution:

$$\hat{H} = \hat{U} + P\hat{V}$$

$$\hat{\mathrm{H}} = \left(3790\frac{\mathrm{J}}{\mathrm{mol}}\right) + (1\,\mathrm{atm})\left(24.5\frac{\mathrm{L}}{\mathrm{mol}}\right)\left[\frac{1\,\mathrm{m}^3}{1000\,\mathrm{L}}\frac{1.01325\times10^5\frac{\mathrm{N}}{\mathrm{m}^2}}{1\,\mathrm{atm}}\frac{\mathrm{J}}{\mathrm{N.m}}\right] = 6272.46\,\mathrm{J/mol}$$

The enthalpy transport rate:

$$\dot{H} = \dot{n}\hat{H} = (200\times1000)\times6272.46 = 1.25\times10^9\ \mathrm{J/h} = 348.47\,\mathrm{kJ/s}$$

Now, let us do an example, for this calculation of a specific enthalpy based on that internal energy change there. Now, if we say that a system under a you know certain condition at least you know that the rate of enthalpy is transported by stream with a molar flow rate of 200 kilomole per hour, in this case, the specific internal energy of that system of a gas at 25 degrees celsius and one atmosphere is you know 3.79 kilojoule per mole and also specific molar volume is given that is under same condition is 24.5 liter per mole.

So, under this condition of this system at the rate of flow of 200 kilometres per hour stream, which will you know transport this enthalpy change because of this you know internal energy and this pressure or flow energy and what we that you know rate of enthalpy will be there that you have to calculate. Now, in this case we know that the specific enthalpy is defined as you know that the summation of specific internal energy plus that P into V hat.

So, according to this equation, if you substitute this internal energy that is given in this problem specific internal energy is given and then substitute this air pressure is in one atmosphere. So, you have to convert it to Newton per meter in square.

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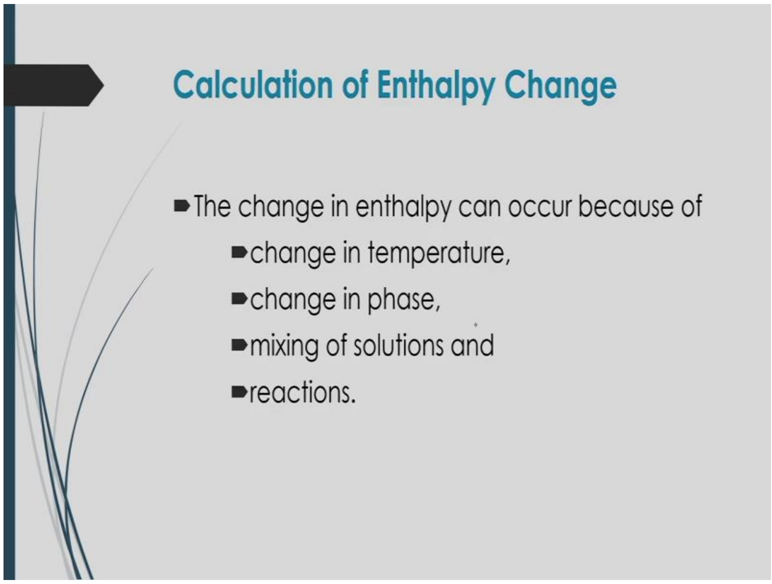

Calculation of Enthalpy Change

- The change in enthalpy can occur because of
  - change in temperature,
  - change in phase,
  - mixing of solutions and
  - reactions.

And also what would be the volume this specific volume is what will be that, this is given here, the specific volume is 24.5 liter, then you have to convert it to meter cube, we know that one meter cubical 1000 liter. So, you can see that, conversion of this volume will be equal to 24.5 by 1000 liter to be mole than and one atmosphere to be converted to Newton per meter square just by multiplying 1.01325 into 10 to the power of 5.

And then finally the unit for this specific enthalpy becoming a joule per mole and final value after calculation it is coming 6 to 72.46 per mole. So, that total enthalpy transport rate can be then you know that calculated by this equation here to tell you know enthalpy transport rate, it will be difficult to you know specific enthalpy into molar rate. So, here molar rate you have to convert it to you know that like this you have molarities given 200 kilomole per hour.

Then you have to multiply again into 1000s it will come to that you know more per hour few you know substitute the value of that is a number of moles there with this you know, this in specific enthalpy of 6 to 72.46 then, finally, you can have this you know 1.25 into 10 to the power of 9 joule per hour, that will be equal to 348.47 kilojoules per second. And this calculation of enthalpy change, you know who are getting here, based on that internal change that change in enthalpy can occur because of change in temperature change in phase mixing of solutions and reactions.

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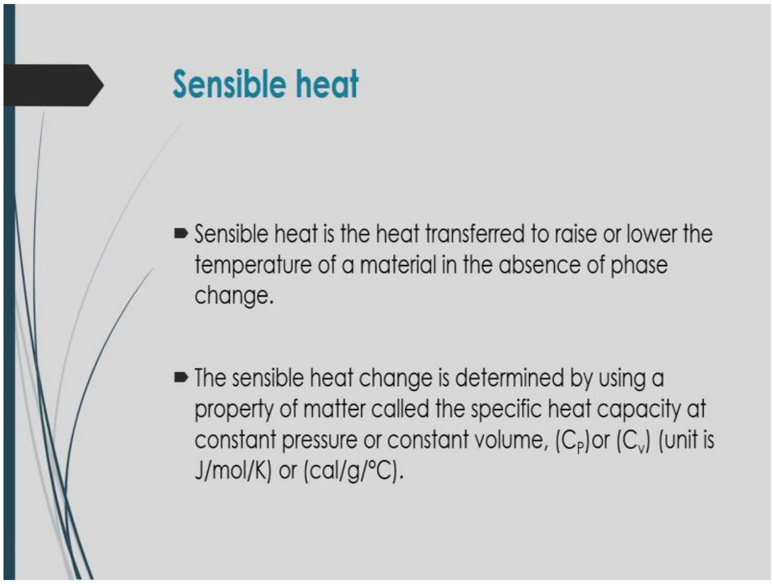

Sensible heat

- Sensible heat is the heat transferred to raise or lower the temperature of a material in the absence of phase change.
- The sensible heat change is determined by using a property of matter called the specific heat capacity at constant pressure or constant volume, (C_P)or (C_v) (unit is J/mol/K) or (cal/g/°C).

And this enthalpy also can be regarded as a sensible heat, this is basically a heat transport to raise your lower the temperature of a material in the absence of a change and this sensible heat change is basically determined by using a you know property of matter called the specific heat capacity at constant pressure or constant volume and it is represented by you know that joule per mole per K or calorie per gram per degree Celsius.

So, in this case, this sensible heat basically that one type of enthalpy change because of the temperature change. Now, that enthalpy change or sensible heat can be calculated based on that, you know temperature change and that temperature change will give you that sensible heat based on that, how much you know materials sexually being heated is being heated and also what will be the heat capacity or specific heat capacity of that material.

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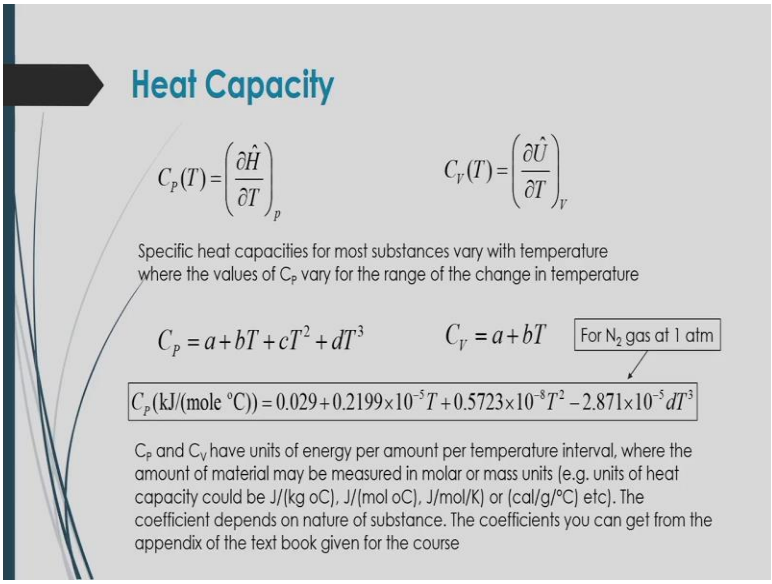

Heat Capacity

$$C_P(T) = \left(\frac{\partial \hat{H}}{\partial T}\right)_P \qquad C_V(T) = \left(\frac{\partial \hat{U}}{\partial T}\right)_V$$

Specific heat capacities for most substances vary with temperature where the values of C_P vary for the range of the change in temperature

$$C_P = a + bT + cT^2 + dT^3 \qquad C_V = a + bT$$

For N_2 gas at 1 atm

$$\boxed{C_P(\text{kJ/(mole °C)}) = 0.029 + 0.2199\times10^{-5}T + 0.5723\times10^{-8}T^2 - 2.871\times10^{-5}dT^3}$$

C_P and C_V have units of energy per amount per temperature interval, where the amount of material may be measured in molar or mass units (e.g. units of heat capacity could be J/(kg oC), J/(mol oC), J/mol/K) or (cal/g/°C) etc). The coefficient depends on nature of substance. The coefficients you can get from the appendix of the text book given for the course

So, based on which we can calculate that sensible heat as you know that delta H or you can see delta Q in that case that will be equal to CP into dT or this CP is the specific heat capacity there at constant pressure and also you can get that you know internal energy change based on that temperature change also and for that also how that you know specific heat capacity at constant volume is changing that also to be required to know for that particular materials.

So, in that case specific heat capacities for most substances very temperature where the values of CP vary the range of the change in temperature and within a certain range of temperature that specific heat capacity will change with respect to temperature. So, according to that, there will be a you know, there is a you know a correlation to calculate that specific heat capacity for constant pressure and specific heat capacity at constant volume.

Since, it is you know temperature dependent, but for the specific heat capacity at constant pressure it will be you know nonlinear it generally follows that polynomial equation of temperature and it is you know expressed as by this CP which is equal to a plus b t plus c T squared plus d T cube. Here T is the absolute temperature, or you can see that in Kelvin and a b c and d are the, you know constants and this constants depends on the material or you can say that gas or liquid like that.

And for you know that specific heat capacity for material at constant volume will be a linear function of temperature, it will CT equal to a plus b T, where a and b are also constants which are depending on the nature of the substance or method or material you can say and these coefficients you can get it from your textbook is given in the appendix for different you know, materials how what will be the value of a b c and a and b for that specific heat capacity for constant pressure and volume respectively.

As an example for nitrogen gas at one atmospheric pressure efficient this specific heat capacity of the nitrogen gas kilojoules per mole per degree Celsius is given here in the slides here see how this a b c are they are this a b c and d value for this specific heat capacity at constant pressure. So, accordingly you can say that this a b c and d coefficients would be varying with other gas even other materials also. So, those you can find it out from the textbook at it is given in the appendix.

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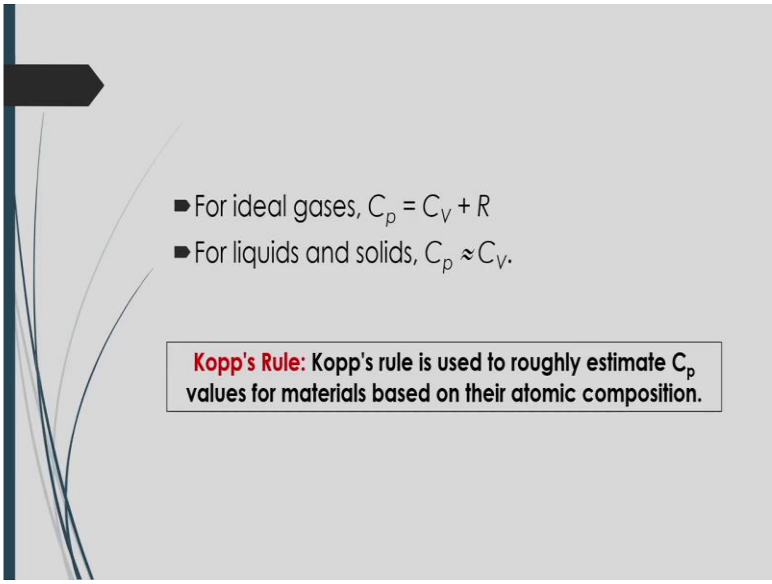

- For ideal gases, $C_p = C_V + R$
- For liquids and solids, $C_p \approx C_V$.

Kopp's Rule: Kopp's rule is used to roughly estimate C_p values for materials based on their atomic composition.

Now, for ideal gases, you will see there will be a certain relationship between these you know specific heat capacity at constant pressure and a specific capacity at constant volume. So, this relationship here as expressed as you know, a CP will be equal to CV plus R where R is called you know universal gas constant. For liquids and solids the CP will almost will be equal to CV according to Kopp’s rule, this CP can be estimated for a particular materials based on their atomic composition.

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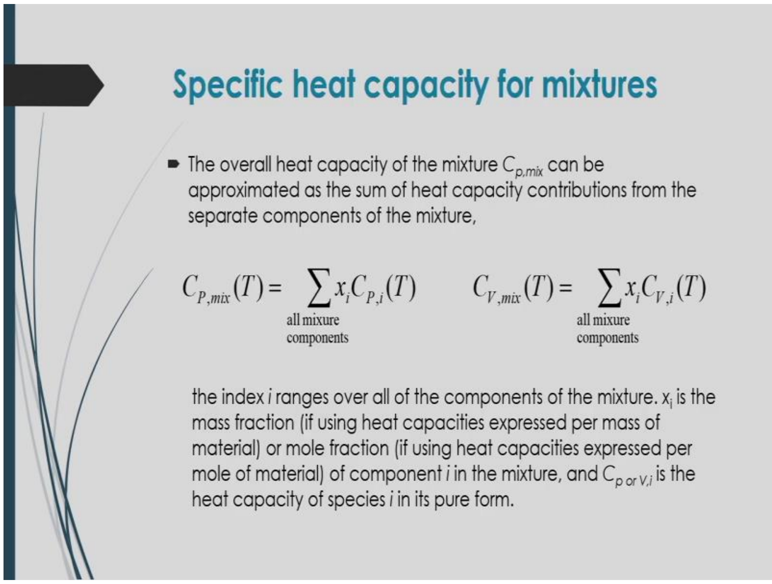

Specific heat capacity for mixtures

- The overall heat capacity of the mixture $C_{p,mix}$ can be approximated as the sum of heat capacity contributions from the separate components of the mixture,

$$C_{P,mix}(T) = \sum_{\substack{\text{all mixure}\\ \text{components}}} x_i C_{P,i}(T) \qquad C_{V,mix}(T) = \sum_{\substack{\text{all mixure}\\ \text{components}}} x_i C_{V,i}(T)$$

the index *i* ranges over all of the components of the mixture. x_i is the mass fraction (if using heat capacities expressed per mass of material) or mole fraction (if using heat capacities expressed per mole of material) of component *i* in the mixture, and $C_{p\ or\ V,i}$ is the heat capacity of species *i* in its pure form.

Now, how you can get you know that specific heat capacity for a mixture will see for any chemical engineering operation you will see there are several components will be you know mixed or it is actually processing to have certain you know product. In that case, you have to find out what should be the specific capacity of that mixture. So, the overall heat capacity in that case you have to define since the overall this capacity will be changing from its individual components.

And since there is a mixture of different components and it will have different units specific heat capacity, but you cannot directly add those you know that specific capacity of all components to air it depends on also mole fraction of all those components in the mixture. So, overall specific heat capacity can be you know defined as that summation of the specific heat capacity of that pure material into each you know mole fraction in that mixture.

So, it can be retained mathematically by this equation as given in the slide here then CP is at particular temperature that will be called the summation of x I into C pi into T. Here x i is called mole fraction of our component i and C pi is the specific heat capacity at constant pressure of that particular component. Similarly, you can express that you know a specific heat capacity at constant volume for the mixture and this overall heat capacity can be you know expressed again by this you know equation as you know value of this equation that will be close to summation of x i into C Vi into T.

In this case x i is that mole fraction of that components in the mixture and CV is the specific heat capacity of that particular components at constant volume, your index i ranges over all, you know, over all of that components of the mixture and excited is the mass production or it may be mole fractions also according to your calculation.

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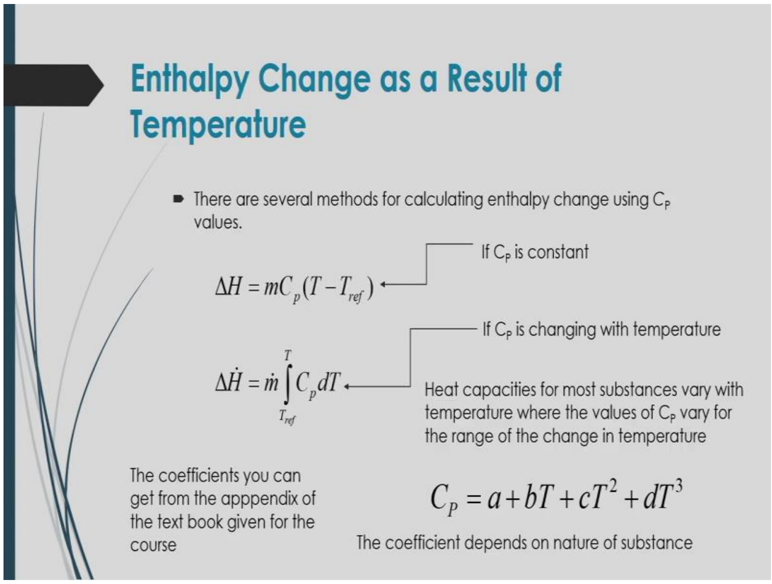

Enthalpy Change as a Result of Temperature

- There are several methods for calculating enthalpy change using C_P values.

$$\Delta H = mC_p(T - T_{ref})$$

If C_P is constant

$$\Delta \dot{H} = \dot{m}\int_{T_{ref}}^{T} C_p \, dT$$

If C_P is changing with temperature

Heat capacities for most substances vary with temperature where the values of C_P vary for the range of the change in temperature

The coefficients you can get from the apppendix of the text book given for the course

$$C_P = a + bT + cT^2 + dT^3$$

The coefficient depends on nature of substance

Now, in enthalpy change as a result of temperature, how it can be actually calculated. Whenever temperature will be changes, then how enthalpy will also be changed and how it can be calculated basically, there are several methods, you can you know, calculate this enthalpy based on who is you can say that if you know that a specific heat capacity of a particular material, then this enthalpy change can be calculated based on that temperature difference from the reference temperature by this equation here given in this slide.

Here delta H will be equal to m into CP into T minus T difference here, suppose the temperature is increasing prom t reference to that you know, a final temperature of t and if you know the material property of its specific heat capacity at constant pressure and also want to be the mole or mass of that materials then you can easily calculate enthalpy change based on this temperature change from its reference temperature and this you can express these in you know, in integral form also based on this integral form we can write here delta H dot that will be equal to m dot integration of CP dT.

Here in this case, since CP is a function of temperature, so, within a certain range of temperature, what would be the enthalpy change you can directly get after him you know integration of that you know function of specific heat capacity at constant temperature with temperature and also have to multiply it with the amount of that material there. So, by this equation you can easily then calculate for with enthalpy change, if that CPU will be changing with temperature.

Now, you know that that CP capacity is the most substances period that temperature where the values of CP vary for the range of change in that temperature. So, this functionality of that CP can be expressed by this you know polynomial equation of function T.

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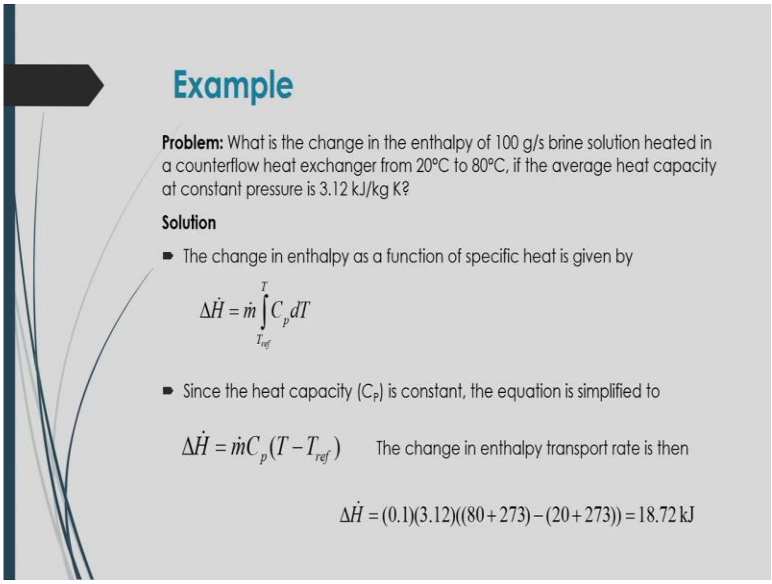

Example

Problem: What is the change in the enthalpy of 100 g/s brine solution heated in a counterflow heat exchanger from 20°C to 80°C, if the average heat capacity at constant pressure is 3.12 kJ/kg K?

Solution

- The change in enthalpy as a function of specific heat is given by

$$\Delta \dot{H} = \dot{m} \int_{T_{ref}}^{T} C_p \, dT$$

- Since the heat capacity (C_P) is constant, the equation is simplified to

$$\Delta \dot{H} = \dot{m} C_p (T - T_{ref})$$

The change in enthalpy transport rate is then

$$\Delta \dot{H} = (0.1)(3.12)((80+273)-(20+273)) = 18.72 \text{ kJ}$$

Let us do an example for this you need to calculate what is the change in enthalpy of 100 gram per second brine solution heated in a counter flow heat exchanger form 20 degrees Celsius to 80 degree Celsius? If the average heat capacity at constant pressure is 3.12 kilojoule per kg. So, in this case you have to fast calculate the temperature change there in absolute you know temperature and also you have to first calculate cash flow rate there.

And then what is the you know that specific heat capacity there, if this is specific heat capacity is constant over a range of that temperature that you can directly you know, use that you know specific heat capacity of that constant value. Otherwise, you have to use that to you know a functionality of specific capacity which is you know, given earlier as like this CP is equal to a plus b T plus c T squared plus d T cube and after substitution of that CP value within a range of that temperature up here it is given 20 degrees Celsius to 80 degrees Celsius.

Then, you can get this you know that enthalpy change at the rate of you know 18.72 kilojoules per second. So, in this way, you can actually calculate how this enthalpy change will be there, if the specific heat capacity will be changing within a certain range of temperature.

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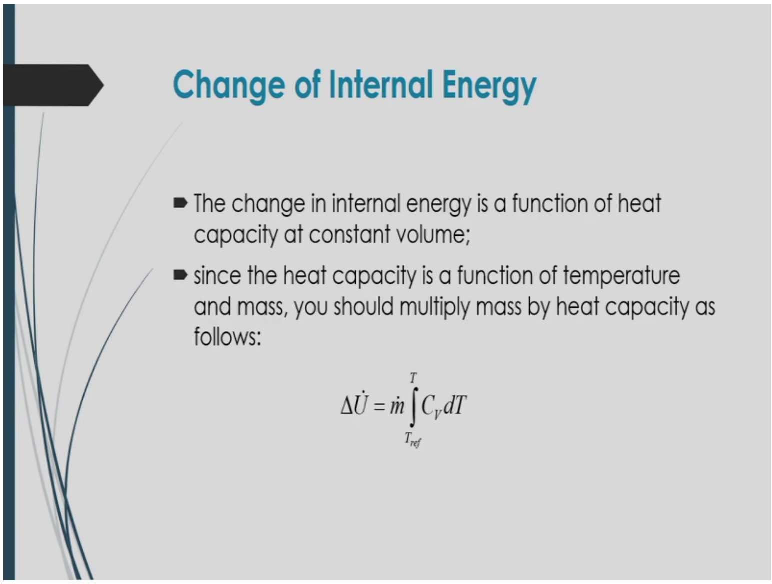

Change of Internal Energy

- The change in internal energy is a function of heat capacity at constant volume;
- since the heat capacity is a function of temperature and mass, you should multiply mass by heat capacity as follows:

$$\Delta \dot{U} = \dot{m} \int_{T_{ref}}^{T} C_V dT$$

Also, according to that second law of thermodynamics, you can see that there will be a change of internal energy, if you supply some heat energy into the system. In that case, the change in internal energy again it will be a function of you know heat capacity at constant volume and that heat capacity again will be a function of temperature there. So, according to that, you should multiply the mass by the heat capacity as follows by this equation to get that internal energy change.

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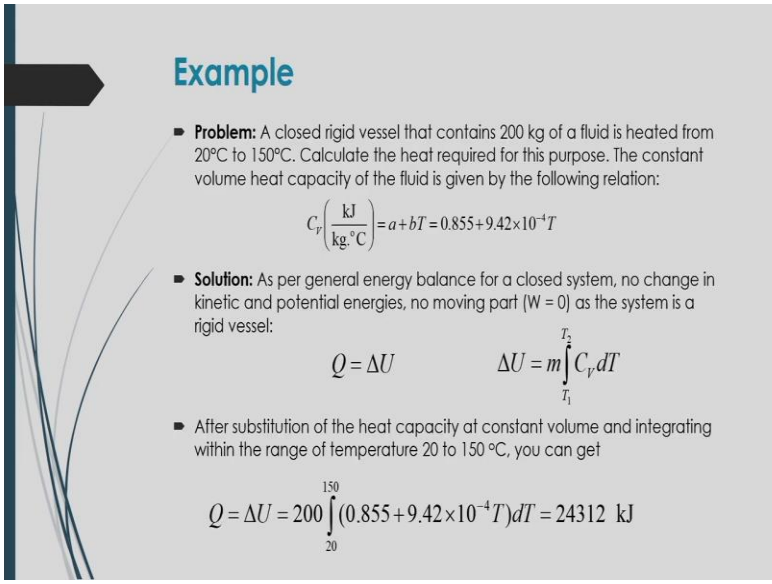

Example

- **Problem:** A closed rigid vessel that contains 200 kg of a fluid is heated from 20°C to 150°C. Calculate the heat required for this purpose. The constant volume heat capacity of the fluid is given by the following relation:

$$C_V\left(\frac{\text{kJ}}{\text{kg.}^\circ\text{C}}\right)=a+bT=0.855+9.42\times10^{-4}T$$

- **Solution:** As per general energy balance for a closed system, no change in kinetic and potential energies, no moving part (W = 0) as the system is a rigid vessel:

$$Q=\Delta U \qquad \Delta U=m\int_{T_1}^{T_2}C_V\,dT$$

- After substitution of the heat capacity at constant volume and integrating within the range of temperature 20 to 150 °C, you can get

$$Q=\Delta U=200\int_{20}^{150}(0.855+9.42\times10^{-4}T)dT=24312\ \text{kJ}$$

Now, let us do an example for this internal energy change also, in this case, if a closed rigid vessel that contains 200 kg of fluid is what is heated from 20 degrees Celsius to 150 degree Celsius. In this case you have to calculate the heat required for this purpose, the constant volume heat capacity of the fluid is given by the following relation here for that particular material as for general energy balanced for closed system in this case, there is no change in kinetic energy, there is no change in potential energy also, there is no moving part there.

So, in that case you can say that there will be no shaft work done on the system. And as the system is received vessel we can say that mass is constant there. So, according to that, we can write this you know, an energy balance equation as Q will be equal to delta U are this delta, U will be calculated based on this equation here, according to that, you know, a specific heat capacity change with respect to temperature.

So, after substitution of the heat capacity at constant volume and integrating within the range of temperature of 20 degree 250 degrees Celsius, you can get this internal energy change as 24312 kilojoule.

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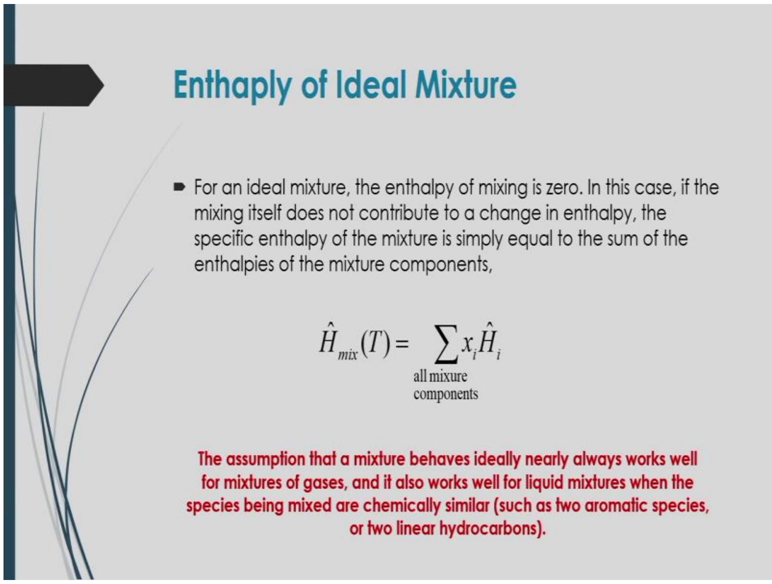

Enthaply of Ideal Mixture

- For an ideal mixture, the enthalpy of mixing is zero. In this case, if the mixing itself does not contribute to a change in enthalpy, the specific enthalpy of the mixture is simply equal to the sum of the enthalpies of the mixture components,

$$\hat{H}_{mix}(T) = \sum_{\substack{\text{all mixure}\\ \text{components}}} x_i \hat{H}_i$$

The assumption that a mixture behaves ideally nearly always works well for mixtures of gases, and it also works well for liquid mixtures when the species being mixed are chemically similar (such as two aromatic species, or two linear hydrocarbons).

Now, how to calculate the enthalpy of ideal mixture, you have to remember that, for an ideal mixture, the enthalpy of mixing will be zero. In this case, if the mixing itself does not contribute to a change in enthalpy. The specific enthalpy of the mixture is simply equal to the sum of the enthalpy of the mixture components. But the condition is that if the mixing itself does not contribute to a change in enthalpy, so, we can represent this mixture enthalpy as H mix t that to be summation of x i to H i hat were x i is the mole or mass fractions of that components in the mixture and x i is the enthalpy that is specific enthalpy of the particular component side.

In this case the assumption that a mixture behaves ideally nearly always works well for mixtures of gases and it also works well for liquid mixtures when the species are being mixed or chemical is similar sauces to aromatic species or to lead your hydrocarbons.

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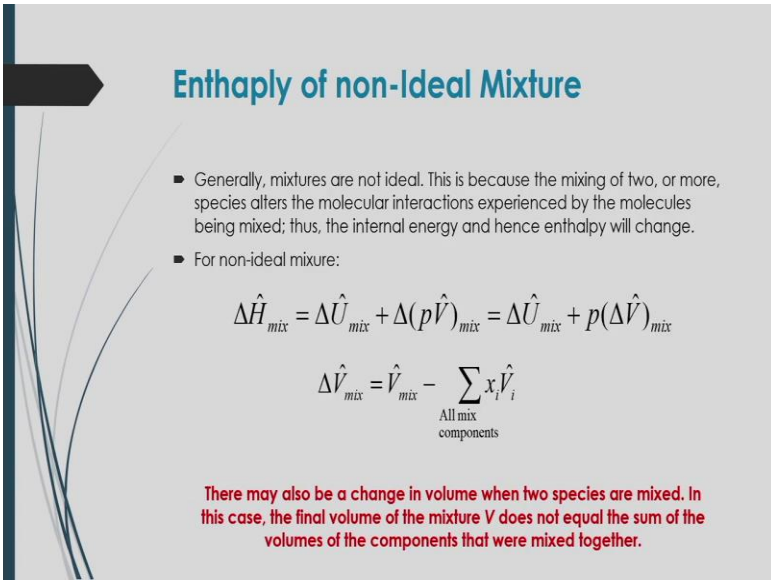

Enthaply of non-Ideal Mixture

- Generally, mixtures are not ideal. This is because the mixing of two, or more, species alters the molecular interactions experienced by the molecules being mixed; thus, the internal energy and hence enthalpy will change.
- For non-ideal mixure:

$$\Delta\hat{H}_{mix} = \Delta\hat{U}_{mix} + \Delta(p\hat{V})_{mix} = \Delta\hat{U}_{mix} + p(\Delta\hat{V})_{mix}$$

$$\Delta\hat{V}_{mix} = \hat{V}_{mix} - \sum_{\substack{\text{All mix}\\ \text{components}}} x_i\hat{V}_i$$

There may also be a change in volume when two species are mixed. In this case, the final volume of the mixture V does not equal the sum of the volumes of the components that were mixed together.

Now enthalpy of non-ideal mixture also to be you know, assist their because mixtures are not ideal anywhere in real application. This is because of the mixing of two or more species alters the molecularity interactions which is experienced by the molecules being mixed to their does the internal energy and hence you can say that there will be a change of enthalpy and for non-ideal mixture up that enthalpy change for that mixture can be repeated at specific enthalpy change of that mixture.

As you know that he specific internal energy of the mixture that changed plus you know, how that flow work or flow energy can be changed for that mixture they are so, we can expressed by this equation that is given in the slides. And in this case, very interesting that the change of volume of this mixture will be you know different from that, you know summation of that volume change of individual components based on each more factions.

So, in this case delta V mix that will because to be V mix minus summation of x i to V i here. So, it is important to do that, that how that volume of that mixture will be changed that especially the volume of that mixture will be changed if there is a change of individual you know specific volume of that components will be changed and in that case, what would the total mixture volume that is specific mixture volume that you have to subtract those you know summation of, you know, specific you know, volume of that components there.

In this regard you have to remember also that there may also be a change in volume when 2 species are mixed. In this case, the final volume of mixture B does not equal to the sum of the volume of the components that are mixed together. So, this is very important to note here.

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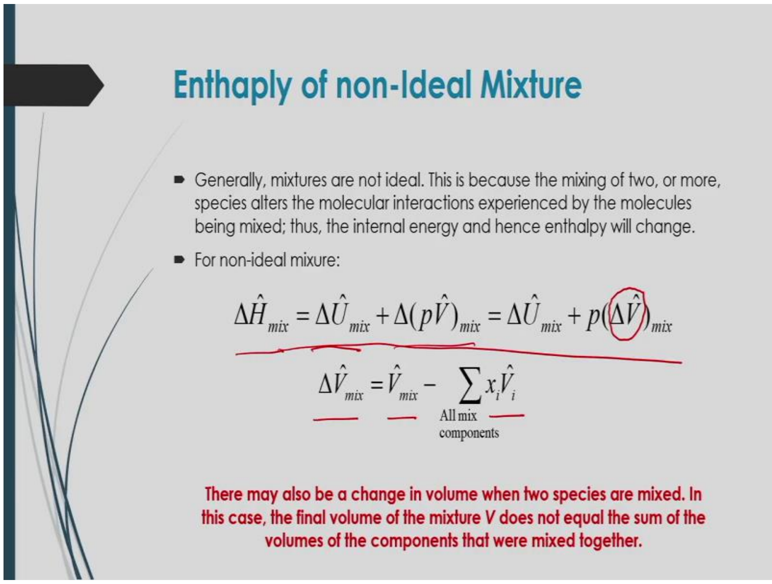

Enthaply of non-Ideal Mixture

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- For non-ideal mixure:

$$\Delta\hat{H}_{mix} = \Delta\hat{U}_{mix} + \Delta(p\hat{V})_{mix} = \Delta\hat{U}_{mix} + p(\Delta\hat{V})_{mix}$$

$$\Delta\hat{V}_{mix} = \hat{V}_{mix} - \sum_{\substack{\text{All mix}\\ \text{components}}} x_i\hat{V}_i$$

There may also be a change in volume when two species are mixed. In this case, the final volume of the mixture V does not equal the sum of the volumes of the components that were mixed together.

Let us do an example here, let us see that 1000 kilo moles per hour of liquid mixture of 70 moles percent acetone and 30 moles percent benzene is heated from 10 degrees Celsius to 50 degree Celsius in a shell and tube heat exchanger using a steam as the heating medium in this case you have to calculate the changes in a specific enthalpy of acetone and benzene mixture in this case is the mixture contains 70% acetone and 30% benzene.

You have to first find out what will be the most of that acetone and benzene since total amount is you know, given to you as you know, 1000 moles kilomoles. So, in that case, the moles of acetone will be equal to 700 kilomole whereas, moles of benzene will be equal to 300 kilomole the change of mixture specific enthalpy can be written as here in the slides. So, in this case if we substitute that more factions of individual components.

And enthalpy a specific enthalpy change of individual components we can get that you know, total you know change of mixture specific enthalpy their so can be written as here enthalpy specific enthalpy change of mixture will be equal to 0.7 delta H you know acetone hat and 0.3

into delta benzene hat that can be represented by this you know, equation here integration of you know CP mix into dt within a range of 10 degrees Celsius to the 50 degree Celsius temperature.

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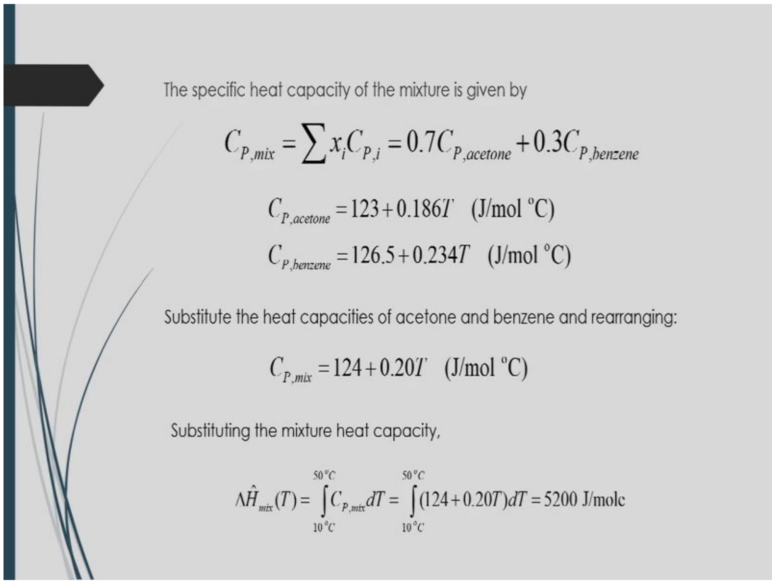

The specific heat capacity of the mixture is given by

$$C_{P,mix} = \sum x_i C_{P,i} = 0.7C_{P,acetone} + 0.3C_{P,benzene}$$

$$C_{P,acetone} = 123 + 0.186T \quad (\text{J/mol °C})$$

$$C_{P,benzene} = 126.5 + 0.234T \quad (\text{J/mol °C})$$

Substitute the heat capacities of acetone and benzene and rearranging:

$$C_{P,mix} = 124 + 0.20T \quad (\text{J/mol °C})$$

Substituting the mixture heat capacity,

$$\Delta\hat{H}_{mix}(T) = \int_{10°C}^{50°C} C_{P,mix}\,dT = \int_{10°C}^{50°C} (124 + 0.20T)\,dT = 5200 \text{ J/mole}$$

Now, you have to then calculate the Cp mix, he has specific heat capacity of the mixture then given by this equation here, and then Cp acetone can be calculated based on this equation and Cp benzene can be calculated based on this equation. And then after substitution of the heat capacity of acetone and benzene, and after rearranging we can get the Cp mix will be equal to this and then substitution of this Cp mix in that integral form.

And after integration and substitution of this, you know, limit of these 10 to 50 degrees Celsius and finally, you can get this 5200 per mole. So, this way we can calculate what should be the specific enthalpy change of the mixture.

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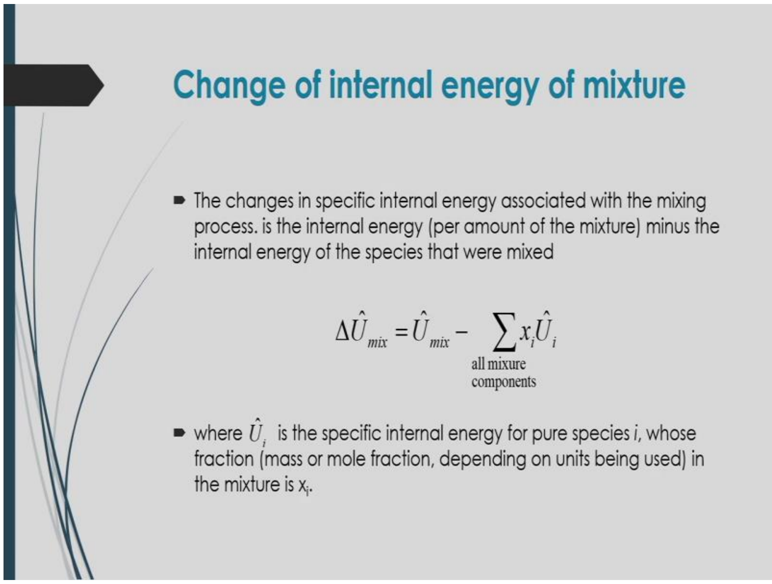

Change of internal energy of mixture

- The changes in specific internal energy associated with the mixing process. is the internal energy (per amount of the mixture) minus the internal energy of the species that were mixed

$$\Delta \hat{U}_{mix} = \hat{U}_{mix} - \sum_{\substack{\text{all mixure}\\ \text{components}}} x_i \hat{U}_i$$

- where $\hat{U}_i$ is the specific internal energy for pure species *i*, whose fraction (mass or mole fraction, depending on units being used) in the mixture is x_i.

Similarly, we can calculate the change of internal energy of the mixture in this case the changes in a specific internal energy associated that mixing processes, which is the internal energy power, you know, amount of mixture that will remind us the internal energy of the species that are mixed there so, this way you can calculate here given as equation the slides in this case, U i hat is the specific internal energy popular species whose fractions are given as you know x i. So, from this equation you can easily calculate the internal energy change of the mixture.

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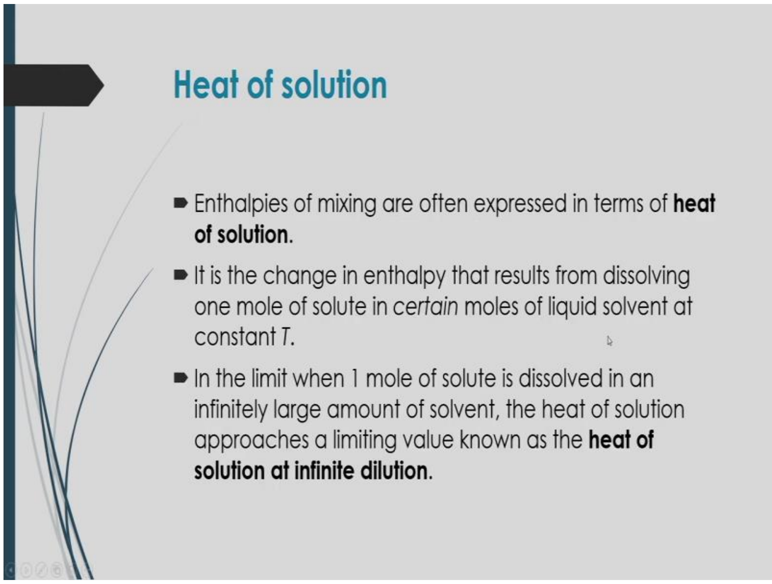

Heat of solution

- Enthalpies of mixing are often expressed in terms of **heat of solution.**
- It is the change in enthalpy that results from dissolving one mole of solute in *certain* moles of liquid solvent at constant *T*.
- In the limit when 1 mole of solute is dissolved in an infinitely large amount of solvent, the heat of solution approaches a limiting value known as the **heat of solution at infinite dilution.**

Similarly, you can express that you know how heat will be changing a solution based on that you know enthalpy calculation that is called as a heat of solution or enthalpy of the solution. So, enthalpies of mixing are often expressed in terms of that heat of solution, it is the change in enthalpy that results from dissolving one mole of solute inserted moles of liquid solvent at constant temperature. Now, in this case when one mole of solute is dissolving and infinitely, large amount of solvent in the heat of solution will be approaching to a limiting value, which is known as heat of solution at infinite dilution.

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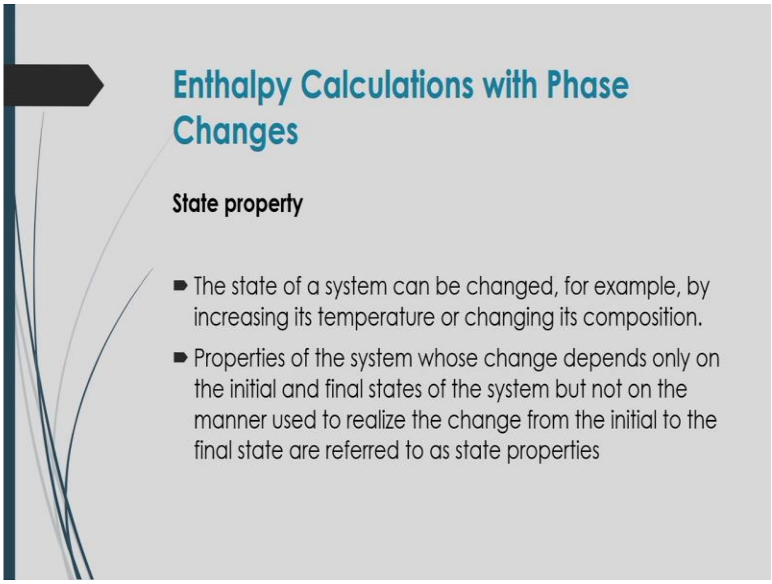

Enthalpy Calculations with Phase Changes

State property

- The state of a system can be changed, for example, by increasing its temperature or changing its composition.
- Properties of the system whose change depends only on the initial and final states of the system but not on the manner used to realize the change from the initial to the final state are referred to as state properties

You also have to sometimes calculate the enthalpy change when you but there will be a change of state like you know that suppose liquid water is you know are becoming into paper. So, in that case what will be the you know change of you know enthalpy when exchanges it is you know phase from liquid to paper or sometimes solid is becoming you know, liquid, then how the change of enthalpy will be there from you know it is a phase change from solid to liquid.

Similarly, from gases to liquid whenever it will be changing how that enthalpy will be changed that you have to calculate. So, in this case you have to remember that the state of your system can be changed, for example, by increasing its temperature or changing its composition properties of the system will change depends on the on the initial and final states of the system but not on the manner used to realize the change from the initial to the final state as referred to as a state properties.

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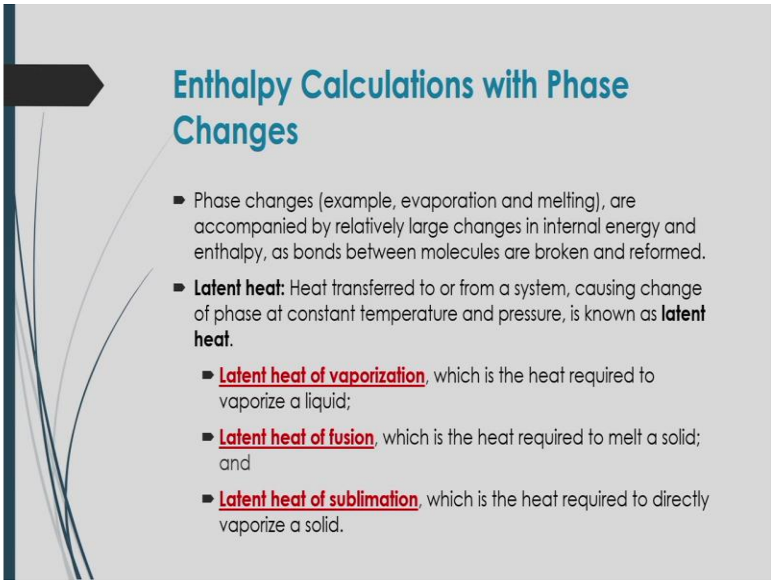

Enthalpy Calculations with Phase Changes

- Phase changes (example, evaporation and melting), are accompanied by relatively large changes in internal energy and enthalpy, as bonds between molecules are broken and reformed.
- **Latent heat:** Heat transferred to or from a system, causing change of phase at constant temperature and pressure, is known as **latent heat**.
  - **Latent heat of vaporization**, which is the heat required to vaporize a liquid;
  - **Latent heat of fusion**, which is the heat required to melt a solid; and
  - **Latent heat of sublimation**, which is the heat required to directly vaporize a solid.

In this case when a bar you know, phase will be changing from one phase to that another phase the respective enthalpy you know, can be you know, regarded as like latent heat here like fit changes like you know evaporation and melting are accompanied by relatively large changes in internal energy and enthalpy and in that case you have to you know referred what will be the change of that heat or change of that internal energy and that heat you know change and which will give you that result of that enthalpy change at a constant temperature for changing it is you know phase from one to another.

So, that you know heat of change of that phase is called Latent heat there are different types of Latent heat of vaporization. Which is actually required to vaporize the liquid letting it to a fusion which is required to melt a solid letting heat of sublimation which is required to you know directly vaporize a solid. So, this latent heat of vaporization, latent heat of fusion, latent heat of sublimation, this is basically an enthalpy change temperature change at a constant temperature when there is a change of you know phase from its original to another.

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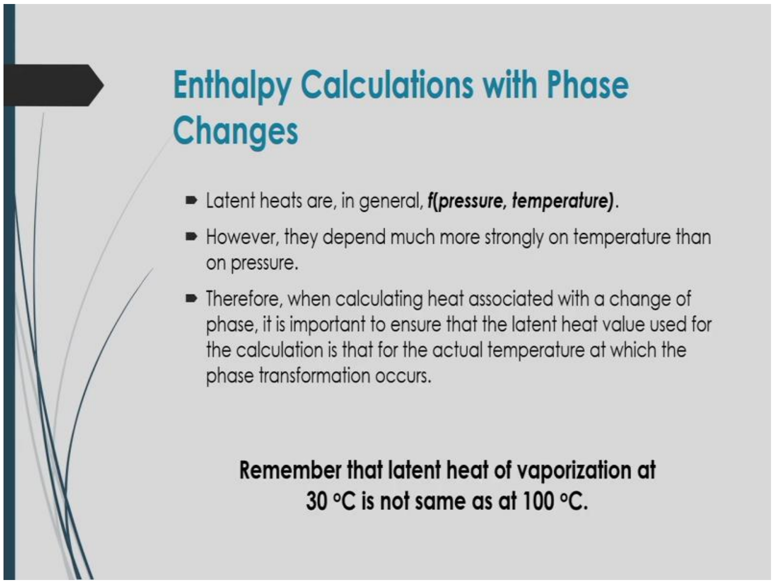

Enthalpy Calculations with Phase Changes

- Latent heats are, in general, ***f(pressure, temperature)***.
- However, they depend much more strongly on temperature than on pressure.
- Therefore, when calculating heat associated with a change of phase, it is important to ensure that the latent heat value used for the calculation is that for the actual temperature at which the phase transformation occurs.

Remember that latent heat of vaporization at 30 °C is not same as at 100 °C.

Now, latent heats are in general a function of pressure and temperature, however, then depend much more strongly on temperature, then on pressure. Therefore, we can say that, when calculating heat associated with the change of phase it is important to ensure that the latent heat value used for that calculation with that it is that for that actual temperature or not at which this phase transformation occurs.

So, in this case, remember that latent heat of vaporization cannot be the same as what it is in 30 degrees centigrade or some 30 degrees Celsius which is in which is at 100 degrees Celsius. So, you can see that the latent heat of vaporization at 30 degrees Celsius is not same as that 100 degree Celsius.

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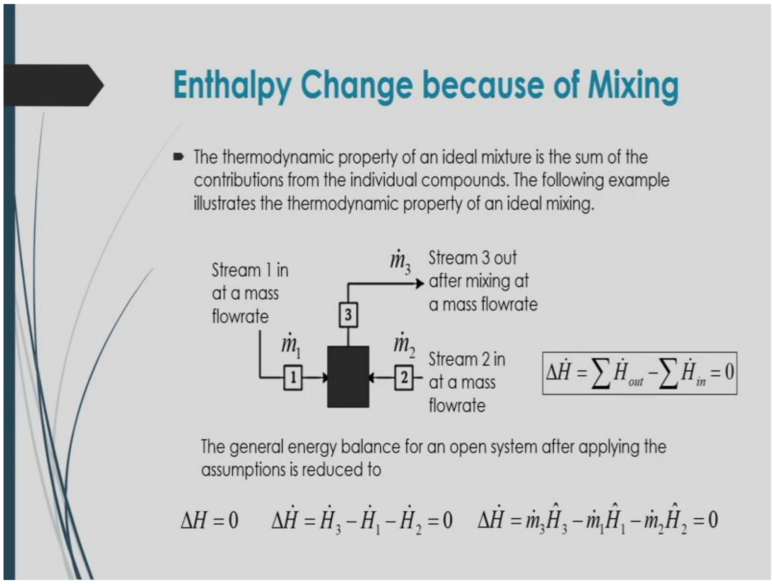

Enthalpy Change because of Mixing

- The thermodynamic property of an ideal mixture is the sum of the contributions from the individual compounds. The following example illustrates the thermodynamic property of an ideal mixing.

$$\boxed{\Delta\dot{H} = \sum \dot{H}_{out} - \sum \dot{H}_{in} = 0}$$

The general energy balance for an open system after applying the assumptions is reduced to

$$\Delta H = 0 \qquad \Delta\dot{H} = \dot{H}_3 - \dot{H}_1 - \dot{H}_2 = 0 \qquad \Delta\dot{H} = \dot{m}_3\hat{H}_3 - \dot{m}_1\hat{H}_1 - \dot{m}_2\hat{H}_2 = 0$$

Now, sometimes you will see that in the particular chemical engineering process, there will be a process unit and that process unit will have several input and several output streams. Now, in that case in a particular streams there will be mixture of components and also you can that that you know components may be the inlet and that components may be in the outlet streams also, sometimes if there is no reaction on the physical operations will be there in the inlet stream you know that components will be there after a physical operation, there may be you know that some unwanted or you know that unused you know components are also will be in the outlet streams.

So, there will be a mixture in the inlet outlet streams of that several components. So, in that case that this you know how that enthalpy change will be there, based on that you know different mixing in different streams their let us see 1 process unit given here they are 3 you know that streams 123 here for has mentioned in the slides in stream 1 here in a mass flowrate is given mass is coming and then in the outlet streams that the mass 3 and mass 3 are coming out there.

So, in this case, you will see that there will be several you know components will be coming in and coming out from this inlet and outlet streams. So, according to that, you have to you know calculate that enthalpy change because of this you know, final stream and this you know inlet streams enthalpy So, how to be the enthalpy change in the live streams first you have to calculate and what will be the change of enthalpies in the outlet streams, it may be in that mixture of components in heat streams also.

So, the enthalpy change because of this you know, change of enthalpy in different you know inlet and outlet streams, we can say that this enthalpy overall enthalpy change it because to zero, so, we can have this equation as like this summation of you know enthalpy in outlet the streams minus summation of enthalpy in the inlet streams, there will be more than one inlet. So, accordingly you have to sum it up that total enthalpy change in the inlet streams. So, the general energy balance for an open system after applying that assumptions is reduced to like this delta H will be equal to 0. So, according you can see that delta is equal to here.

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Further reading......

Text Books:

- R. M. Felder, Ronald W. Rousseau, Lisa G. Bullard, Elementary Principles of Chemical Processes, 4th Ed., John Wiley & Sons, Asia, 2017.
- D. M. Himmelblau, J. B. Riggs, Basic Principles and Calculations in Chemical Engineering, 7/8th Ed., Prentice Hall of India, 2012.

Reference Books:

- N. Chopey, Handbook of Chemical Engineering Calculations, 4th Ed., Mc-Graw Hill, 2012.
- Olaf, K.M. Watson and R. A. R. Hougen, Chemical Process Principles, Part 1: Material and Energy Balances, 2nd Ed., John Wiley & Sons, 2004.

H 3 minus H 1 minus H 2 is H 3 is basically that what is that outlet streams H 1 and H 2 are the inlet streams there so, according to that enthalpy of those streams we can simply write this here delta H that will be equal to H 3 minus H 1 minus H 2 that will be equal to 0 and also you can represent it as you know, this equation here H 3 hat H 1 hat and these H 2 hat are the specific enthalpy at each you know that inlet and outlet streams there.

So, we have learned here some thermodynamic properties like internal energy enthalpy, latent heat of vaporization and also how this you know enthalpy can be calculated, how enthalpy change can be calculated for the mixture components, how enthalpy can be calculated while in a you know, specific process you need having more than 1 inlet and outlet streams, also internal energy how it can be calculated.

And also that enthalpy an internal energy, how it can be calculated from the specific heat capacity, you know, which is a function of temperature all those things. So, I think you understood a little bit about this you know this enthalpy change an internal energy change and how it can be calculated from the energy balance equation, I would suggest you to go to this textbook and reference books for more information about those you know, thermodynamic properties.

And in the next lecture we will try to you know, discuss more about that, you know enthalpy. They are some heat of solution heat of formation in the reactive mode, how that in enthalpy will be changing and also in internal energy, how it will it will be changed that would be, you know, discussed in the next lecture. So, thank you for your kind attention.