Material and Energy Balances

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Module No # 08
Lecture No # 40
Energy Balances Objectives and Procedures

Welcome to today's lecture on energy balances and how to perform them basically we will be looking at the objectives and procedures involved in performing energy balance calculation. In the previous lecture we had looked at mechanical energy balances from this point on we will be focusing more on chemical processes where change in enthalpy and internal energy play a much huge roll compared to kinetic energy and potential energy.

So we will be looking for these types of processors and performing energy balances on them before we start performing these calculations we will have these introductory lecture where we will talk about overall objective and procedures which are involved in calculating in changes in internal energy and enthalpy.

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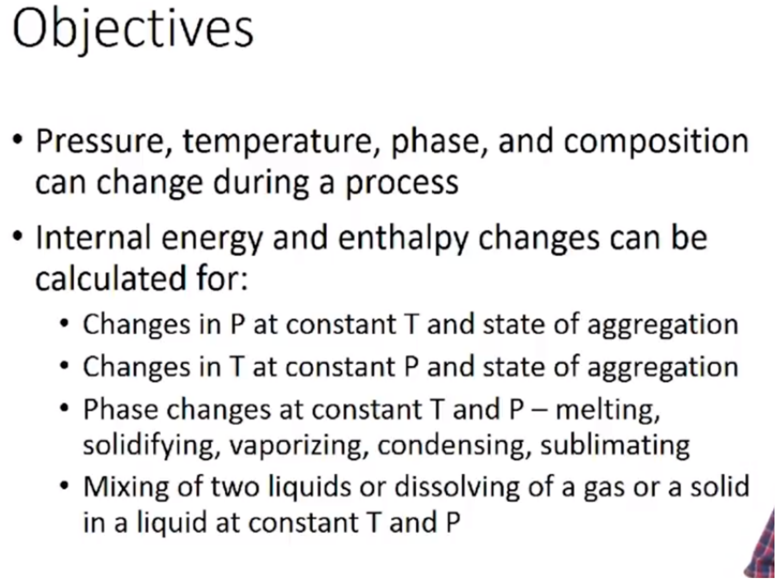

Objectives

- Pressure, temperature, phase, and composition can change during a process
- Internal energy and enthalpy changes can be calculated for:
  - Changes in P at constant T and state of aggregation
  - Changes in T at constant P and state of aggregation
  - Phase changes at constant T and P – melting, solidifying, vaporizing, condensing, sublimating
  - Mixing of two liquids or dissolving of a gas or a solid in a liquid at constant T and P

So what are the objectives of performing energy balance calculations for chemical processors. The chemical processors are the once where you have pressure temperature phase and composition are changing during the process happening. So for this type of a process we might to be calculating internal energy and enthalpy changes so you will be using changes in internal energy for closed system and changes in enthalpy for open system.

So to calculate the changes in internal energy and enthalpy we would not be able to do all things which I have mentioned is changing if everything like temperature pressure and phase are changing we cannot use one simple equation to solve for all these values instead that we can actually do is calculate change in internal energy or enthalpy for the following process where pressure changes at constant temperature and state of aggregation or phase where temperature changes at constant pressure and phase.

Where phase changes at constant temperature and pressure and when there are mixing of two liquids and solving of gas or solid in a liquid at constant temperature and pressure. So these are the types of processes for which we can actually quantify or calculate changes in internal energy or enthalpy. So the process would have to have two of the parameters to be a constant and only one of the parameter needs to changed.

For something like this happen it has to be hypothetical case we was in real scenario's you would not have a step by step procedure were you would go from changing pressure first and then changing temperature usually processors are done in a way that both temperature and pressure changing simultaneously. So in such scenarios how do we actually calculate the internal energy and enthalpy.

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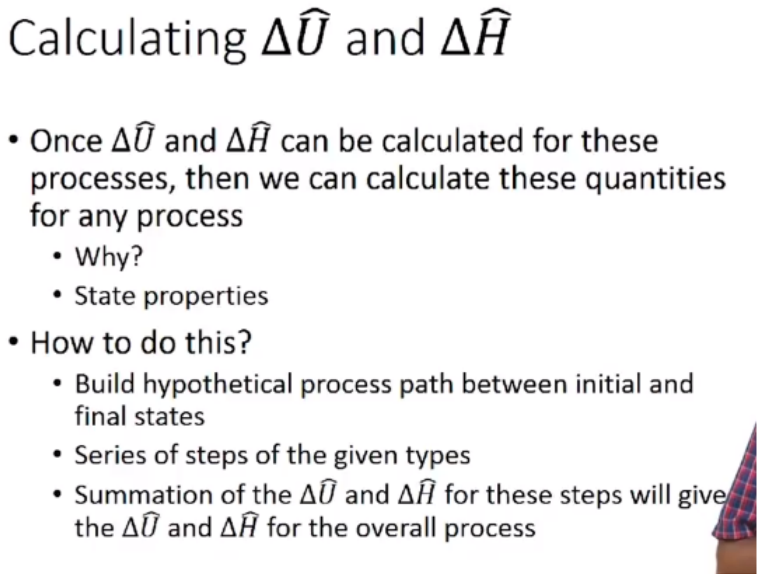

Calculating $\Delta\hat{U}$ and $\Delta\hat{H}$

- Once $\Delta\hat{U}$ and $\Delta\hat{H}$ can be calculated for these processes, then we can calculate these quantities for any process
  - Why?
  - State properties
- How to do this?
  - Build hypothetical process path between initial and final states
  - Series of steps of the given types
  - Summation of the $\Delta\hat{U}$ and $\Delta\hat{H}$ for these steps will give the $\Delta\hat{U}$ and $\Delta\hat{H}$ for the overall process

So we will look at how the procedure for calculating these would be the first step is you can actually understand that these values can be calculated for processors when all process where changing where both temperature and pressure where even phase is changing we can actually calculate the total change in internal energy or enthalpy using the steps which I have given below.

So if you calculate the change in internal energy or enthalpy for these individual states you can actually build a hypothetical process which can actually be brought together to find any process in this step. Why is this possible? Why are we able to do this? It is because of the fact that these two properties are state properties and not path functions.

This means that the change in enthalpy can be calculated for any path and as long as the summation of the path represents the actual path you would not have any problems with the numerical value you have obtained for the change in enthalpy that is beauty of using the state functions and you will be trying to exploit this properties of enthalpy and internal energy to perform calculations which are feasible.

So how do we do this we will be building a hypothetical process path between the initial and final states. We will explain that in greater detail with some example but what we basically do is we create a series of steps which are of the given types where you have only temperature changing at constant pressure and phase or where you have pressure changing at constant temperature and phase and so on.

So each of these steps will follow these rule and we will have a series of step so that the initial condition reaches the final condition through this smaller step the change in enthalpy for these individual steps are calculated or summation of the change in enthalpies for all the steps will give you a total change in enthalpy or total energy for true process which we are looking at.

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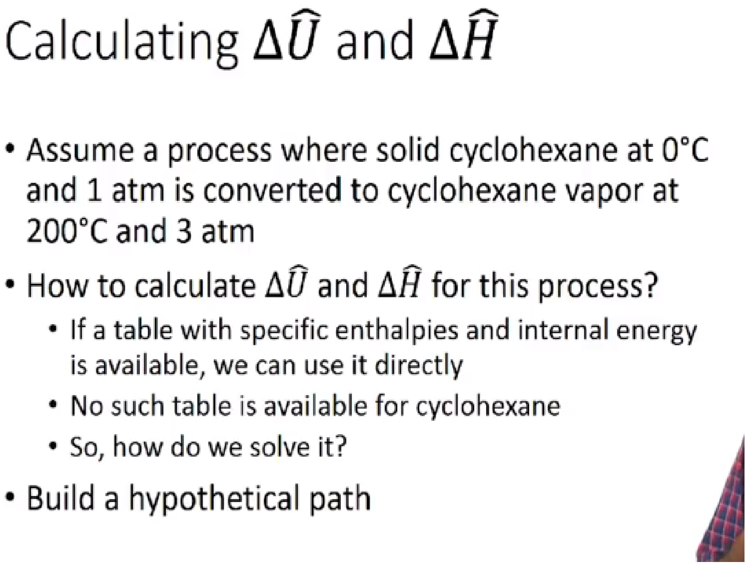

Calculating $\Delta\hat{U}$ and $\Delta\hat{H}$

- Assume a process where solid cyclohexane at 0°C and 1 atm is converted to cyclohexane vapor at 200°C and 3 atm
- How to calculate $\Delta\hat{U}$ and $\Delta\hat{H}$ for this process?
  - If a table with specific enthalpies and internal energy is available, we can use it directly
  - No such table is available for cyclohexane
  - So, how do we solve it?
- Build a hypothetical path

So let us assume this process where solid cyclohexane at 0 degree Celsius at one atmosphere is converted to cyclohexane vapor at 200 degree Celsius and 3 atmosphere. What you see here is all 3 factors are changing your temperature is changing from 0 degree Celsius to 200 degree Celsius pressure is changing from 1 atmosphere to 3 atmosphere phases changing from solid to vapor.

So what you actually have is all three things changing and most probably simultaneously how do you calculate change in internal energy or enthalpy for such a process. If you had a table like a steam table if you had a table for cyclohexane which gives you the internal energies and enthalpies in reference to a reference state you and basically take two conditions identify what they are internal energies or enthalpies are and find the difference and you would able to get the change in internal energy or enthalpy.

However no such table exist for cyclohexane so what do we do to solve it that is where building a hypothetical path comes into play.

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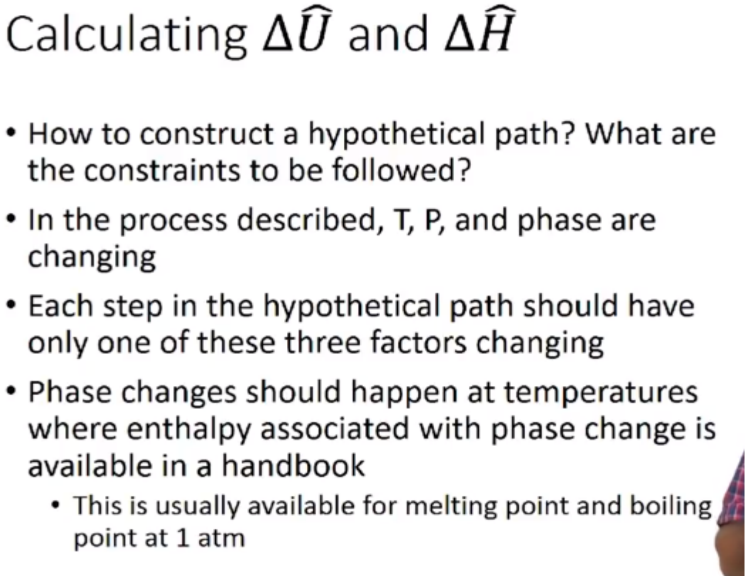

Calculating $\Delta\widehat{U}$ and $\Delta\widehat{H}$

- How to construct a hypothetical path? What are the constraints to be followed?
- In the process described, T, P, and phase are changing
- Each step in the hypothetical path should have only one of these three factors changing
- Phase changes should happen at temperatures where enthalpy associated with phase change is available in a handbook
  - This is usually available for melting point and boiling point at 1 atm

So how do we build this hypothetical path so what are the constraint which need to be followed. As I already mentioned we would have to be able to calculate internal energy changes in enthalpy changes only when one of the three factors changing temperature, pressure or phase. So we would have to make sure that each of the step only one these three changes and other two remain a constant.

So what we would have is a process where each step and hypothetical path would have only temperature or pressure or phase changing not more than 1. So the phase changes would also have to happen at temperatures where enthalpy associated with phase changes available for us from some table. This is usually available for melting point and boiling point at 1 atmosphere.

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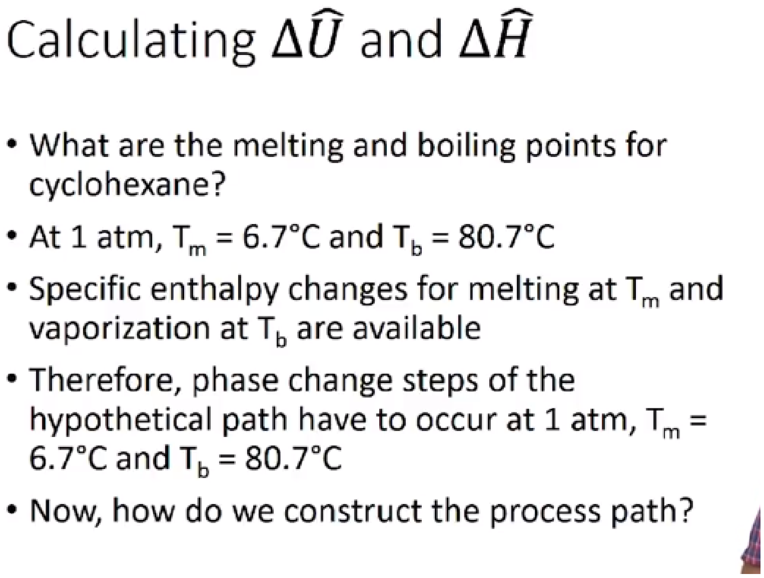

Calculating $\Delta\widehat{U}$ and $\Delta\widehat{H}$

- What are the melting and boiling points for cyclohexane?
- At 1 atm, T_m = 6.7°C and T_b = 80.7°C
- Specific enthalpy changes for melting at T_m and vaporization at T_b are available
- Therefore, phase change steps of the hypothetical path have to occur at 1 atm, T_m = 6.7°C and T_b = 80.7°C
- Now, how do we construct the process path?

So the phase change itself would have to happen at the melting point and boiling point of the cyclohexane. So first thing to identify then is what are the melting points and boiling points of cyclohexane at one atmosphere the melting point for cyclohexane is 6.7 degree Celsius and boiling point is 8.7 degree Celsius. Now that we know these two values we should verify if specific enthalpy changes for the process of melting and vaporization are available in some handbooks.

Usually these are available in handbooks given for data so let us suggest Perry's handbook or even one of the prescribed text books as appendixes which have these data. So using these enthalpy values we will be able to directly plug them in the for the hypothetical path. So the phase change steps would have to happen at one atmosphere and melting point of 6.7 and boiling point of 3.7.

This means that when cyclohexane solid is getting converted to cyclohexane liquid that has to happen at one atmosphere at 6.7 degree Celsius and cyclohexane liquid to cyclohexane vapor has to happen at 1 atmosphere and 80.7 degree Celsius so the hypothetical path that you build would have to have these two steps. Now let us see how we can construct this hypo ethical path.

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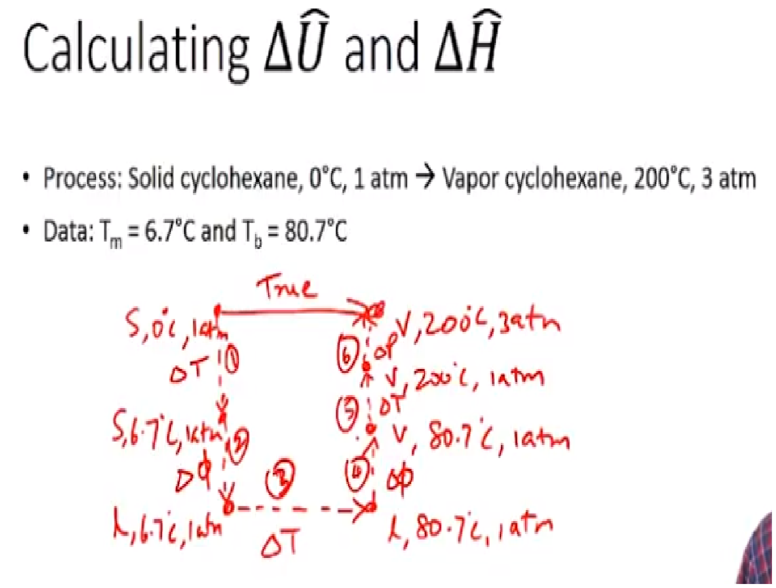

Calculating $\Delta\hat{U}$ and $\Delta\hat{H}$

- Process: Solid cyclohexane, 0°C, 1 atm → Vapor cyclohexane, 200°C, 3 atm
- Data: $T_m = 6.7°C$ and $T_b = 80.7°C$

So we have been told that the overall process is solid cyclohexane at 0 degree Celsius one atmosphere going to vapor cyclohexane at 200 degree Celsius at 2 atmospheres and we have also been given data that melting point for cyclohexane is 6.7 degree Celsius and boiling point for Cyclohexane is 80.7 degree Celsius.

Using this information let us try to built the hypothetical path so the real true path is this where you go from initial which is solid 0 degree Celsius and one atmosphere from here you go to vapor is that true path. Now we are going to built a hypothetical path so we know that melting point is 6.7 degree Celsius so that change of phase form solid to liquid has to happen at these temperature.

So let us assume that the first step takes this initial phase to solid to 6.7 degree Celsius and one atmosphere. Here in this process what you have here is only delta T only temperature is changing whereas pressure and phase or not changing phases still are solid and pressure is still at atmosphere. So the next step let it be the change in phase so at 6.7 degree Celsius one atmosphere cyclohexane will start to melt.

So you would end up with liquid 6.7 degree Celsius one atmosphere as the next step of the process. So from here so in this process you only had change in phase there is no change temperature or pressure. So from here you can actually heat the process up further heat the system up further to reach liquid at 80.7 degree Celsius at one atmosphere.

So here there is again only delta T which is change in temperature phase is still in solid and sorry it is still a liquid and pressure is still at one atmosphere. So from here we can have change in phase where it goes to vapor at 80.7 degree Celsius at one atmosphere. So this is delta 5 there is only change in phase here temperature and pressure are remaining a constant and from this we can go to the step where it is vapor at 200 degree Celsius and one atmosphere.

So here you have only change in temperature and the vapor is we being heated from 80.7 degree Celsius to 200 degree Celsius and it is at the constant pressure of 1 atmosphere so from here we can reach the final step of the process which is 200 degree Celsius vapor at 3 atmosphere so here only pressure is changing and there is no change in phase or temperature so this is a hypothetical path we have been built.

So the 1 process step which is the true process has been built into step 1 to 3, 4, 5 and 6 so instead of having 1 single path we have 6 steps to describe the overall process with these 6 steps, we can actually calculate the change in enthalpies for each of the step the first step is only change in temperature. So would be able to use internal CPDT the second step is only change in phase the value is directly available from the text books or any hand book the third step is again just change in temperature.

So again you can use integral CPDT the only important thing we should notice for integral CPDT you would have used the CP for cyclohexane solid, and the second integral CPDT for the process step 3 you would be using integral CPDT with CP of liquid as cyclohexane the third step is change in phase which is vaporization of cyclohexane. So you have the heat of vaporization again available from a text book or hand book.

The step after the fifth step is the change in temperature which is heating from 80 degree Celsius to 200 degree Celsius, here you can calculate enthalpy as integral CPDT here you will be using CP of cyclohexane vapor and the last step is change in phase which is sorry change in pressure. The change in pressure is from 1 atmosphere to 3 atmosphere if you were to assume an ideal gas behavior this particular change in pressure would not cause any change in enthalpy or internal energy so that would be 0.

So the summation of enthalpies of each of this steps can actually be brought together to give you the total change in enthalpy for the overall process which has been described. So this process which we followed is called as building a hypothetical path so I will give more tutorial problem and exercise problem which will help you build this hypothetical path this is not the only hypothetical path which you can build.

For the same process you might be able to built different hypothetical path depending on what information is available to you so here I have given you is that the information for enthalpy was available to you is that specific boiling point and melting points and based on this you have built hypothetical path if the data given is different you might be able built a completely hypothetical path and you will be able to arrive at the same answers.

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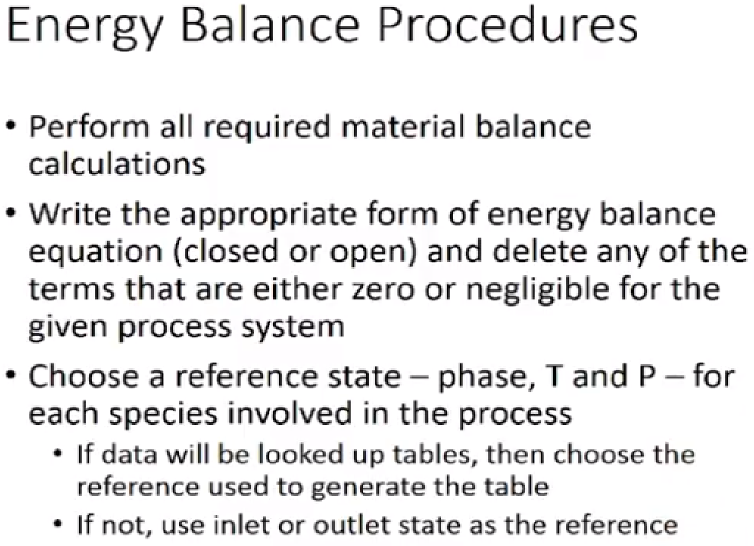

Energy Balance Procedures

- Perform all required material balance calculations
- Write the appropriate form of energy balance equation (closed or open) and delete any of the terms that are either zero or negligible for the given process system
- Choose a reference state – phase, T and P – for each species involved in the process
  - If data will be looked up tables, then choose the reference used to generate the table
  - If not, use inlet or outlet state as the reference

Now that we are familiar with building hypothetical path we will look at overall procedure which needs to be followed for performing any energy balance calculations. So we did something like this when we prepared material balance calculations we looked at overall process. So we will look at overall process and we will try to stick to the process and procedure whenever we perform any energy balance calculation so that we get completely familiarized and it becomes second nature for us to follow this procedure while you perform energy balances.

So this is meticulously prepared so that we can avoid any error so please try to follow the procedures strictly while you perform these calculations in any example or even when you performing these calculations for assignment and practice. Energy balance calculation themselves are lot harder or lot trickier than material balance calculations because for performing energy balances you should need to have completed material balances.

In some cases especially in exams sitting and assignment we hand out you might end up having material balances already solved for you. However in real life scenarios material balances might not solved for it so if you are going to design a plant and you need to understand the energy requirement you first need to complete all the material balances which are associated with it. So that you know how much energy would be required for by the process.

So because of this the first step for any energy balance calculation which you will be doing is to perform all the required material balance calculations so that you have information about all the flow rates if you remember you had the specific enthalpy calculation which I described earlier. So from this specific enthalpy you would have to calculate the total enthalpy changes similarly if you are having the closed system you would have to calculate total internal energy changes.

So this can be done only when the mass flow rate are masses are moles or molar flow rates or known so this means understanding an calculating balances is crucial. So for the first step for any energy balance problem is to perform material balances even if I skip them while performing them energy balances here it is probably because the material balances are not required as they have already been given to us.

In real life that would not be the case having said all these let us go on to the next step. The next step is to identify the type of system which you are working in you need to whether it is a open system or closed system and you need to write down the appropriate form of energy balance either it is open or close system and you would have to delete any 0 term so or negligible term so if you have no change in velocity you would assume critical energy to be 0 if there is no change in position you would assume change in potential energy to be 0.

If there are no moving parts you would assume shaft work to be 0 if the process is adiabatic then you would have Q or heat transfer to be 0. If you have such a sister you would have to make sure every factor is cancelled before you perform for the calculations. You would have to choose something called a reference state while we perform material balances we always used a bases.

So based on basis we performed all the calculations when we perform energy balances it is important to choose a reference state.

Because if you remember we mentioned this in earlier lectures enthalpy and internal energy changes can be measure however we cannot measure the absolute balance. So this means whatever calculations we are performing would have to be in reference to a reference condition so the reference state will be defined as a particular phase, temperature and pressure. You can actually choose difference reference states for different components in the system.

If you have a four component system all four components can actually have four different reference state and you can choose the data reference states based on how you are going to perform a calculations. If data is available from a table then the reference state used in the table might be the most appropriate reference state to use for example if you have steam as one of the components in the process you would be smart to use steam tables rather than perform calculations every single time.

So to use steam tables you would have to use the appropriate reference state which has been used in the steam tables you are using. If you were to use the steam tables from Felder Rousseau you would use water liquid at triple point as the reference state. So if you are not using data from a table then you can use either the inlet condition or outlet conditions. This will you can actually lesson the number of calculations you might have to perform.

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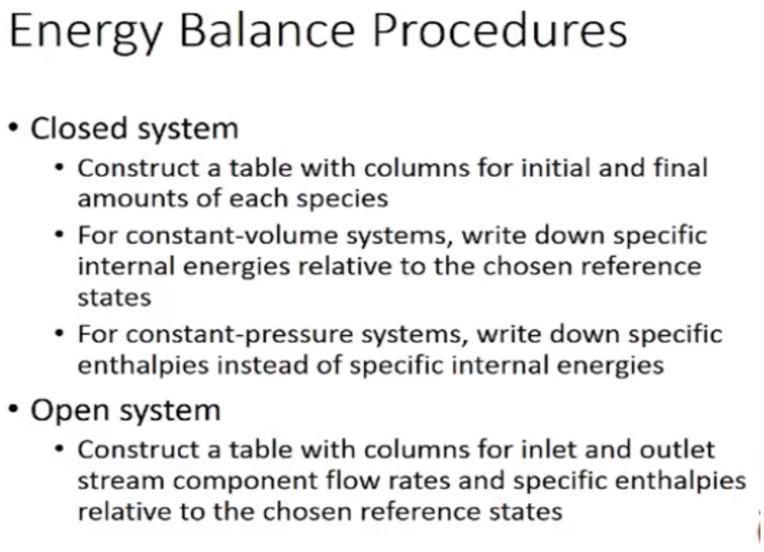

Energy Balance Procedures

- Closed system
  - Construct a table with columns for initial and final amounts of each species
  - For constant-volume systems, write down specific internal energies relative to the chosen reference states
  - For constant-pressure systems, write down specific enthalpies instead of specific internal energies
- Open system
  - Construct a table with columns for inlet and outlet stream component flow rates and specific enthalpies relative to the chosen reference states

Once you have the reference state you start looking at the system which is closed system or an open system. If the system is a closed system you would basically construct a table which has columns for initial and final amounts of each species and for constant volume systems you will be writing down specific internal energy changes relative to the chosen reference state and the for constant pressure system you will be writing own the specific enthalpy changes instead of internal energy changes.

For an open system you will again construct a similar table instead of initial and final condition you will have inlet and outlet conditions and you will be calculating changes in specific enthalpies.

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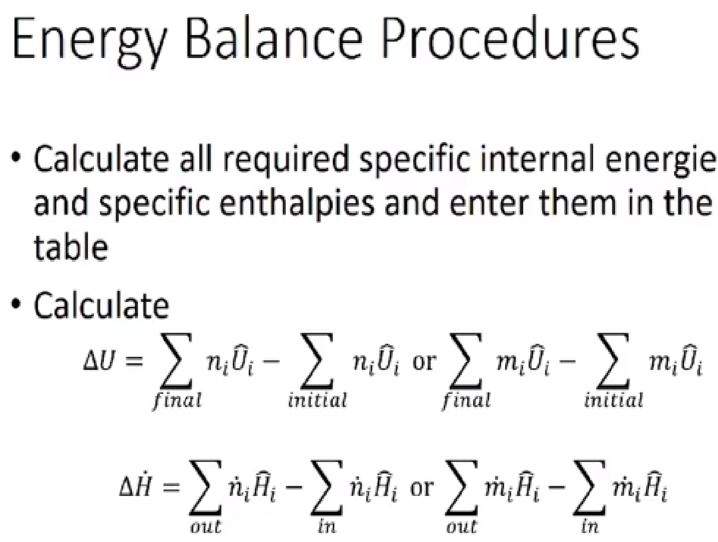

Energy Balance Procedures

- Calculate all required specific internal energies and specific enthalpies and enter them in the table
- Calculate

$$\Delta U = \sum_{final} n_i \hat{U}_i - \sum_{initial} n_i \hat{U}_i \text{ or } \sum_{final} m_i \hat{U}_i - \sum_{initial} m_i \hat{U}_i$$

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

The first important thing which we need to do is this table as to be complete there cannot be any unknown so we need to calculate all the required specific internal energy and specific enthalpies and enter them into this tables with this the table will have the data required for performing energy balance calculations. Once you have this you would have to calculate the total change in internal energy or enthalpy so this would be the formula you would use.

Total change in internal energy would be sigma of internal energy changes associate with individual components of the final competition – the similar thing for initial condition which is sigma final NIUI cap – sigma initial NIUI cap it could also be in terms MIUI cap instead of NIUI cap depending on the units for internal energy which you have calculated.

If the specific internal energy you calculated is joules per mole then you would use number of moles of each component if the units for specific internal energy is sued per kilogram you would use masses instead of moles. Similarly you can calculate the total change in enthalpy as sigma of the outlet stream which would be NI dot HI cap – sigma for the inlet steams which is NI dot HI.

So here your difference which are calculating as between the outlet and inlet instead of final and initial so you might also have to use mass just like how we did for internal energy in case the enthalpy specific enthalpy values are given as kilo joules per kilogram instead of kilo joules per mole. So if it is kilojoules per kilo mole you would use molar flow rates and if it is joules per kilo gram or gram then you use mass flow rate.

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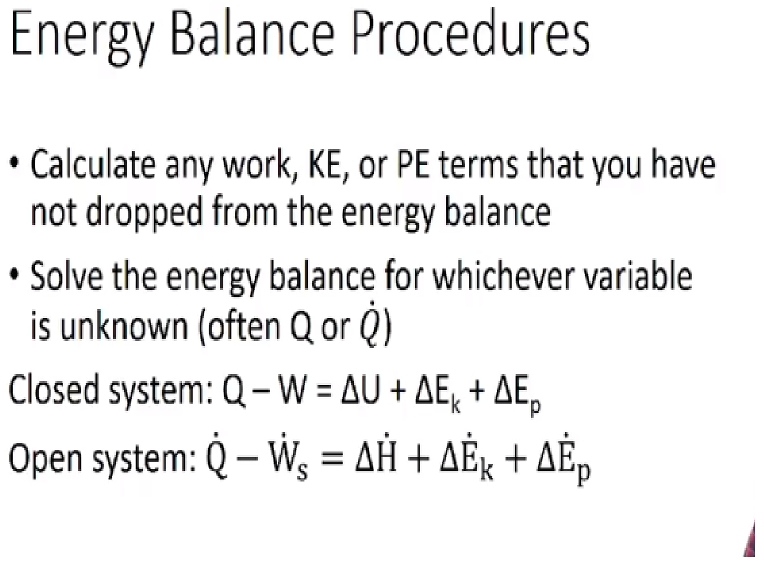

Energy Balance Procedures

- Calculate any work, KE, or PE terms that you have not dropped from the energy balance
- Solve the energy balance for whichever variable is unknown (often Q or $\dot{Q}$)

Closed system: $Q - W = \Delta U + \Delta E_k + \Delta E_p$

Open system: $\dot{Q} - \dot{W}_s = \Delta \dot{H} + \Delta \dot{E}_k + \Delta \dot{E}_p$

So once you do all this the calculations are not complete because you have only calculated total change in enthalpy you still have to calculate if there is any work done by the system or on the system if there is any change in potential energy or kinetic energy which you are not dropped from the general energy balance equations. The equation which you wrote down some of the term would have gone to 0 but some still remain.

You need to make sure that you calculate the numerical values for all the term that still remain you need to make sure that you calculate the numerical values for all the terms that still remain once you calculate all these values you would plug them into the equation which you had and you would be able to solve for the unknown. The unknown could most of probably be Q which is the heat which needs to be transferred so Q dot in case of open systems.

So what the equation use could be is for closed system it is Q – W equals delta U delta EK + delta EP and for open system it is Q dot – WS dot = H dot + delta EK dot delta EP dot. So with this you would be completing your general energy balance calculations to fully understand the procedure which we described just now I will show an example problem.

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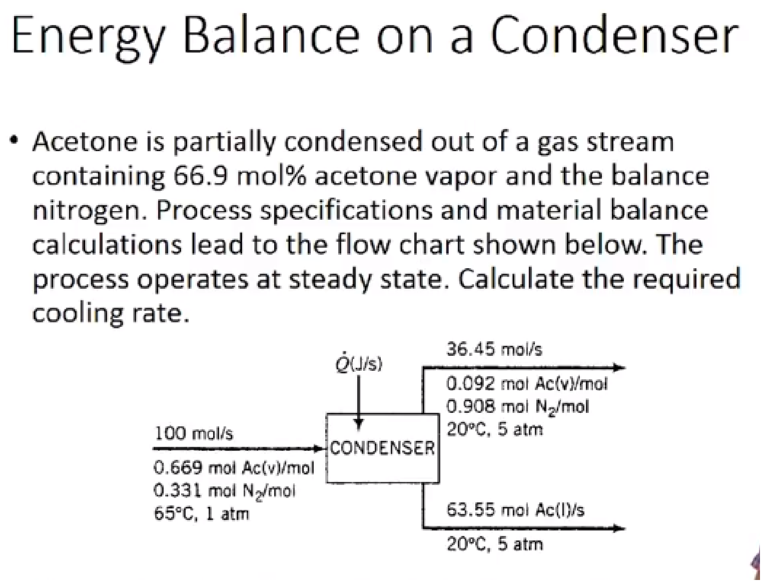

Energy Balance on a Condenser

- Acetone is partially condensed out of a gas stream containing 66.9 mol% acetone vapor and the balance nitrogen. Process specifications and material balance calculations lead to the flow chart shown below. The process operates at steady state. Calculate the required cooling rate.

For this problem we will actually not be performing any numerical calculations we will only follow the steps which we have to go through. So here is the problem acetone is partially condense out of a gas steam containing 66.9 mole % acetone vapor and the balance is nitrogen. Process specifications and material balance calculations lead to the flow chart below the process operated at steady state calculate the required cooling rate.

So you have been given a flow chart and you have been asked to calculate the rate of cooling which is Q dot. So you have also been given all the flow rates the material balance are already done for you so now let us see how you would go about approaching such a problem. So again I am not going to be performing any numerical calculation here I only want to emphasize the procedure which should be followed.

So please try to follow this procedure clearly I will try to use the same procedure for every energy balance calculation which we perform throughout this course.

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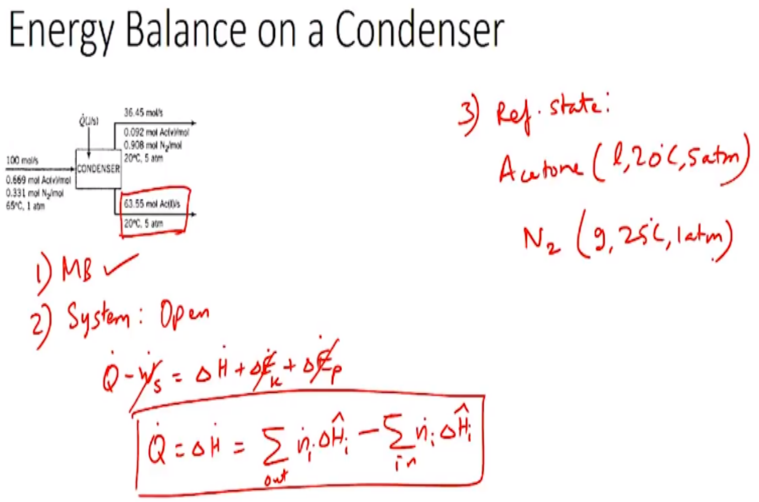

Energy Balance on a Condenser

1) MB ✓

2) System: Open

$$\dot{Q} - \cancel{\dot{W}_s} = \Delta\dot{H} + \cancel{\Delta\dot{E}_k} + \cancel{\Delta\dot{E}_p}$$

$$\boxed{\dot{Q} = \Delta\dot{H} = \sum_{out} \dot{n}_i \Delta\hat{H}_i - \sum_{in} \dot{n}_i \Delta\hat{H}_i}$$

3) Ref. state:

Acetone (l, 20°C, 5atm)

N_2 (g, 25°C, 1atm)

What did we say for the first step for any energy balance calculations material balances. Here do we need to perform any material balances? The information given to us is 100 moles per second coming in 36.5 moles per second leaving in one steam and 63.55 moles leaving in another steam and we also have the composition of each of these steam given to us. This means all the material balances have been done.

So the first step is material balances which is already been done for us the next step is to identify what type of a system it is so what is this system is this an open system or closed system. We see that there is a molar flow rate which is coming in and molar flow rates for steam leaving which means that it is a open system. So the appropriate equation for an open system would be Q dot – WS dot = delta H dot + delta EK dot + delta EP dot.

So in this equation which terms would go to 0 there are no moving part in this system it is only a condenser so shaft work will be 0 you also have no change in velocity which has been given to you. So kinetic energy change will go to 0 there is no change in position which has been given to us. So we can assume potential energy changes for also negligible or closed to 0.

So the equation simplifies to Q dot = delta H dot and we already know that delta H dot for an open system is basically sigma of outlet NI dot delta HI cap – sigma of inlet NI dot HI cap. Now we need to calculate this so that we can get Q dot so that is what is been asked for so the next step is to identify reference states. So what would be the reference state we can use. As I had mentioned earlier for every distinct chemical component in the system we can use a difference reference state.

In this particular system we have two components one is acetone and second is nitrogen. So we can actually choose two different reference state or acetone and nitrogen. Let us see what would decide what reference states to you. For acetone we do not have any table we can look out which means we would have to use either the inlet the outlet conditions as our reference with that in mind I have identified the reference for acetone as liquid 20 degree Celsius 5 degree 5 atmospheres.

So this would be the reference state of the outlet steam of acetone liquid leaving the condenser so i have used this as the reference state so this change in specific energy enthalpy for liquid steam leaving acetone is with reference state would be 0. So that would be one lesser then calculation the other reference state want to choose is for nitrogen.

For nitrogen there are so many tables which are available so Felder Rousseau there is a table which is available in appendix B which gives values for enthalpy change with respect to a particular reference steam. Keeping that in mind I have use the reference state that has been used to table given is Felder Rousseau so the table uses reference state of gas 25 degree Celsius one atmosphere.

So with this I would be able to use values directly from the table rather than from the calculations myself. This will make my life a lot easier when I perform calculations to measure quantify specific enthalpy changes.

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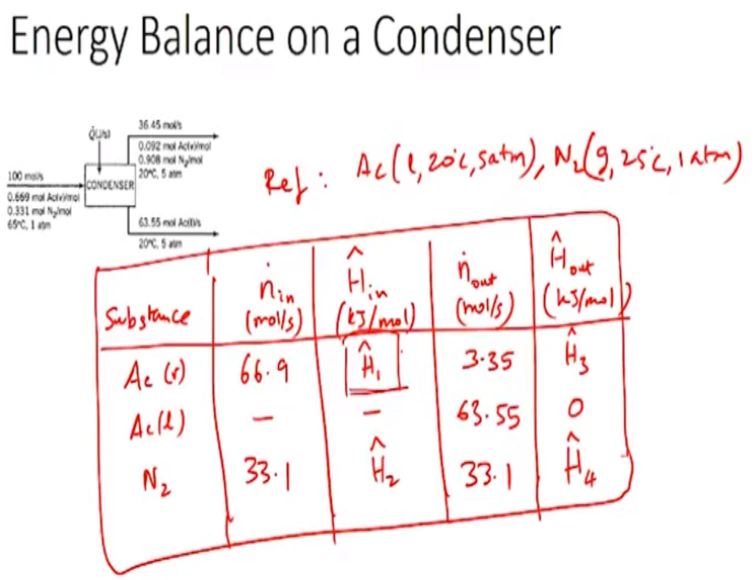

Energy Balance on a Condenser

Ref: Ac(l, 20°C, 5atm), N_2(g, 25°C, 1atm)

Substance	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$ (mol/s)	$\hat{H}_{out}$ (kJ/mol)
Ac (v)	66.9	$\boxed{\hat{H}_1}$	3.35	$\hat{H}_3$
Ac(l)	—	—	63.55	0
N_2	33.1	$\hat{H}_2$	33.1	$\hat{H}_4$

The next step is to construct and inlet outlet enthalpy table so let us look at how the table should be constructed. The first have to write down all the substances and the component which are there so here we will write down the phase distinct components separately acetone vapor will be written down as one component separately as acetone vapor will be written own as 1 component and acetone liquid would be written down another component so that we can expressively understand and account for phase changes.

Nitrogen would be another component so now you have molar flow rates N dot in which in terms of moles per second and you also have to calculate the specific enthalpy changes in terms of kilo joules per moles and you have outlet steam which is N dot out N moles per second and H cap out in kilo joules per mole. So we should not forget that the reference conditions which are used for acetone liquid 20 degree Celsius 5 atmospheres and nitrogen gas 25 degree Celsius 1 atmosphere.

So this is the table could be looking to use so our goal is to fill this table so the molar flow rate for acetone which is entering is 0.669 times 100 so which is 66.9 and you do not have acetone liquid entering nitrogen would be 0.331 times 100 which is 33.1. So similarly the outlet steams you have 36.45 moles of acetone nitrogen vapor mixture leaving so acetone leaving would be 0.92 times 36.45 which is roughly 3.35 acetone liquid leaving is only through this steam.

And we know the number of moles is 63.55 nitrogen is not changing phase or going through any reaction here whatever is entering would be leaving so that is 33.1moles of nitrogen leaving. So amongst this component we now have to calculate specific enthalpy for term which go to 0. Acetone vapor compared to acetone liquid is 20 degree Celsius is 5 atmospheres would have a specific enthalpy term so this term would be labeled as H1 Cap this does not have any inlet.

So let us not worry about that term nitrogen is coming at 65 degree Celsius and one atmosphere and the reference we have used is gas 25 degree Celsius 1 atmosphere. So there is a change in temperature which means this would also have associated enthalpy with. Now for acetone vapor which is leaving through the exit steam it is leaving at 20 degree Celsius and 5 atmosphere however it is a vapor at 20 degree Celsius and 5 atmospheres are not a liquid at 20 degree Celsius at 5 atmosphere.

Which means this would also have a different enthalpy then the reference state so we have to calculate this H3 cap. So the acetone liquid which is leaving the steam as the product is the reference state that we have used which means this would have an enthalpy value of 0 the specific enthalpy in this table would be 0.

Now for nitrogen it is leaving as 20 degree Celsius and 5 atmosphere compare to the reference which is 25 degree Celsius at 1 atmosphere this means that there would be an enthalpy change here also. So there are 4 different enthalpies which need to be calculated to complete this table okay let us try to calculate 1 enthalpy so as I already said I am not going to numerical calculations only going to try to show how the calculations have to be done.

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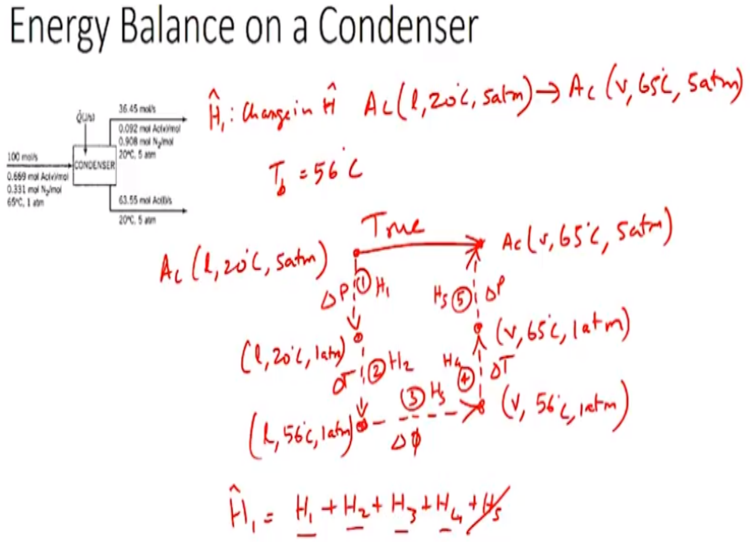

Energy Balance on a Condenser

$\hat{H}_1$: change in $\hat{H}$ $Ac(l, 20°C, 5atm) \rightarrow Ac(v, 65°C, 5atm)$

$T_b = 56°C$

$\hat{H}_1 = \underline{H_1} + \underline{H_2} + \underline{H_3} + \underline{H_4} + \cancel{H_5}$

The specific enthalpy change H1 cap which we are trying to calculate is actually the change in H cap for the process where acetone from the reference state which is acetone liquid a 20 degree Celsius at 5 atmosphere reaches acetone vapor at 65 degree Celsius at 5 atmosphere which is the condition of the inlet acetone.

So for this process we now need to build a hypothetical path because we need to have face and temperature changing so we would have to be build a hypothetical path in a way that we would be able to calculate individual enthalpies. As I already mentioned you can built a hypothetical apt for process having phase change only when you know the enthalpy of phase change at some point.

So for which is usually available for boiling point or for melting point so here you liquid getting converted to vapor so we need to identify the boiling point of acetone and one of the step where phase change happens has to be happen at boiling point at 1 atmosphere. So this means at hypothetical path would have also to be include pressure changes so that process would have the step where phase change happens at boiling point and 1 atmosphere.

So the boiling point for acetone is 56 degree Celsius so this can be looked at any table so once you have this you now have to build an hypothetical path. So what we have is acetone liquid 20 degree Celsius at 5 atmospheres going to acetone vapor 65 degree Celsius 5 atmospheres so this is the true path. Now we need to build the hypothetical path. So there are many ways you can build the hypothetical path.

So the process which I have chosen what I am discussing here so the first step is to reduce the pressure here you have delta P goes to 1 atmosphere here you would have liquid 20 degree Celsius 1 atmosphere. So pressure change happens the next step is to increase the temperature so that it reaches it boiling point. So here it goes to liquid at boiling point which is 56 degree Celsius at 1 atmosphere.

And from this its gets converted where phase change happens so you have delta 5 where only phase change happens to get to vapor at 56% degree Celsius and at 1 atmosphere so from here you have to increase the temperature to vapor at 65 degree Celsius and 1 atmosphere so here you have only delta T and the last step is only delta P reaching acetone vapor at 65 degree Celsius and 5 atmosphere.

Now we have built a hypothetical path where there are 1, 2, 3, 4 and 5 steps so the first step is delta P second step is delta P third step is delta Pie or phase change fourth step is again delta T fifth step is delta P. So we will call the enthalpy changes are associated with each of these steps as H1, H2, H3, H4 and H5 so I have labeled his as H1, H2, H3, H4, H5 please do not confuse it with the H1 and H2 I have used in the table.

So the total enthalpy change in H1 cap would be equal to the summation of these H1 + H2 + H3 + H4 + H5. So we already know that H5 will be 0 because it is gas where there is very small amount of pressure assuming ideal gas behavior this would not matter so the equation will simplifies to change in enthalpy for the four steps which are there.

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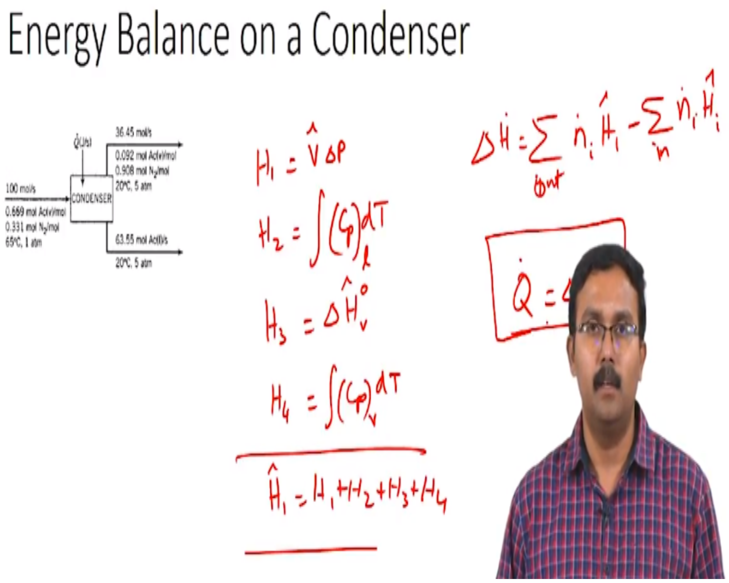
Energy Balance on a Condenser

$$H_1 = \hat{V}\Delta P$$

$$H_2 = \int (C_p)_l \, dT$$

$$H_3 = \Delta \hat{H}_v^{\circ}$$

$$H_4 = \int (C_p)_v \, dT$$

$$\hat{H}_1 = H_1 + H_2 + H_3 + H_4$$

$$\Delta \dot{H} = \sum_{out} \dot{n}_i \hat{H}_i - \sum_{in} \dot{n}_i \hat{H}_i$$

$$\boxed{\dot{Q} =}$$

The first step is there is a change in pressure the enthalpy change in first step H1 would be equal to ZV cap delta P it is change in pressure in liquid so would be V cap delta P. the second step is change in temperature which should be integral CPDT where you would use CP of liquid where the component is liquid.

The third step is where phase change is happening you would look up the heat of vaporization from the tables the first is where you have again change in temperature it will be CPDT again where we will use the CPDT for acetone vapor so now the summation of these four things together will give you H1 cap which is equal to H + H2 + H3 + H4.

Now that you have H1 cap you have filled one value in our table so the table which you had this value now has been calculated similarly you might have to perform calculation for H2 cap, H3 cap and H4 cap. Once you have all these tables your table is complete so now that you have completed the table you would calculate delta H dot as sigma of outlet NI dot HI cap – sigma of inlet NI dot HI cap.

So this will give you change in enthalpy so substituting back into the equation we had Q dot = delta H dot so this is the energy balance equation we came up with after we need all the 0 terms and we end with calculating the value for Q dot using this simple equation. So this is the overall procedure for performing calculations to get energy balances done as you saw the calculations are not easy forward there are many changes in making errors.

So please follow the procedure I described here strictly and meticulously so that we can minimize any chance of errors with that thank you and see you in the next lecture.