Material and Energy Balance Computations
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Lecture –16
Material Balance of Recycle and Bypass Units

Hello everyone, welcome back once again the NPTEL online certification course on Material and Energy Balance Computations. We are in the section where we were discussing the balance on multiple units with a specific focus on recycle and bypass.

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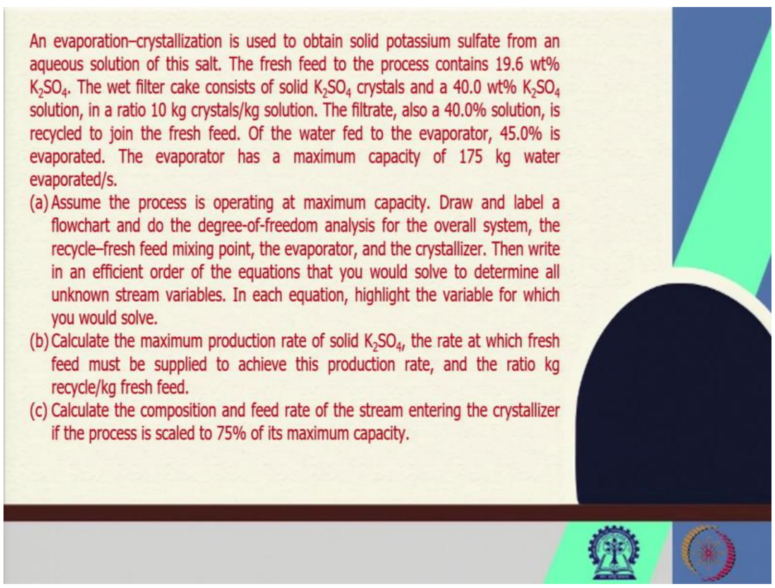

So, in the last lecture I have demonstrated the utility of having a recycle stream and we started to solve a problem which is shown here again. In this context I have also elaborated the sequence of evaporation crystallization operation how it works? So, based on that principle let us again read the problem statement and let us say proceed for solution. So, the problem statement says we have an evaporation crystallization which is used in this case to obtain solid potassium sulphate from an aqueous solution of its salt.

The fresh feed to the process contains a certain known wt % K_2SO_4 the wet filter cake consists of solid K_2SO_4 crystal and certain portion of K_2SO_4 aqueous solution. In that aqueous solution also the concentration of K_2SO_4 was given which is 40 % in this case and this filter cake is formed with a ratio of 10 kg of crystal being formed per kg of solution. So, this filtrate that is also of 40 wt % of the solution is recycled to join the fresh feed which means it is now a recycle stream.

Now the amount of water that is fed to the evaporator 45 % of that is evaporated. The evaporator has a maximum capacity of evaporating 175 kg water per second. So, we have to assume that this is operating at a maximum capacity and then we have to draw and level a flowchart we have to perform the degree of freedom analysis for the overall system for the recycle fresh feed mixing point the evaporator and crystallizer.

And then we have to write an efficient order of equations that would be solved to determine all unknown stream variable. In each equation you have to mark or you have to highlight the variable for which you would solve that equation this is the first part. And then we have to calculate the maximum production rate of solid K_2SO_4 the rate at which fresh feed must be supplied to achieve this production rate and the ratio of kg recycle per kg fresh feed this is the second point or the second part of the question.

The last part is to calculate the composition and feed rate of the stream entering the crystallizer if the process is scaled to 75 % of its maximum capacity. So, in this context in the last class I mentioned that before coming to this last part that is the scaling operation here we have to scale down that is from a maximum capacity to 75 % of the maximum capacity we have to have at first the levelled flow chart and balanced flowchart at the same time.

So, until unless we have the balanced flow chart we cannot scale it. And remember the scaling would happen only with the flow rates the mass or the molar compositions, compositions would remain constant. So, anyhow before coming to the discussion of the last part let us solve the problem.

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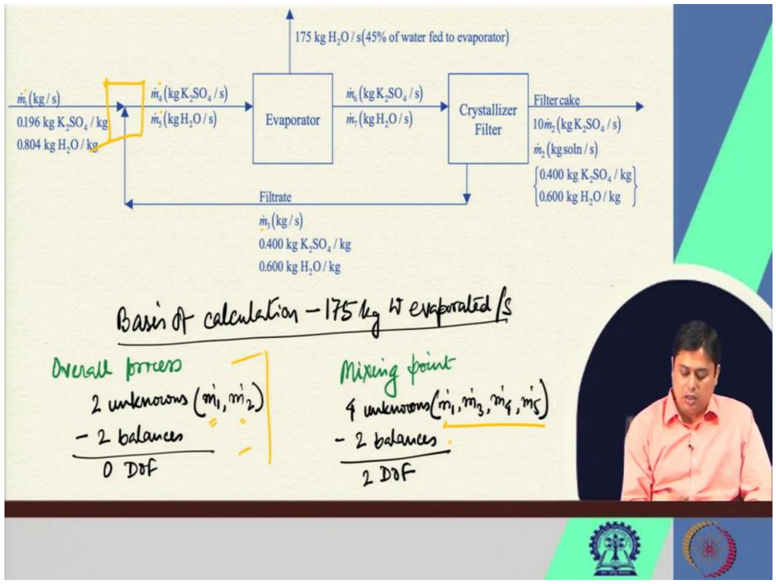

And in the last class I also showed you this schematic of the problem that this is how we should draw a schematic of the problem that we have just gone through. So, what is happening we have evaporator and crystallizer in sequence. An aqueous solution of K_2SO_4 is coming into the evaporator in which amount of water is being evaporated and the maximum capacity is that 175 kg water per second which is 45 % of water fed to the evaporator.

By now we understand and we know that such details we have to write on the flow chart otherwise we may miss the relation between this stream and the m_4 here because it is the 45 % of the stream that is coming into the evaporator. So, we have a relation between this stream and this stream. So, the concentrate that is leaving the evaporator it is now crystallized filtered, the filter cake contains the product or the wet cake in a ratio of 10 : 1 that of the crystal per kg of the solution.

So the filter cake will have, if I consider or if we assume m_2 kg solution then we have 10 $\dot{m}_2$ here $\dot{m}$ is the mass flow rate. So, per kg K_2SO_4 per second now in this solution this $\dot{m}_2$ kg solution per second this aqueous solution its concentration is also known its concentration is 40 % of K_2SO_4. So, 40 wt % that is also mentioned in the problem statement. So, the filtrate which is also having same composition with the same composition the filtrate is now recycled and mixed with the fresh feed.

So, this is a mixing point and then this mixture again goes to the evaporator and it continues. Now the question here is that calculate maximum production rate of K_2SO_4 the rate at which fresh feed must be supplied and the ratio of kg recycle per kg fresh feed. Now here the logical basis of calculation would be the maximum capacity of evaporator. Because that will help us to calculate all the unknown parameters, when the plant or the units are operating at its maximum capacity.

So, that is why we write here that the basis of calculation is 175 kg water evaporated per second. So, w is abbreviated for the water. So, then we follow our classical approach which is that we at first check whether the overall problem is solvable or not. So, for the overall system, the overall system here if we look at it the overall system is basically this yellow enclosure which has one input and 2 output streams. Now the unknowns on the output stream if we identify we see here we have $\dot{m}_1$ kg per second this is the unknown mass flow rate of the feed that comes in to the system it goes out with the composition of $\dot{m}_2$ kg solution per second and 10 $\dot{m}_2$ kg K_2SO_4 per second.

So, that means $\dot{m}_2$ is another unknown here the water flow rate is known to us. So, which means we have 2 unknowns for the overall process. It is a non-reactive system. So, how many balanced or the independent balance equation we can write for this system that would be the number of species that is involved in the calculation or in the system.

So, here we can see the species we have 2, one is K_2SO_4 the other one is the water. So, we can write 2 independent balance equations. So, that means our degree of freedom is 0 for the problem which means the information that has given here is sufficient to solve the problem. Now we look at the other subsystems or the units. So, that we can understand what would be the efficient order of solving the problem.

The order of equations which we would write where we try to avoid the solution of simultaneous equations if the equations contain only one unknown that would be the easiest way to solve the problem. So, let us see that what we have starting with the mixing point. So, for the mixing point coming from left to right, so, this mixing point where the recycle stream and the fresh feed is being mixed.

So, that is the additional consideration that you have to do while considering a recycle stream and rest it remains similar to that of the examples we have seen in multiple unit balances. This recycle streams one additional individual unit as a mixing point. So, in multiple units we have additional consideration that is of mixing point in case of recycle stream. Now here for the mixing point we see here we have multiple streams.

Particularly we have 2 input streams and one output streams. So, for this case this is our unit for the mixing point around which or on which we will apply the balance equation. So, here how many unknowns we have the unknowns we have here is $\dot{m}_1$, $\dot{m}_4$, $\dot{m}_5$ and $\dot{m}_3$. So, if we write that in sequence we have m_1, m_3, m_4 and $\dot{m}_5$. Now this is again is shown that if someone does not calculate the overall process at first and starts with the mixing point balance. So, irrespective of solving this part because once you write the degree of freedom for the overall process 0 you can assume that $\dot{m}_1$ and $\dot{m}_2$ are known. So, that in this case it becomes 3 unknowns the m_1 is known.

So, which means you have one degree of freedom but the way it is shown here is kind of a showing an isolated manner that an individual unit balance and then we realize that what should be the sequence of solving which unit first whether it is the overall process or any sub units at first. So, if we separately look at the mixing unit we can see that we have 4 unknowns we have 2 species in this junction.

So, we can write 2 independent species balance equation which means our degree of freedom is 2. Now we go to the evaporator.

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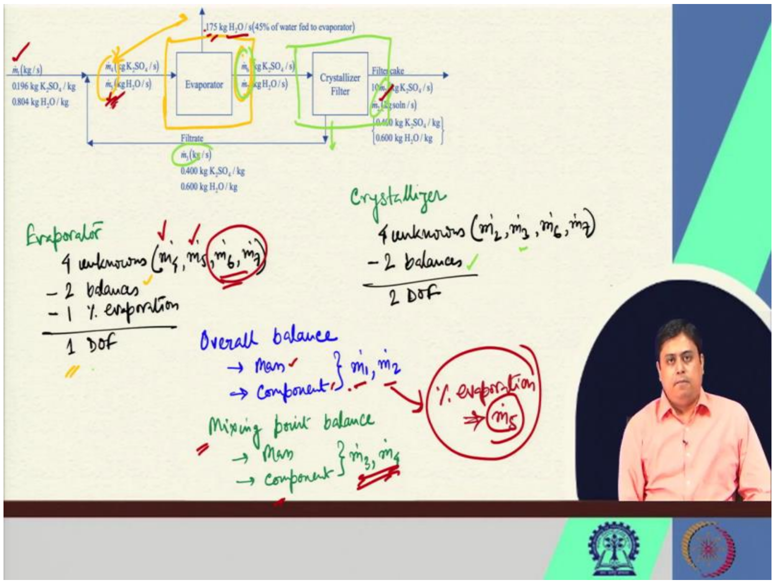

So, for evaporator we have this system where we can see that m_4, m_5, m_6, m_7 these 4 are the unknowns. Here we can write 2 balances individual balance or independent balance for the 2 species and we must not forget that we have to put here the percent evaporation criterion that is the additional information that is given which links between these 2 streams. So we have one degree of freedom in this case. Coming to the crystallizer the next unit and the crystallizer we see this is the balance this is the system boundary imaginary.

So, here similar to the previous case we can see that these are the unknowns of the input stream $\dot{m}_2$ is unknown. So, 1, 2, 3 and m_3 of this stream the stream that is coming out of this intersects the system boundary which is $\dot{m}_3$. So, in this case we have 4 unknowns again we can write 2 balance independent balance equation which are either 2 species or one species and one overall relating this subsystem.

So, we have 2 degree of freedom. So, which means we have 0 for overall and 2 for crystallizer and the mixing point and 1 for the evaporator these are the degrees of freedom. So, the logical sequence would be to solve the overall balance at first. So, once we solve the overall balance here or the overall process we would find what are $\dot{m}_1$ and $\dot{m}_2$. So, this would be known to us. And again we must not forget the relation between the $\dot{m}_4$ or the $\dot{m}_5$ and the water.

Because this is the amount of water being evaporated which is 45 % of the amount that comes into the evaporator. So, this relation we must not forget. So, overall process if we apply mass and any component balance any one of the components or the species we would get $\dot{m}_1$ and $\dot{m}_2$ and then say if we go to the mixing point balance. In the mixing point balance we can write the overall mass balance and also the component balance there which will help us to have the values $\dot{m}_3$ and $\dot{m}_4$ provided we know $\dot{m}_5$.

And this $\dot{m}_5$ we know from this relation which is given already. So, the sequence is that overall process we calculate $\dot{m}_1$, $\dot{m}_2$. $\dot{m}_5$ does not require any other information directly it is related with 175 and 45 % this relation. So, once $\dot{m}_1$, $\dot{m}_2$ and m_5 is known if you look at it here. So, $\dot{m}_1$ known, $\dot{m}_5$ known, so, for mixing unit 4 unknowns reduces to 2 unknowns.

So which means, now this point is solvable. So, if we solve it we will have $\dot{m}_3$ and $\dot{m}_4$ and then if we apply the evaporator balance because. Now here you can see this $\dot{m}_4$ is known $\dot{m}_5$ is known. So, now easily we can find out what are the other unknowns which is $\dot{m}_6$ and $\dot{m}_7$ from this point.

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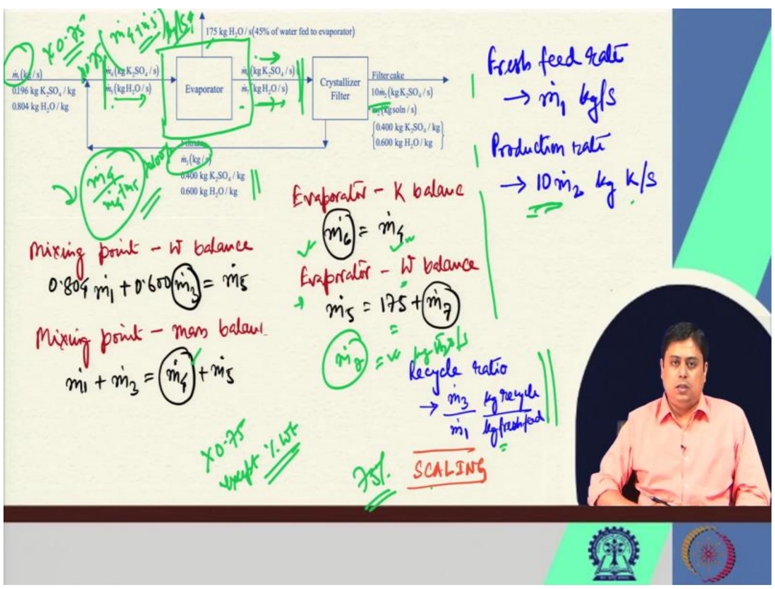

So, if we try to write it. Now the equations we see for the overall mass balance for this whole system. The things we have this is the input, the output are this one and this one these are the streams that intersect the system boundary. So, $\dot{m}_1$ = 175 + these 2 which are 10 $\dot{m}_2$ and $\dot{m}_2$ these are the composition of the filter K. So, this gives us the overall mass balance. But here in this equation we have 2 unknowns we cannot avoid it even if we start the overall process balance.

So, which means we have to write the other equation which is say the K_2SO_4 balance which we can write the weight fraction × the mass flow rate = what we have this 10 m_2 the amount that this section we have and the solution in which the m_2 is coming in which we have 40 wt % of K_2SO_4. So, this m_2 solution we know that it has 40 wt % of K_2SO_4.

So, $m_2 \times 0.4 + 10\ m_2$ which is the wet filter cake. This is the overall K_2SO_4 balance. So, here we see we have 2 unknowns and 2 equations. So which means we can easily solve for $\dot{m}_1$ and $\dot{m}_2$. So, we get the solution after solving this, these 2 equations. Now as I mentioned this relation does not require any other consideration which is the percentage of water being evaporated which says that 45 % of the water fed to the evaporator is evaporated at its maximum capacity.

So, $\dot{m}_4$, $\dot{m}_5$ here which is the water kg per second we have marked × the 45 % = 175 kg. So, here we can easily find the value of $\dot{m}_5$ in kg water per second. So which means we now know what are the m_1, m_2 and $\dot{m}_5$ and then as we mentioned we go to the mixing point balance. So, here if we look at the water balance because we know here $\dot{m}_1$, $\dot{m}_2$ and $\dot{m}_5$.

So, $\dot{m}_1$ and $\dot{m}_5$ these two are known, so here that means if we now in the mixing point if we apply the water balance this $\dot{m}_5$ that is going out or the output stream = the summation of 2 input streams which is the fresh feed + the filtrate the water in the fresh feed and the water in the filtrate compositions are known. So, we can easily write this expression and here $\dot{m}_1$ is known $\dot{m}_5$ is known.

So, we can easily calculate what is the value of $\dot{m}_3$ in kg per second and as we can write 2 independent balanced equations. So, if we now see at the total mass balance around the system or on the system is $\dot{m}_1$ the input + this $\dot{m}_3 = \dot{m}_4 + \dot{m}_5$. The reason for writing $\dot{m}_4$ and $\dot{m}_5$ I discussed in the last class it is not written in the percentage of the fraction basis it is directly translated in terms of kg K_2SO_4 and kg water per second.

So, that is why we have $\dot{m}_4$ and $\dot{m}_5$ here. Again this value is known, this value is known we just have calculated $\dot{m}_3$. So, we can easily calculate what is $\dot{m}_4$ from this expression which is kg

K_2SO_4 per second. Then we move to the evaporator in evaporator we can write 2 balances if we look at the 2 species the first piece species that we can balance. So, evaporator we have this system in this outlet we have only water.

So that means it is easy to balance K or K_2SO_4 at first because it has in only one input stream that should be equal to with the other output stream which is $\dot{m}_6$ that is coming out $\dot{m}_6$ kg K_2SO_4 per second = $\dot{m}_4$ kg K_2SO_4 per second. If someone has already understood this concept while drawing the flowchart he could have written $\dot{m}_4$ and $\dot{m}_4$ itself here he did not or she did not write another unknown variable.

If she understood the concept that the evaporator is only evaporating the water the rest is being concentrated and is coming out as concentrate. So, here the water amount changes only not the K_2SO_4. So, we easily can find out what is $\dot{m}_6$ because we have calculated $\dot{m}_4$ here and then the other species balance on the evaporator or the component balance. So, we have if we apply it for water it is $\dot{m}_5 = 175 + \dot{m}_7$ which is pretty simple.

We can calculate $\dot{m}_7$ here in kg water per second. So, once these unknowns are now known to us, we look at the problem statement once again because the thing that has been asked we have to absolutely be clear about that and we have to be very pin pointed on the answer. So, here it is written what is the maximum production rate of K_2SO_4 the rate at which fresh feed must be supplied to achieve this production rate and the ratio of recycle per kg of fresh feed.

So, the fresh feed rate is $\dot{m}_1$ the maximum production rate is $10\dot{m}_2$ because this is already operating at of maximum capacity and that was the basis of calculation. So, this $10\dot{m}_2$ is the production rate of K_2SO_4 crystals per second and the recycle ratio, recycle ratio is the recycle stream per kg of the fresh feed which is $\dot{m}_3 / \dot{m}_1$. So, I leave this algebra to you to calculate and these are the specific answer that you have to write.

The last point which you must not forget is the scaling to 75 %. So, once all the values you write on the flowchart which means you now know the compositions, the compositions remember would not change while multiplying the flow rates by 0.75. After writing all the things on the flow chart you know the composition. So, for example here you would have $\dot{m}_4 + \dot{m}_5$ is the total flow rate for this case but your composition would be $\dot{m}_4$ by $\dot{m}_4 + \dot{m}_5$ in percentage multiplied by 100 % the weight percentage.

This percent would not change but it would be × 0.75 for the flow rate kg per second. So, all the flow rates in this problem would be × 0.75 in order to scale this down except weight percentages the compositions that would give you the final result of part C. So, I hope you have understood the problem that we started in the last class today we have gone through this in detail in the next class also we will practice couple of problems related to this recycle also the bypass what is bypass I will explain later till then, thank you for your attention.