Material and Energy Balances
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Module No # 06
Lecture No # 27
Purge

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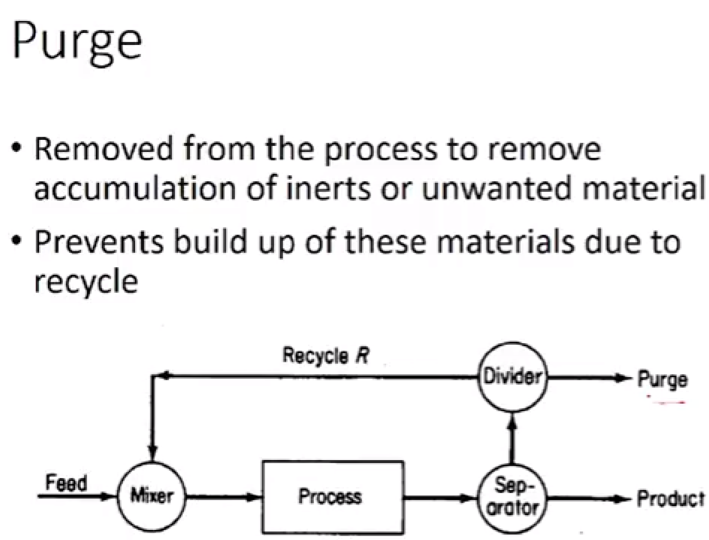

Hello everybody, welcome to today's lecture on system with purge. What is purge? Purge is basically a process where some of the components are removed to ensure that there is no accumulation of unwanted material or inners which would reduce the efficiency of the process so this prevents build of these materials which can usually happen during recycle.

So if you look at this process you have a separator which takes out some of the materials that can be recycle back into the system, and whatever is being recycled if it is continuously being recycled without actually having a purge you might end up with higher concentration of the inner or undesired materials. So this would drive down the efficiency of the process of interest to ensure that does not happen you have the stream called the purge stream.

And these purge stream make sure that the concentration of the unwanted components and inners are kept at a desirable level to ensure process is effective.

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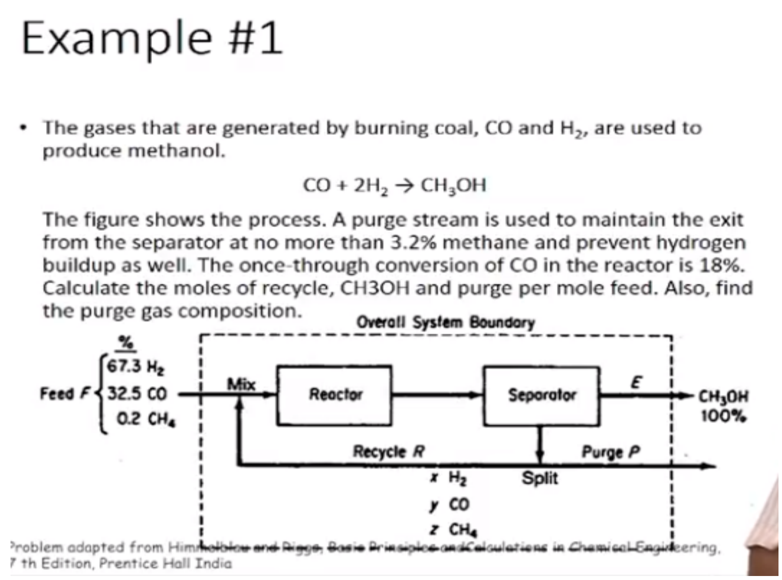

Here are some example problems which will help us understand this concept in a better ways so the gases are generated by burning coal which is carbon monoxide and hydrogen are used to produce methanol and the reaction is given. The figure which is shown here shows the process and a purge stream here it is used to maintain that the exit concentration of methane is only 3.2% and does not exceed that this also prevents hydrogen build up.

The once through conversion of carbon monoxide in the reactor is 18% and you are asked to calculate the moles of recycle methanol and purge per mole of feed which is sent into the system. Also you are asked to calculate the purge gas composition.

So you have the feed which is given the composition of the feed is also given you have a reactor and a separator whatever cases coming out of the separator is either the methanol product or you have a recycle stream which is then split into two components one being the recycle and other being purge and the recycle is sent back to be mixed with the fresh feed. So this what the process is.

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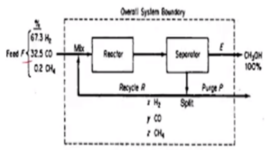
Example #1



Basis - 1 mol F

Overall:

CH_4 : I = 0

$0.002F = zP$

$z = 3.2\% = 0.032$

$\boxed{P = 0.0625 \text{ mol}}$

C : I = 0

$0.325F + 0.002F$

$= E + yP + 0.032P$

$0.325 = E + 0.0625 \quad (1)$

Now let us see how we can go about solving this problem just like any material problem we will start with the basis. So the basis for this system would be 1 mole of fresh feed it has been given in the problem that we have to calculate all the values per mole of fresh feed so we use that as the basis so we can start with the overall system. So if you were to assume the overall system we can write balances for the different components.

So let us first write the balance for methane because methane is non-reacting component it would be a simple balance to write. So we will have the methane balance as input = output at steady state so giving us an input of 0.002 times F and your output would be Z times P where Z is the mole fraction of methane in the recycle stream. So as there is a splitter which splits the recycle and purge stream we know that the concentration of methane in the recycle stream and purge stream would be the same.

So therefore the mole fraction Z can be used for purge stream also so that is why I am writing it as Z times P. Another information we have from the problem is we do not want the concentration of methane to go beyond 3.2%. So this means the Z would be maintained at 3.2% which is equal to 0.00 sorry 0.032. So substituting these values we can get the value of P as 0.0625 moles. So this is the purge stream which is being purged from the system.

So now to calculate the composition of the recycle and the mass of the recycle stream we can write balances for the elements. So we can write the carbon, hydrogen and oxygen balances so when we write the carbon balance you would have input = output at steady state. So the input for carbon in the for the overall system comes from the fresh feed so this would be 0.325 times F so 1 atom of carbon enters into the form of carbon monoxide.

So that would be the fraction of carbon in the carbon monoxide + 0.002 times F giving us the amount of carbon which is entering in the form of methane and we have carbon leaving in the form of methanol. So which would be E + carbon leaving in the form of methane and carbon monoxide through the purge. So that would be Y times P + Z times P which is 032 times P so that we have this equation we can simplify this and we already know the value for P.

So using the values for FP we can actually write this equation as substituting the value for F and P we can simply this equation to 0.325 equals E + 0.0625. So let this be equation 1.

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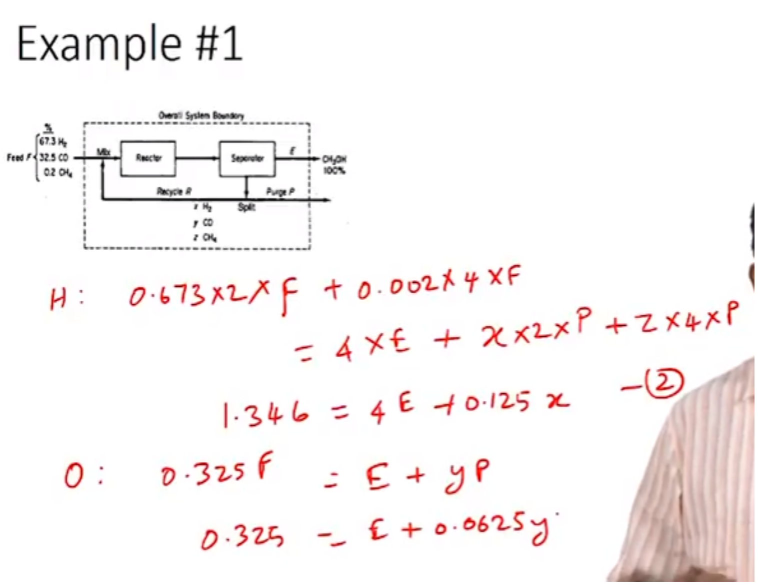

We can also write the hydrogen balance for overall system, the hydrogen balance would be 0.673 times 2 times F which is the number of atoms of hydrogen entering into the form of molecular hydrogen + 0.002 times 4 times F which is the number of atoms of hydrogen entering the system in the form of Methane.

And you would have the output as 4 times E which is 4 atoms of hydrogen leaving with every molecule of methanol + X times 2 times P + Z times 4 times P which would be the number of atoms of hydrogen leaving per molecule of hydrogen and methane through the purge stream. So now this equation can be simplified by substituting the situation for F and P and we would end up with equation that would be 1.346 = 4E + 0.125X. So let this be equation 2.

We could also write a balance equation for oxygen so the atomic balance for oxygen would be 0.325 times F would be equal to E + Y times P this equation becomes 0.325 equals E + 0.625 times Y. So what you see here is this equation is the same as the first equation you got hence these two equations are dependent now you still have 2 equations and 3 unknown, the unknown being E, X and Y.

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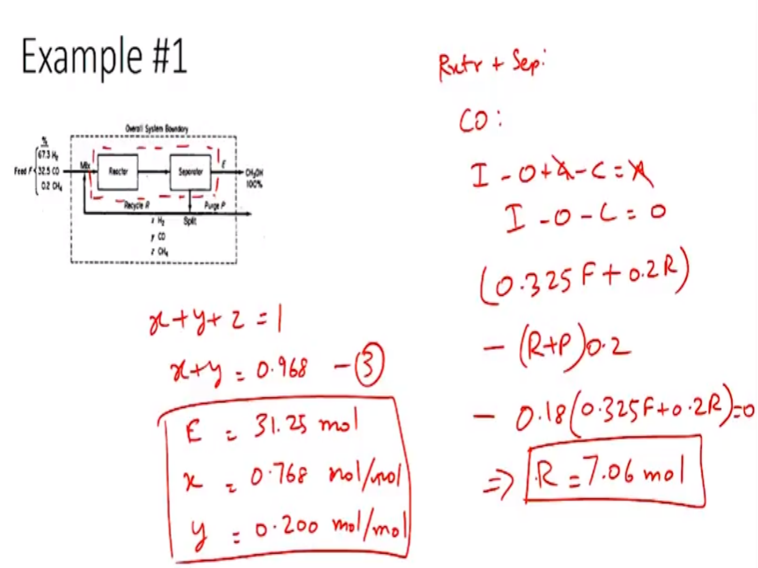

So we need one more equation what equation what equation can we use as X, Y and Z are the mole fraction we know that X + Y + Z would be equal to 1. Now using this equation we have three equations and three unknowns we can substitute the value for Z which is 0.032 and we will get X + Y would be equal to 0.968. Now solving 1, 2 and 3 simultaneously we can get the values for E, X and Y.

So we get V which would be equal to 31.25 moles and X = 0.768 moles per mole and Y = 0.200 moles per mole. Now that we have the information about methanol which is produced and the moles fractions of the recycle stream and the purge stream we still have to calculate the amount of component which is being recycled which is R. For doing this we can choose different systems. So looking back at the problem the one information which we have in addition to whatever we have used is 18% single pass conversion.

So to use this 18% single pass conversion we have to choose a system in a way that the feed enters and leaves the reactor only once. As we do not know the composition of the stream which is leaving the reactor however we know the composition of the stream which leaves the separator we can choose a system which would be the rector + the separator ensuring that we can use he single pass conversion and also perform all the material balances that are required.

So the simple system of interest for this part of the problem would be recycle + separator reactor + separator. So taking the reactor + separator as the system for the reactor and the separator and system we can write a carbon monoxide balance why do we choose carbon monoxide because that is the component for which we have the single pass conversion. So this equation would be input – output + generation – consumption = accumulation at steady state we do now have an accumulation there is not generation because carbon monoxide is a reactant.

So you have input – output – consumption = 0 so the input would be 0.325 times F + 0.2 times R this accounts for the carbon monoxide entering through the fresh feed and the carbon monoxide which is entering through the recycle stream – output would be leaving through the stream which then being split us recycle and purge. So the flow rate for the stream which is leaving the separator would be R + P times Y which is 0.2 and you have consumption term which would be 0.18 times input which is 0.325F + .2R.

Now we have the values for F and P already so substituting them we can get the value for R so this is equal to 0 so the value for R would be 7.06 moles. So with this we have calculated the recycle stream also. Let us move on to one more example problem to ensure we have full understanding of how to perform these calculations.

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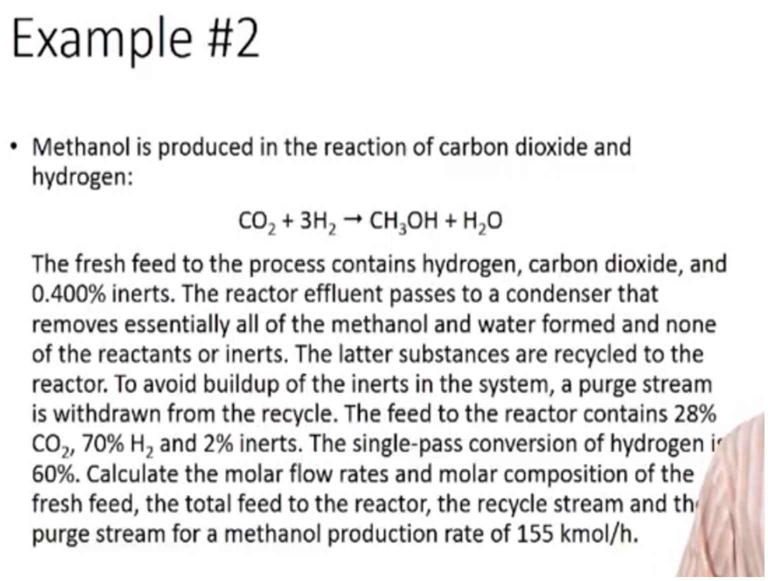

Again for this we will also draw a flow chart which will help us understanding how to convert word problems into flowcharts and then perform necessary calculations. Methanol is produced in a reaction of carbon dioxide and hydrogen and the reaction is given the fresh feed to the process contains hydrogen, carbon diode and 0.4% inerts. The reactor effluent passed through a condenser that removes essentially all of the methanol and water which is formed and none of the reactants are inert the later substances are recycled to the reactor.

To avoid buildup of the inerts there is a purge stream which is withdrawn from the recycle the feed to the reactor contains 28% carbon dioxide 70% hydrogen and 2% inert. The single pass conversion hydrogen is given as 60% we asked to calculate the molar flow rates molar composition of the fresh feed the total feed to the reactor and the recycle stream and purge stream for a methanol production rate of 155 kilo moles per hour. Now let us try to draw this into a flow chart.

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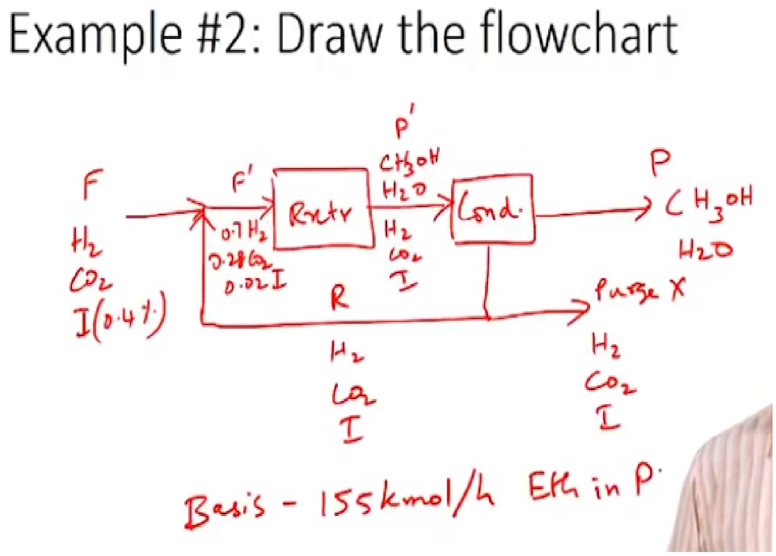

Looking at the problem you have a fresh feed which is entering this feed contains hydrogen carbon dioxide and inerts. The only information we have about stream is the inters components component is 0.4%. So this is mixed with ahh recycle stream which then becomes a total feed entering into the reactor. So the total feed information has been given so total feed F prime we have been told that 70% hydrogen 0.28 carbon dioxide and 0.02 inerts.

So this composition of total stream has been given and you have a reactor output which then goes into a condenser and this condenser separates the products which contains methanol and water so this would be the product stream and the rest of it actually collected and either recycled back or it is disbursed so we have a purge so this is a purge stream we call this X and the purge stream would contain hydrogen carbon dioxide and inerts and so will the recycle stream hydrogen, carbon dioxide and inerts.

So the product total product stream would contain the methanol which has been produced, the water which has been produced hydrogen carbon dioxide and inerts all leaving the reactors. So this gives us the flow chart in addition the problem also states that 155 kilo moles of methanol needs to be produced so we will use that as the basis. So the basis for the problem would be 155 kilo moles per hour of ethanol in the product stream P.

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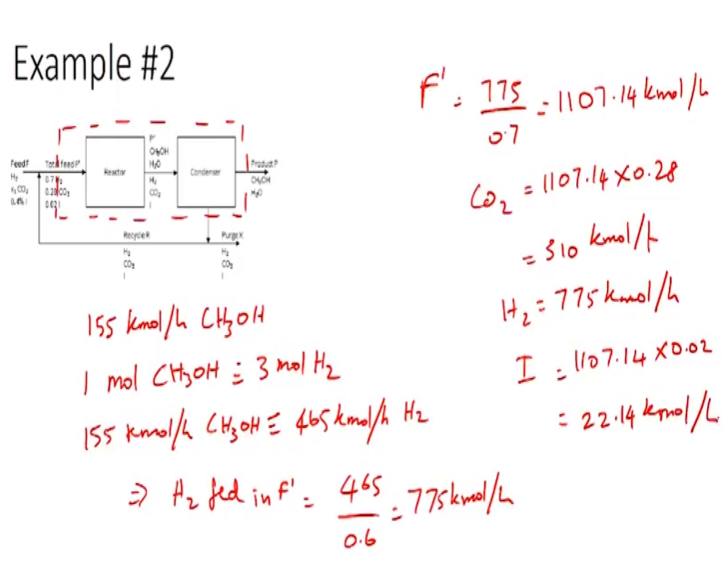

Let us first consider a system where we have enough information about the composition. For this reason we will choose the system which is the reactor + condenser. So this system we have information about the total feed we also know the amount of methanol which is being produced in the product. So using this let us try to calculate what would be the total feed so what we have is 155 kilo moles per hour of methanol being produced.

Looking at the stoichiometric so you have 1 mole of carbon dioxide reacting with three moles of hydrogen produced 1 moles of methanol. So if 155 kilo moles per hour the among of hydrogen which is consumed would be so 1 moles of methanol is produced by consumption of 3 moles of hydrogen. So 155 kilo moles per hour of methanol is produced by consumption of 465 kilo moles per hour of hydrogen.

For the given system we also know that there is 60% single pass conversion which means 60% of consumption results in formation of 155 kilo moles per hour of methanol. So that would imply the consumption we have calculated here 465 kilo moles per hour of hydrogen would account for 60% of hydrogen entering into the reactor. So this implies hydrogen fed in the total feed would be 465 divided by 0.6 giving a value of 775 kilo moles per hour.

Now that we have the information about the amount of hydrogen we can calculate the total feed as total feed F prime would be equal to 775 divided by 0.77 giving a value of 1107.14 kilo moles per hour. So we can also calculate the composition of the total feed so we should contain carbon dioxide and 28% giving you 1107.14 times 0.18 sorry 0.28 giving you a value of 310 kilo moles per hour and hydrogen would be 775 kilo moles per hour and you have inerts which should be coming in as 1107.14 times 02 which is 22.14 kilo moles per hour.

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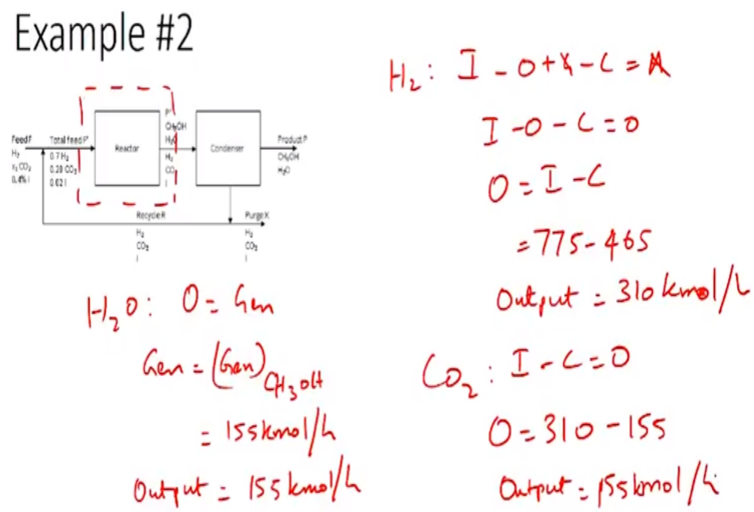

Now that we have all the information about the composition of the total feed and also the single pass conversion of hydrogen into the reactor we can calculate the total product which is leaving the reactor by choosing the reactor as the system of interest. Let us take the reactor as the system and we can write the relevant balances to calculate the amount of methanol and amount of water hydrogen carbon dioxide and interts which should be leaving the system.

So obviously water is only being produced so your output will be equal to generation using the stoichiometric the generation of water would be equal to the generation of methanol so we know that 155 kilo moles per hour of methanol is being generated so this means the generation of water is also at 155 kilo moles per hour so this would be the water which is leaving the system. So output for water would be 155 kilo moles per hour.

So we can calculate the other things also so hydrogen is consumed at 3 times the amount of methanol which is being produced so we know 465 milo moles was being consumed from out earlier calculations. The equation which becomes input – output + generation - consumption becomes input – output - consumption = 0 because there is generation and accumulation getting cancelled so your output is equal to input – consumption which is 775 – 465.

So your output for hydrogen would be 310 kilo moles per hour so for carbon dioxide you have any input of 310 so and you again would have only consumption and output terms so this here output would be input – consumption so the output term would be 310 – consumption which would be equal to the same amount of methanol which is generated. Because 1 mole of methanol is generated from one mole of carbon dioxide.

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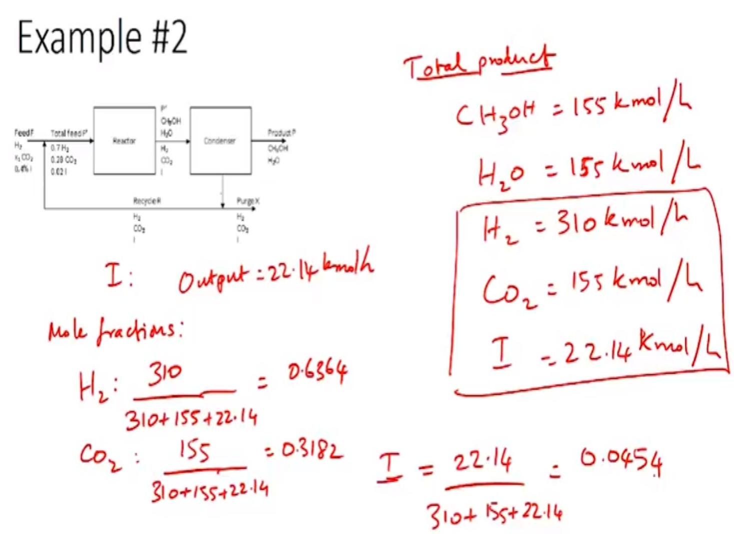

So this would be 155 so your output for carbon dioxide would be 155 kilo moles per hour as inerts are taking part in the reaction whatever inert is entering in the system will be leaving. So your output for inerts would be 22.14 kilo moles per hour so from this we have calculated all the information about the P prime or the total product stream.

So for the total product stream this is the information we have for the total product we know that it contains methanol at 155 kilo moles per hour water at 155 kilo moles and it is also contains hydrogen at 310 kilo moles per hour and carbon dioxide at 155 kilo moles per hour and inerts at 22.14 kilo moles per hour.

So this product stream then enters into the condenser all the methanol and water leaves through the final product stream and the rest of the components which is hydrogen carbon dioxide in inerts is split into the recycle and the purge. Now we need to know how much is actually being recycled and how much is being purged. So what would be the system we can choose to calculate this.

So we could write a balance equation this total product then enters into the condenser where methanol and water is condensed to form the product stream and the rest of it is then sent to being split as recycle and purge stream. So now that we have the information about hydrogen carbon dioxide and inerts which is present in the stream about hydrogen carbon dioxide and inerts and which is present in the stream that is being split we can calculate the composition of the recycle stream and the purge stream using these values.

So the this particular stream which is leaving the condenser contains hydrogen contain 310 kilo moles per hour and carbon dioxide is 155 kilo moles per hour and inerts at 22.14 kilo moles per hour. Using these values we can calculate the mole fractions as hydrogen mole fraction would be 310 / 310 + 155 + 22.14 giving you a moles fraction of 0.6364 and similarly for carbon dioxide the mole fraction would be 155 / 310 + 155 + 22.14 giving you a value of 0.3182 and inerts would be at 22.14 divided by 310 + 155 + 22.14 giving you a value of 0.0454.

Now that we have the mole fraction of stream which is leaving the separator we also have the information about the mole fractions and the composition of the recycle stream and the pearl stream. Now we can choose appropriate systems to calculate the number of moles of recycle and purge. What system do we choose?

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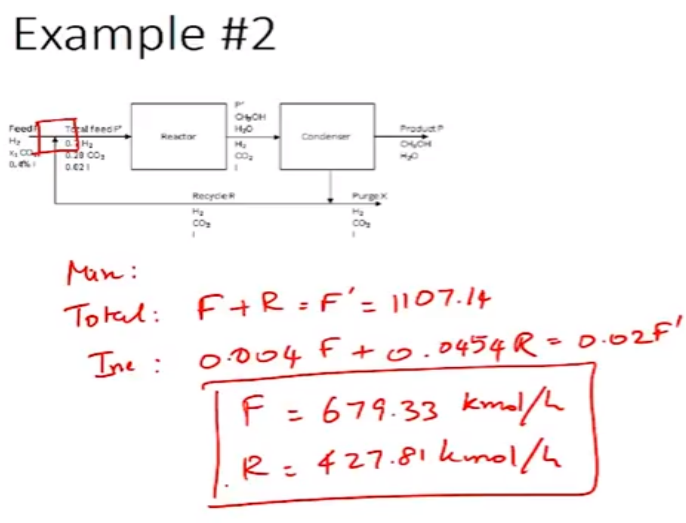

For identifying the recycle stream we need to choose a system where the recycle would cross the system boundary so that we can choose by we can obtain by choosing mixing point so let us choose the mixing point for which we have information about the total feed stream and the compositing of the recycle stream and also we know the information of inerts in the fresh feed.

So taking this system as the mixing point as the system we can write the total mass balance total mole balance for this system would be F + R = F prime and we already know that F prime is 1107.14 and we can also write the inert balances. Inert balances would be 0.004 times F + 0.0454 times R which is the mole fraction of the inerts in stream R would be equal to 0.02 times F prime.

So substituting the value for F prime here we now have two equations and two unknowns and we can solve for F and R giving us an value for F as 679.33 kilo moles per hour and we have R as 427.81 kilo moles per hour. So the fresh feed which is being supplied to the system and the recycle stream which is being sent to the system have both been calculated. We now have the information about the recycle stream and the fresh feed stream.

However we do not know the composition of the feed stream we do not know how much of the fresh feed is actually hydrogen and how much is carbon id oxide. For identifying that we still have to write more material balances so here we can write carbon dioxide balance let us assume X1 is the mole fraction of carbon dioxide in the fresh feed so this would mean so the carbon dioxide balance would be X1 times F which is the input + your carbon dioxide in your recycle stream which is 0.3182 times R would be equal to 0.28 times F prime.

Now that we already know FR and F prime we can calculate X1 which is the mole fraction of carbon dioxide in the feed as 0.256. So with this we have the composition of the fresh feed also we already know the percentage of inerts now we know the mole fraction of carbon dioxide. So this means mole fraction of hydrogen in the fresh feed would be equal to 1-0.256 – 0.004 giving us a value of 0.74 would be the mole fraction of hydrogen in the fresh feed.

So with this we have all the information about the total product stream the product stream recycle stream and the fresh feed we still have to calculate how much of the purge stream is being sent out. How do we go about doing that.

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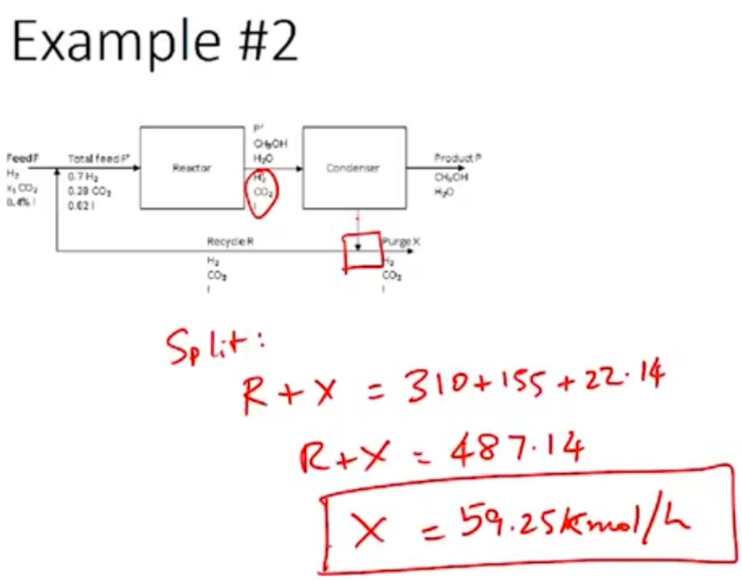

For calculating the purge stream we need to choose where purge stream cross the system boundary so the easier system we choose would be the splitter so for the splitter we can write only one total balance so for this splitter we can write only one mass balance or the mole balance or mole balance which is independent. So here we can write a mole balance for the total moles which is entering the leaving the system.

So the total moles which is entering and leaving the system is through this stream and the moles which are leaving are through R and X. So the output is R + X so the input here would be all the components of hydrogen carbon dioxide and inerts which is entering into the condenser so which we already calculated as 310 + 155 + 22.14 so giving us R + X = 487.14 we can calculate X has 59.25 kilo moles per hour.

So with this we also have calculated the number of moles of purge stream which is being sent out of the system we already have calculated the composition to summarize this is the data we have.\
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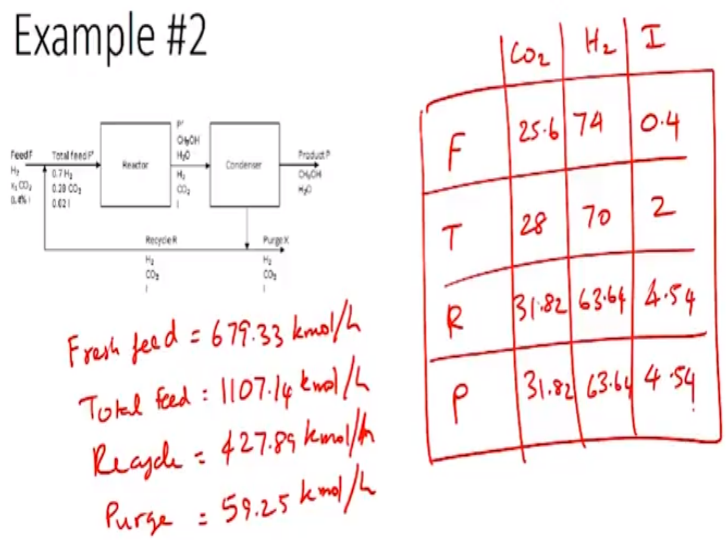

Based on the calculation which we have performed we can summarize the final answer as we have fresh feed which is coming in at 679.33 kilo moles per hour and you have total feed which is in coming in at 1107.14 kilo moles per hour and you have recycle stream coming in at 427.89 kilo moles per hour and we have the purge stream flowing at 59.25 kilo moles per hour. So with this we can also calculate the compositions we call them as F, T, R and P.

Let me call the compositions for the difference components so we have CO2 H2 hydrogen and inerts so we have the stream feed as fresh feed would contain 25.6%, 74% hydrogen and 0.4% inerts and we have 28% carbon dioxide and 20% hydrogen and 2% inerts the total feed recycle stream contains 31.82% carbon dioxide and 63.64% hydrogen and 4.54% inerts and the composition the same for the purge at 31.82 and 63.64 and 4.54.

With this we come to the conclusion of the problem I hope you have understood the fundamentals associated with performing this calculations for systems with purge. In the next lecture we will talk about the summary of how to actually solve all these material balance. So this would be revision lecture where we will go through some of the fundamentals associated and whatever we have learnt till now until then thank and good bye.