Material and Energy Balances
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Module No # 03
Lecture No # 12
Material Balance Calculations For Single Units With A Single Reaction (continued)

Hello everybody welcome to today's lecture we will be containing to discuss material balances for single unit operations with a single reaction. Until now we have solved example problems where the chemistry of the reaction happening as actually been expressively given in a form of a traditional chemical equation.

So we have used the stoichiometric directly today we will see an example problem where the reaction is not given expressly however the information regarding the stoichiometric can be obtained based on the different information that has been given in the problem.

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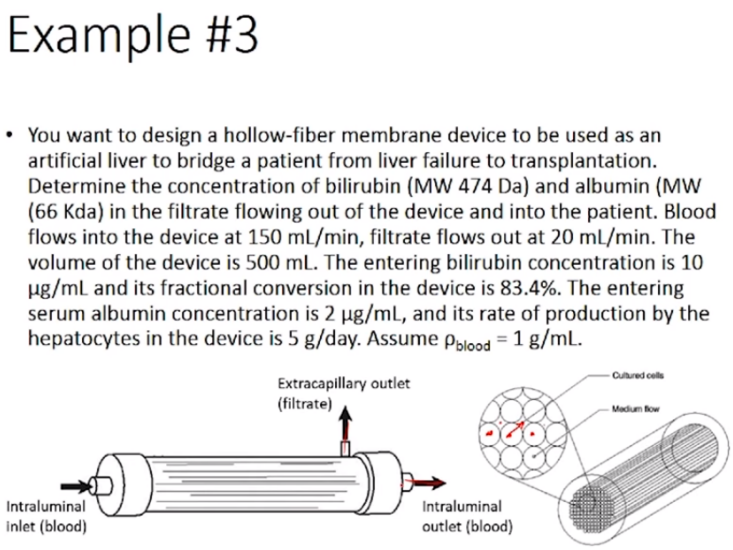

So here is the example problem you want to design a hallow-fiber membrane device to be used as an artificial liver to bridge a patient from liver failure to transplantation. Determine the concentration of bilirubin with molecular weight of 474 Dalton and albumin with molecular weight of 66 kilo Dalton in the filtrate flowing out of the device into the patient. Blood flows into the device at 150 ML per minute and filtrate flows out at 20 ML per minute.

The volume of the device is 500 Milli liters the entering bilirubin concentration is 10 micro grams per ML and it is fractional conversion in the device 83.4%. The serum albumin concentration is 2 micro grams per ML and it is rate of production by the hepatocytes is in the device is 5 grams per day. You can assume that the density of blood is 1 gram per ML so this is a artificial liver device so you can look at the device and try to understand how the system is.

So you actually have multiple tubes which are present inside the hallow membrane so each of these tubes are the once where you have the blood flowing so inside this tubes each tubes you have the blood flowing and there are cultured cells in that gaps between this. So these gaps actually filled with cultured cells which are the hepatocytes free of contaminants and toxics.

So what is being done here is instead of having you natural liver which would regularly perform is you are having the device which is an extracorporeal device so the blood patient is taken and it is allowed to flow through this hallow – fiber membranes it flows into these tubes which are given here why it is flowing through this tubes because there is a fiber which is surrounding these tubes.

Some of the filtrate will get filter and get entered into the space between these tubes where it acted upon by the cultured cells there by purifying the blood and these filtrate which comes out from the extra capillary outlet is mixed with the intraluminal blood to finally be sent back into the patient as purified blood.

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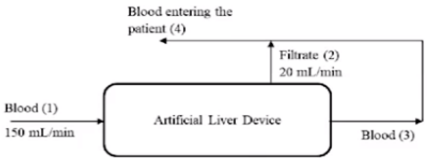
Example #3



Conc. of bil in Filtrate = $\frac{249 \text{ kg/min}}{20 \text{ mL/min}}$

= 12.45 kg/mL

Conc. of bil. in blood entering patient = $\frac{249 \text{ kg/min}}{150 \text{ mL/min}}$

= 1.66 kg/mL

Now to understand this in a simpler block diagram we can draw it these way so we have blood which is coming from the patient at 150 ML per minute and this enters into the artificial device and we have two output the first one is the filtrate which is leaving at 20 ML per minute and you have the other outlet which is the intraluminal blood leaving the artificial liver device. So this blood and the filtrate are mixed together to finally form the blood which is entering into the patient.

Now here for this problem the chemical reaction which is happening is not been expressively given however we can use the data given for generation and consumption and calculate material balances. So let us start solving this problem just like any material balance problem we first need to identify the basis based on the information given in the problem the basis would be 150 ML per minute of blood entering the system.

So we write the basis as 150 ML per minute of blood which is entering the system so this is also = 150 grams per minute of blood because it has been given that density of blood is 1 gram per ML. So now for performing the calculations we have to make certain assumptions the first assumptions we make would be steady state so this is standard assumption we make for all material balance problem and till this point.

And in addition to this we should also make a few other assumption which are specific for this problem we need to assume that albumin and bilirubin is only leaving through filtrate we are

going to assume none of the albumin and bilirubin are going to be leaving through the intraluminal blood which is leaving extra corporeal device. So bilirubin and albumin come out only in the filtrate.

So this is a second assumption we make so the third assumption we would be making is other than this no other cells are large molecules would be leaving through the filtrate no cells are large molecules in the filtrate these assumptions are essential for performing our calculations. So now that we have the system and we have all the information we can start writing the balances the total balance would not be of much value to start with.

So because of that we will start with the component balance so in this we first start with the bilirubin balance. The bilirubin balance would be mass of bilirubin entering through the blood stream 1 which we call as M1 bilirubin and mass of bilirubin which is leaving the system would be only through filtrate based on assumption so we will have through as bilirubin and in addition to this bilirubin is being consumed in the system when this liquid is being exposed hepatocytes.

So we would have a material balance as input – output + generation – consumption = assumptions at steady state there is no accumulation so these bilirubin is not being generated by the system so generation goes to 0 we know there is going to be consumption term there is an input term and output term, So based on this we can write the bilirubin balance as M1 bilirubin would be equal to M2 bilirubin + consumption of bilirubin.

So it has been told that the conversion of bilirubin in the device is 83.4% so this is the percentage conversion. So conversion is defined as amount of bilirubin consumed by amount of bilirubin fed so using this we can calculate the consumption of bilirubin. So this would be conversion is 0.834 would be equal to amount of bilirubin which is entering – amount of bilirubin which is leaving which is basically amount of bilirubin and consumed divided by the amount o bilirubin which is entering which is M1 bilirubin.

So using this we can calculate M2 bilirubin because we know the value for M1 bilirubin to be 150 ML times 10 micro grams per ML which is the concentration of bilirubin in the blood entering. So this is 1500 micro grams of bilirubin is entering so substituting the value there we can calculate the amount of bilirubin which is leaving the system as 249 micrograms per gram so

this should be ML per minute I am sorry this should be ML per minute this is microgram per minute.

And with this we have the amount of bilirubin which is leaving the system now that we have the amount of bilirubin we have to calculate the concentration of bilirubin which has been coming out through the filtrate and the concentration of bilirubin in the blood which is entering the patient. So we know that 20 ML per minute of filtrate is leaving the system which means the rest 130 ML would be coming out through the blood stream.

So the total amount of blood should be entering the patient be the same assuming the total mass balance we would have to assuming the total blood leaving the system still it is 150 grams per minute which is 150 ML per minute. So based on that we can calculate the concentration of bilirubin in filtrate as 249 micro grams per minute divided by 20 ML per minute giving you the concentration 12.45 micro grams per ML.

So the concentration of bilirubin which is entering the patient in blood entering the patient would be the same amount 249 micrograms per minute divided by150 ML per minute giving you a concentration of 1.66 micro grams per ML. So this would be the concentration of bilirubin which is entering the patient now we need to perform this calculation for estimating the concentration of albumin.

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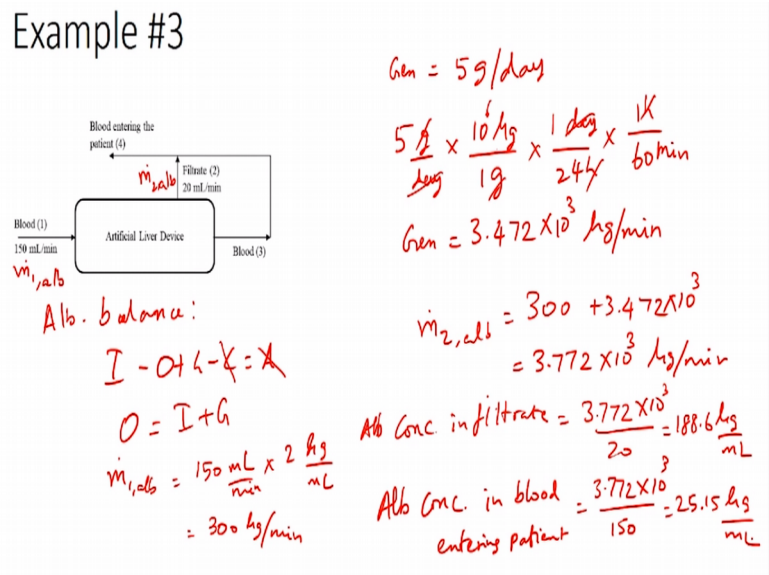

For this we would have to perform albumin balance let us start with the albumin balance here would again have the same term which should be input – output + generation – consumption = accumulation at steady state it is going to be no accumulation albumin is not consumed in the reaction but it is being generated at the rate of 5 grams per day. So there is not consumption however there will be an output and generation term and there is also going to be an input term okay.

So this that to calculate the output of albumin we need to know the input + generation term the input term will call this as M1 albumin is known to be 2 micro grams per ML concentration coming in so 150 ML per minute times 2 micro gram per ML gives concentration gives you an amount as 300 micro grams per minute. So 300 micro grams per minute of albumin is entering into the artificial liver device.

So the generation term can be calculated as 5 grams per day given to you in the problem this needs to be converted to micro grams per minute. So how do we do that so we have to convert the generation term which has been given in 5 grams per day to micro grams per minute so how do we do that 5 grams per day needs to be converted to micro grams per minute. So 1 gram contains 10 power 6 micro grams per gram times 1 day basically contain 24 hours and 1 hour contains 60 minutes.

So cancelling out the days cancelling out the grams and hours we end up with micrograms per minute and when we calculate this the value would be generation equals 3.472 times 10 power 3 micro grams per minute. So now we have the generation from the input term so we can calculate the output term in the filtrate which would call as M2 do albumin. So M2 dot albumin would be equal input + generation which is 300 + 3.472 times 10 power 3 giving you a value of 3.772 times 10 power 3 micro grams per minute.

So now just like how we calculated the concentration of bilirubin and in the blood entering the patient we will have to calculate the concentration of albumin in the filtrate and the albumin entering into the blood entering into the patient. So concentration in filtrate so this is albumin concentration in the filtrate would be 3.772 times 10 power 3 divided by 20 giving you a value of 188.6 micro grams per ML.

Albumin concentration blood entering the patient would be 3.772 times 10 power 3 divided by 150 which is equal to 25.15 micro grams per ML. So with this we have calculated all the concentration that have been asked for as you saw here we have not used the traditional stoichiometric equation however the consumption and generation term which were given in terms of fractional conversion and generation of some protein in grams per day have been used to perform the material balances.

So this is another type of a problem which you would face in many cases especially in biological reactions where reactions are not very straight forward where you do not have the stoichiometric however you might have information of what is being produced at what rate and what is being consumed as what rate. So using this we can still perform material balance calculations as we have demonstrated here.

So with this we will come to a closure for material balances for single unit system with system reaction happening. So we will move on to performing material balances for systems we have multiple reactions. If you remember when we discuss the fundamentals for in reaction systems we talked about terminologies associated with multi reaction processes we will try to apply them to perform material balances in the next lecture thank you.