Mass Transfer II
**Prof. Nishith Verma**
Department of Chemical Engineering
Indian Institute of Technology, Kanpur

Lecture No. # 01

Welcome to NP-TEL Phase two lectures on the course title Mass Transfer 2. Myself; Nishith Verma, I am the Professor at IIT, Kanpur, and in this course we will have 40 odd lectures like each lecture lasting around one hour. Before, we begin this lecture one let us go through some of the administrative procedures. I said there will be 40 lectures and we would like to divide into several sections now. This is third year undergraduate level course, which means it expected that we have some exposure to other chemical engineering courses at least at the second year levels. For example, fluid mechanics some course on heat transfer and some course on stoichiometry and process calculations.

Of course, we begin this course again with some introduction to mass transfer certain basic and fundamentals, what we do right now. Let us note down books, textbooks for this course. Let us note down certain points here.

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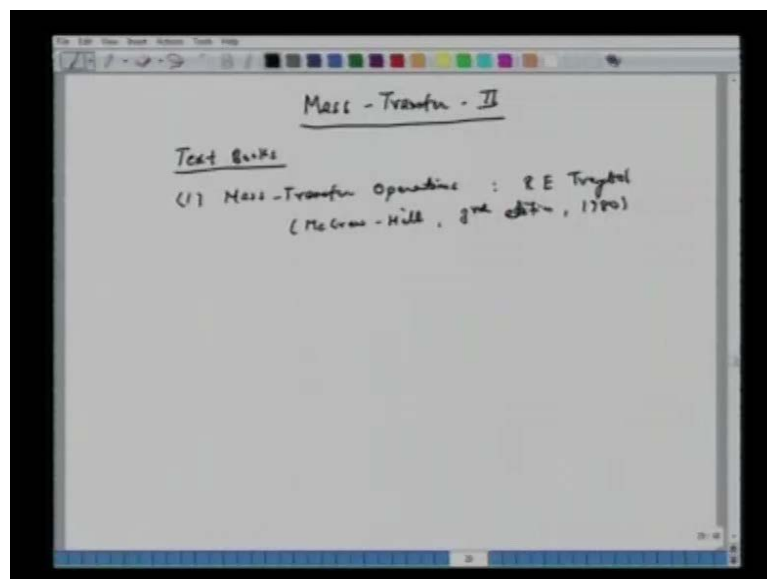
This is the course on Mass Transfer II and here essentially, we will follow textbooks. Let us make a note of these books. One is you may be familiar with these Mass Transfer operations and the author is R E Treybal, it is a very popular book in chemical engineering, it is McGraw-Hill Publication, a third Edition should be available on 1980. We will have most of the lectures are covered from this textbook. There is another very good book by the Indian author B. K. Dutta; this book is also available on Prentice Hall India., what we will do most of the theoretical aspects will covered from this book by Treybal and some of the numerical examples, we will deal with from this book on separation processes . The second book by Dutta it has different levels of examples; we will choose few of them from that. There is another book by a Wankat, let us make a note of these two textbooks as well.

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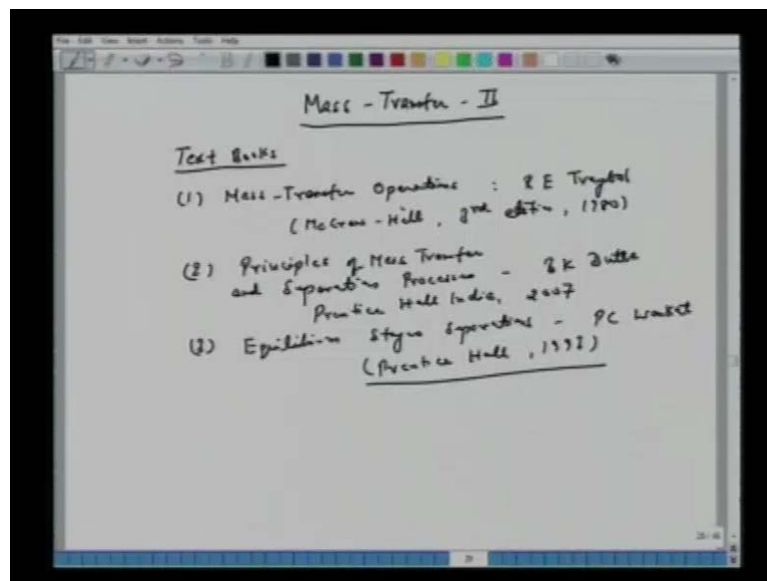
These books are essentially for difference purpose, the title is Principles of Mass Transfer and Separation Processes. The author here is B. K. Dutta and this book is published by Prentice Hall India, 2007. There is another very good book titled Equilibrium Stages Separations and the author is Philip Wankat. This book is also from Prentice Hall on 1993. All these three books should be available in your bookstall you can order the books.

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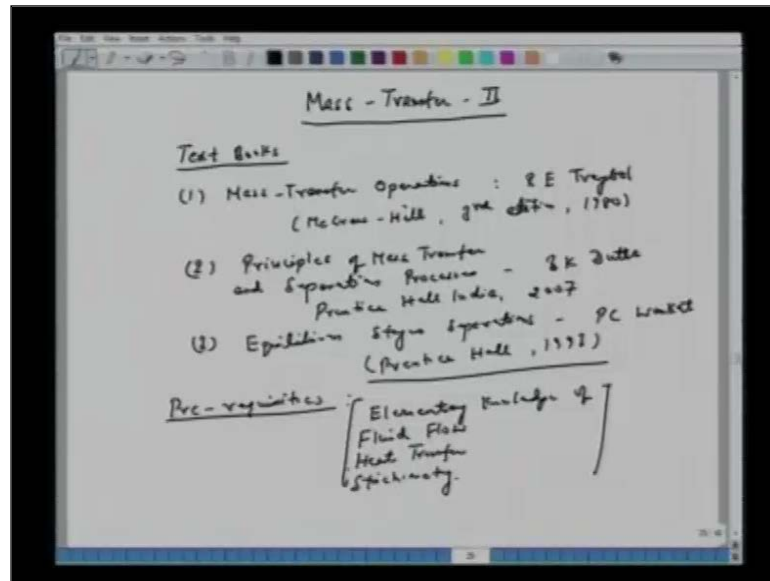
As, we said down the prerequisites for this course, this is the third year level course that means you should have elementary knowledge of fluid flow, I am sure most of the university they have at least one course at the second year level on fluid flow and heat transfer also may be a second year level or at least at the third year level. In chemical engineering this is the first course on a stoichiometry in most of the universities for chemical engineering calculation. Actually, this is a third year level course and what we do in this course is separations. You may have done when you are picking the course on calculation, process calculation or stoichiometries. You must have some calculations on combustion, distillation or absorptions.

The orientation of this course is to deal with certain unit operations. What are the unit operations; we have phases certain phase liquid or gas phase containing at least binary components A and B. We have been asked to separate A and B and we have been asked to deliver a product containing most of its specification for the purity is 99.99 percent; other phase reached B. We have two phases A and B so this is separation. There is one component, which is reaching one phase other component it is reaching the second phase, how do we achieve it we have set of unit operations. In some cases may be we just have one unit operation. What are these unit operations, these are the methods essentially we have some equipment by which you can achieve these separations, for example; distillation, absorption, adsorption, drying and extraction.

These are the several unit operations in chemical engineering for this course, we have listed certain unit. We said in the beginning that we will have few lectures on introductions to basic and fundamentals, we will have elementary introduction to this diffuse and its first law that we can set up the basic and fundamental equations, which is required in solving certain class of problems.

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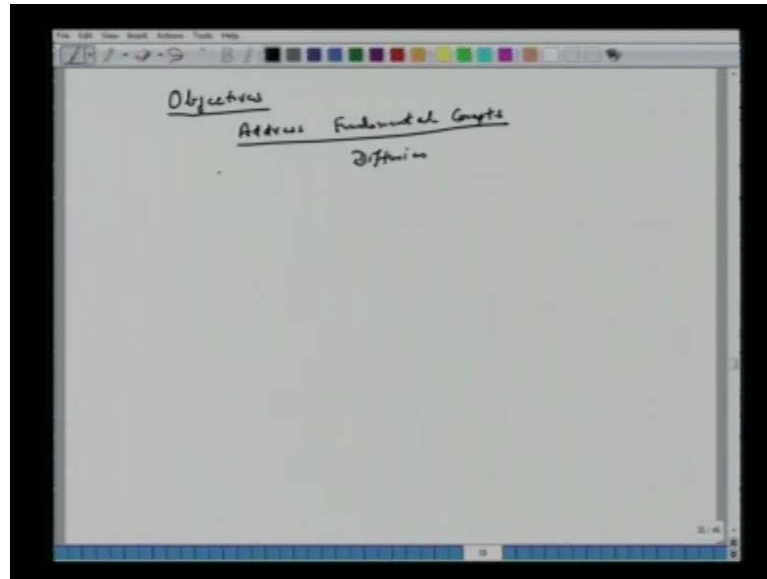
Let us note down again the objectives here in this course. The objective is the main objective is that you want to address, we will begin with fundamental concepts. When we fundamental concepts here will be essentially dealing with diffuser molecular diffusion.
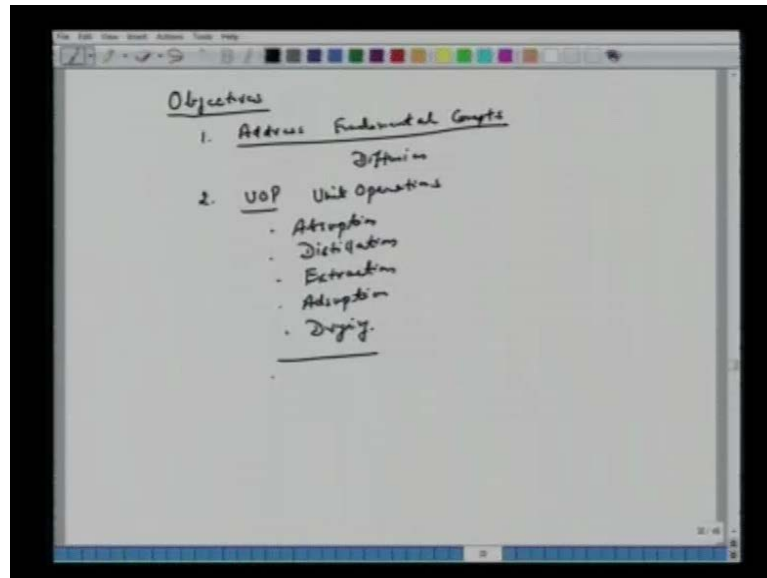
And then we will switch or we will start certain unit operations U O P. What are the unit operations which are listed in this course is absorption, we will begin with absorption. This is the way this course is divided starting with absorption, distillation; we have extraction, adsorption, and drying. Of course, we will begin with diffusion and then you may come across the parameters like mass transfer coefficient. We will have certain theories here which will tell us how to calculate these quantities like mass transfer coefficients.
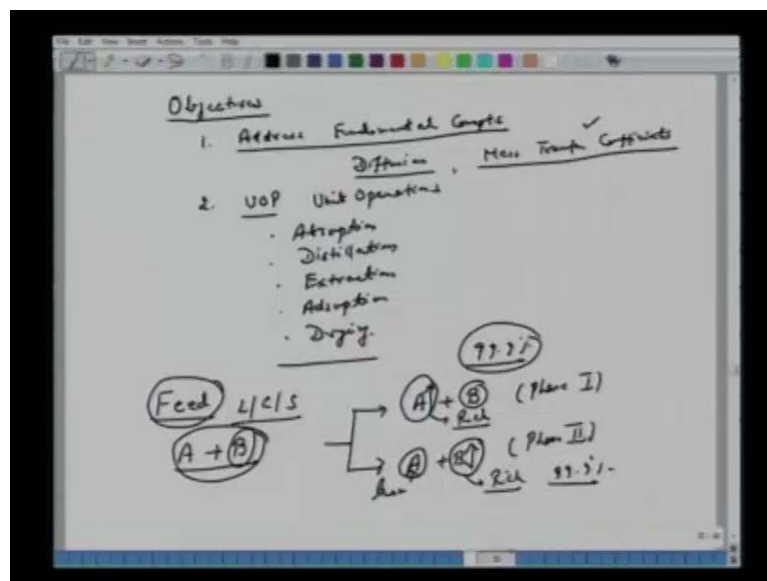
Before we begin take these topics here absorption, distillation or different unit operations. Let us try to understand what we do here. Let us say, we have a feed. When we feed this is our starting material. Now, this could be liquid or this could be gas or you can have even the solid phase. This contains let us say at least two components A and B and we have been asked to separate B from A, that means when we save separations practically, we do not have 100 percent in separations that means what we are expecting here that we will have two phases. Most commonly both phases contains A and B. However, in one phase A will be larger and the other phase B will be larger than phase one and this is phase two.

In phase one A is rich, it's richer than B. it has certain purity of 99.9 percent. Other components it is rich with B, so A is lean here. A is lean and it is rich in B and the composition here this could also be 99.9 percent. This is the way we are separating it. We have two phases in one A is very large quantities that is our desired product but B will appear as an impurity, we would not be able to 100 percent separations. In other phase, we have the second component B which is rich like 99.9 percent and A will appear as an impurities. Now, how do we achieve this going from the left, a phase, liquid, gas, or solid containing A plus B in 2 different phases in 2 different streams in which A is larger and the second is B is larger, we accomplish it through u o p unit operations.

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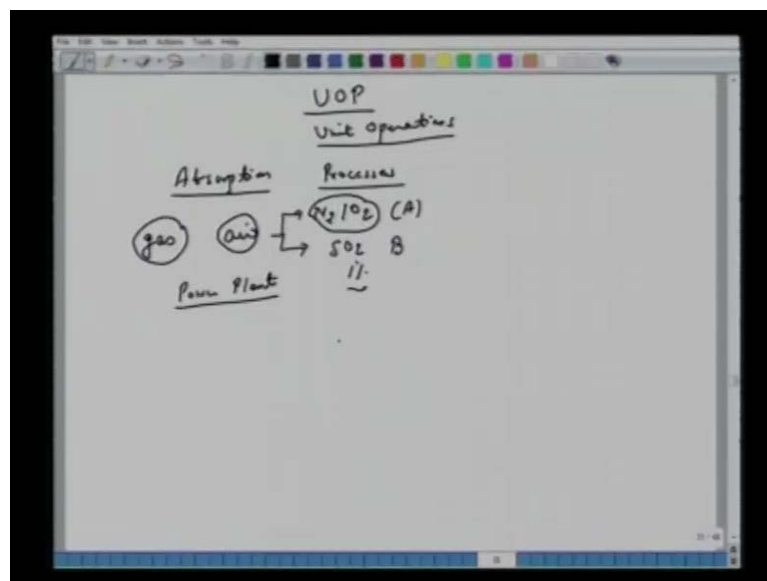
The schematic of this unit operation now does not like one unique geometry here. We have different type of unit operations, so we have absorptions. Absorption is one of the unit operations it is all ==(( ))== safe process when we unit operations we are saying that these are different processes. Let us give an example here that we have a gas phase and air. So, air it is in gas phase it contains we know nitrogen, oxygen and other species let say by enlarge this into or oxygen and the other species. So, this we call it as A when we you know it is a mixture of nitrogen and air in bulk quantities and the next B which we want to separate let us say it is the sulphur dioxide, which is very small quantity in atmosphere let us say maximum is one percent.

We are trying to here that this air, which comes out from power plant. It contains some amount of sulphur dioxide. So, we are aware of air pollutions environmental aspects. Air if it contains one percent of sulphur dioxide this has to be treated. One has to remove the sulphur dioxide from the air stream before we throwing to atmosphere, it is a regular. There are some environmental regulations, it is an air pollutant. What we do? How do we achieve? We bring in contact with water, water is a very good solvent and we can also bring in contact with caustic sodium hydroxide K O H etcetera.

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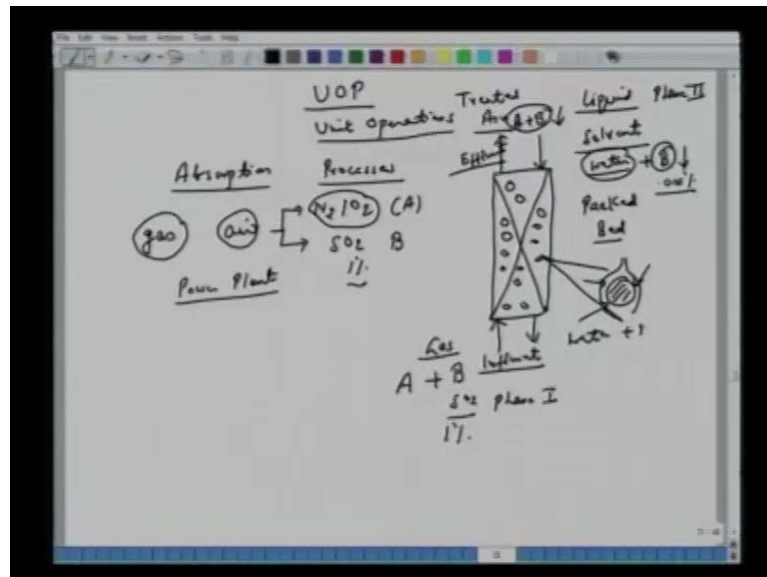
We are looking at to know the unit operations or the method or the process, which is absorption. What we do in absorption: we have this absorption column, which is packed. We will talk about that this will come back to this at later class. We have essentially

packed bit, there are certain packing inside. These packing what do they do, they improve contact between air, which we want to treat with water or let us put general solvent. We are talking of two phases: one phase is gas phase here which contains A, A for air you know, nitrogen plus oxygen plus the second component B, which is sulphur dioxide. We want treat with solvent, so it is a different phase, it is aqueous phase or maybe it is a liquid phase.

Phase II and this also contains same component water. This water could be pure, but very often this water is also contaminated with certain amount of B, which is very, very small quantity. One percent is possible, if this B may be 0.001 percent or we say water is pure. What we are doing here, we are bringing two phases in contact for through this packing PQ look at just one packing, this is some kind of solid materials water typical pass this and air or sulphur dioxide will diffuse into this, so it is going to be solid base. What we do, now we have air which is treated air it is effluent so well, let us call it influent and this is effluent air, but this effluent now contains air in which sulphur dioxide is very small quantities. Here we have A plus B, but this B is a very small quantity.

It is now look at what happens to this water solvent, now it has been solvent and flows passed this absorption column it picks up sulphur dioxide, which means now this water will also contain B the way it was here, but now B will be larger quantities. What we have done by absorptions it is in a unit operation, it is method it is a separation by which we have separated or we have removed sulphur dioxide from one phase, which is air here by bringing another phase, which is water here or aqueous phase or some other liquid and we have carried out this separations. Look at the both the streams: air after treatment and water after treatment. Air after treatment also contains A plus B, air and sulphur dioxide and water after treatment contains water as well as B, but this B is very small quantity and large in air.

So, when the air is coming out from the absorption column it is lean in sulphur dioxide but water or the sprint liquor contains very large amount of sulphur dioxide highly concentrated. We are been able to achieve these separations by absorptions, so there is a mechanism. Sulphur dioxide has a large solubility in water or certain solvent. You can choose instead of sulphur dioxide, if you have carbon dioxide then you have different type of solid.
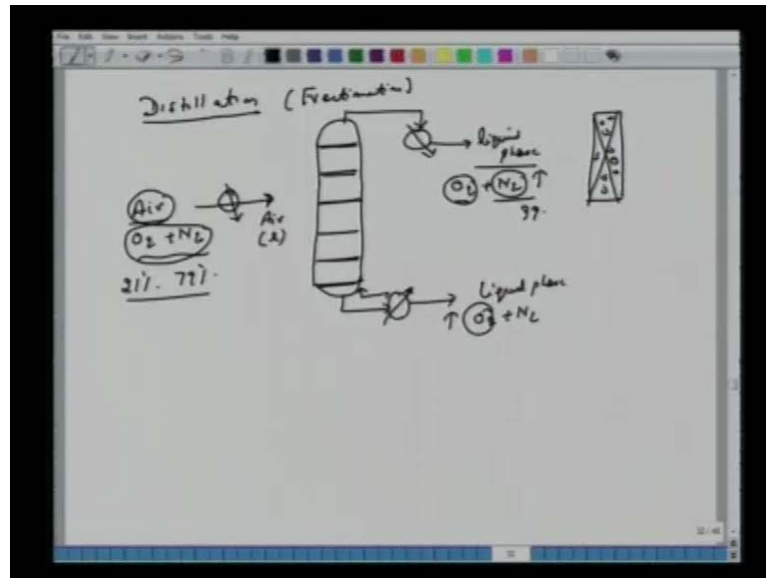
Let us look at different unit operations like distillation. Distillation is also known as fractionation. What here we want to achieve again start with air, we said air contains oxygen plus nitrogen. What we do now this air can be liquefied, so you have some heat exchanger. Now this heat exchanger is beyond this and it may be in different unit operations and different course we have deal with this heat exchangers. For our purpose this air which is gas phase here it is liquefied, so same air is now in the liquid phase. You bring to a column, you may have seen it or you may have seen or you may have seen in the textbooks at least the distillation column. It is a different unit operation. It has a different arrangement here. There we talked of continuous packed bed.

We have this tall column and it was packed continuously with certain solids, it is one type of unit operations. Here, we have different situations and different configurations. These are the trace. We will come back to this in the later class for the time being what we are trying to say here that now this air is brought in here. There is a heat exchanger. By distillations, it is possible to have the top quantities and the bottom quantities two phase here. This is also may be after condenser this is the liquid phase, but this liquid phase will contain both oxygen plus nitrogen, but nitrogen will be much larger here than oxygen. Similarly, at the bottom you will have some heat exchangers arrangements like this. We also have a bottom product, which is also liquid and this will also contain oxygen plus nitrogen, but it is possible here that this oxygen is rich.

We are talking of again separations; we want to separate oxygen from nitrogen. We are producing nitrogen in which oxygen is an impurity. Here if oxygen is in atmosphere 21 percent and nitrogen is 79 percent it is possible to achieve a much larger purity for nitrogen well nitrogen here is 99 percent and oxygen is 1 percent, on the other hand here oxygen is 99 percent and nitrogen is 1 percent. Look at the similarity between this unit operation, distillation and absorptions. Here we start with air, gas phase of course, we liquefy it is a liquid phase contains A plus B and we separate into streams both are liquid phase may be on the top we have the vapour, which again we have to liquefied into liquid phase, there also we have two different phases.

Top phase contains A plus B but is rich in A, Bottom phase contains A plus B, but is rich in B that is separation. What is the mechanism in case of absorption we had solubility, one solvent contains; has strong affinity for one type of species. What is the mechanism, this mechanism we will deal with later it depends upon relative volatility. We have to apply Raoults law. One component is more volatile then the other component, so it appears more in the top stream the one which is less volatile appears in this bottom. From the perspective of chemical engineering point of view both are unit operations and both have achieved separations. The idea is to separate A from B. Here we add energy or we take away energy to achieve the separation.

In case of absorption, we add a third component. We are adding a solvent to separate A from B, so there is a similarity in the two unit operations. There is difference in the unit operations. There is another important thing to note here before we give another example of unit operations, most of on these unit operations may involve chemical reactions and most of the unit operations may be non exothermal is possible, which means it could be production of heat or there could be heat loss reaction could be endothermic. For this course this reaction part of it we assume that reaction is negligible or it is not considered in our case. You have different course on chemical reaction engineering where we deal extensively with the reaction part.

We have very exclusively mass transfer. Why I am telling this, because distillation is possible to have a reactive distillations, so that is a different type of unit operations and there may be combination of distillation and the reaction or you can have extractive distillations so you bring another unit operations. Now talking of this heat transfer aspect of your certain separation process is possible could be exothermic or could be

endothermic. The absorption is possible with sulphur dioxide is absorbed in water that could be production of heat, so the reaction could be non exothermic.

Again, for most of the unit operations you will see that our discussion or analysis will be resuming that processes exothermal or we are neglecting heat transfer aspect except this distillations where, you will see that there will be different method where we have very comprehensive energy balance. There is another unit operation drying that will be our last topic here where you will see that we will have to make extensive energy heat balance. As we said that whatever unit operations, we have very extensive discussion on mass transfer aspect wherever required we will have heat transfer aspect.

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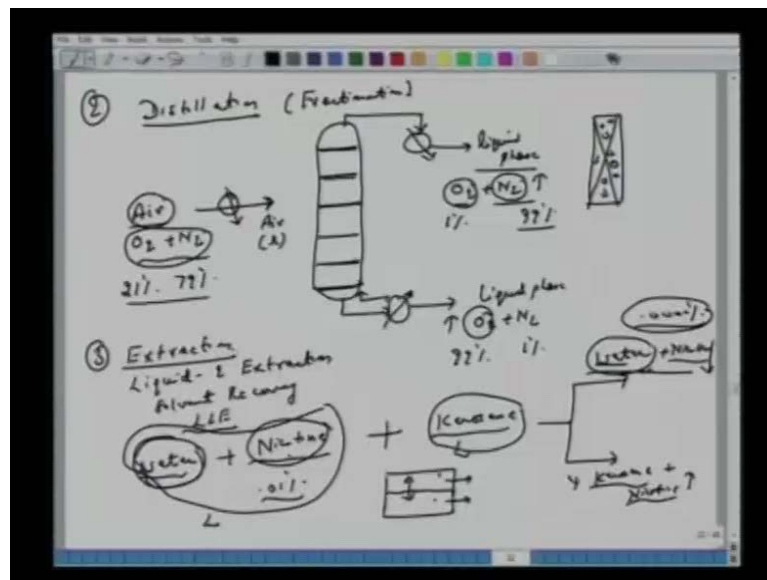
Let us continue and give another unit operation here is extraction. Just like we have absorption and distillation we will have discussion on extractions. What is extraction or sometimes just called liquid extraction and it is also called solvent recovery, LLE. What we have here look at this example water. Let us see water is contaminated with nicotine you must have heard of this toxic substance and organic substance. Water now, it is a liquid phase it contains very small amount of nicotine a very small 0.01 percent but this nicotine is injurious to the health, so how do we remove nicotine from water. Absorption may not work and distillation may not work, because they may not have appreciable amount of solubility or relative volatility.

LLE another unit operation where what we do you bring this liquid of water plus nicotine with another liquid like kerosene. Now, we have a liquid phase and we have also bring another liquid phase but different species of kerosene. Now, when you mix these two what you will get? you get two different phases. In other words, in a beaker if you take a small beaker and water nicotine and bring this kerosene you will see the two phases have appeared you can see them very clearly they all it mean they are immiscible.

Now both phase the top and the water will contain nicotine. So, one phase we are saying that water contains nicotine, but it is a very small amount another phase, which is kerosene will also contain nicotine and nicotine will be in very large amount. It is possible that certain kerosene will also appear here and certain water will also appear as possible, but what we have done essentially we have brought down this level of nicotine in this water by bringing another liquid here kerosene. So, that now this water, which contains very small amount of nicotine that is may be acceptable for whatever purpose we have.

This extraction is also similar to that previous unit operation of distillations and absorptions. Here, what we have done a liquid phase to bring another liquid phase, which is immiscible. So, that we have two phases and you transfer one component from one phase to another phase. Water at the end of this unit operations, you will have two phases both phases will contain nicotine, but in one case nicotine is very small amount which is tolerable and another phase is highly rich in nicotine. So, essentially we have achieved our objective that we have been able to separate nicotine from water, this unit operation is extractions.

I again talking of similarity, we have separation talking of difference. Now, we have different mechanism. What is the mechanism here, now we are talking about difference in solubility? Solubility of nicotine and water is different from that in kerosene. It is more soluble in kerosene, so kerosene is able to extract nicotine from water. What was the mechanism in distillation relative volatility? A component was more volatile in B. What was the mechanism in A absorption, A is more soluble in water. This is the way, we extract sulphur dioxide from air and water, which sprint liquor; which recollect contains most of the sulphur dioxide and air has become vapour. So, from practical point of view all these three are unit operations in which we have separations. There is a

difference in mechanism. We have different approach to address in certain set of problems.

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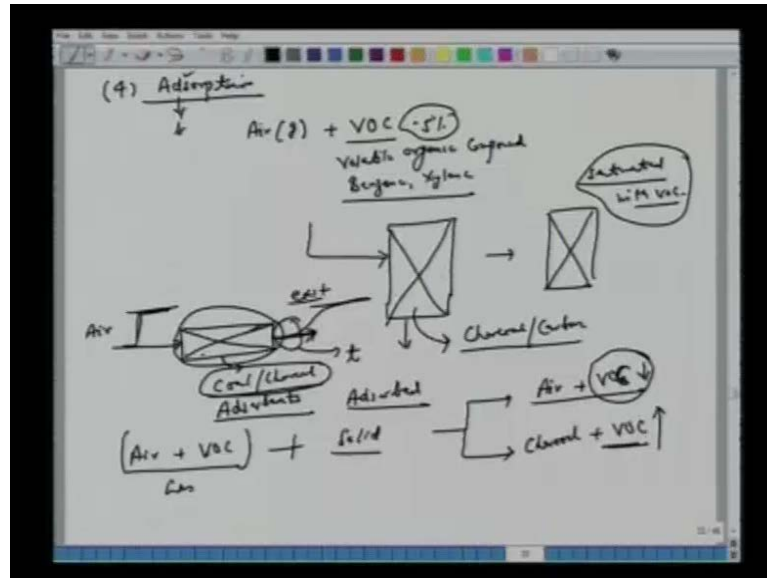
Let us take another example of unit operation which is adsorption. Notice here state of adsorptions B, we have this adsorption. What it is that air gas phase contains say contaminants like VOC; volatile organic compound. We have benzene we have xylene these are example of volatile organic compounds. It contains VOC very small amount 0.05 percent, so it is vapour toxic compounds and we want to remove this VOC, so what we do? We bring this stream of air in another packing. We have this again very similar to absorptions packed bed column. This packing is of charcoal or let say carbon. So, what happens here now brings in contact with this air here and then after sometime what will happens this charcoal bed or packed bed will become saturated.

This packed bed will be now saturated bed with VOC. If you start with again this packing, we have this horizontal packing, bring in contact with air packing of some coal charcoal. We will talk about different type of adsorbents; it contains certain level of VOC. In the beginning when the charcoal or these adsorbents are fresh then at the exit you will see that there is no VOC is coming out of it. We put some instrumentation here it will not be able to major VOC why? Because V O C has been absorbed by this charcoal. After sometime you will see that slowly and slowly this concentration will

increase at the exit, till this level has reached same as the inlet then one will have to stop it. What operation is here, we are starting with air which contains VOC.?

We bring in contact with a different phase, so this is gas phase. Now, we are bringing contact with the solid phase and here also we achieved separations. For this time t till the bed is saturated with V O C. we also have two phases: one is treated air this also contains V O C, but very small amount of V O C. For a long time this V O C amount is almost negligible and the second phase, which is stationary here is charcoal and this charcoal is containing V O C and this amount of V O C is slowly and slowly is increasing till it gets saturated. The adsorption is also very important unit operations. It is also used in water decolourisation, this very old practice and very old application of charcoals or just like today we have in case of water purifier.

You have continuously water you feed to this purifier; water contains lot of dissolved solids TDS is getting adsorbed in this charcoal or whatever adsorbents you have. For sometime till this adsorbent gets saturated, you have two phases: one is a water phase, but that contains very small amount of TDS; very small amount of fluorides and the second phase, which is stationary a solid phase, which is slowly and slowly picking up second unit component whatever we have fluoride, arsenic, TDS or volatile organic compounds. Once that bed is saturated, one has to regenerate this. There is unit operation we will be spending time on this adsorption.

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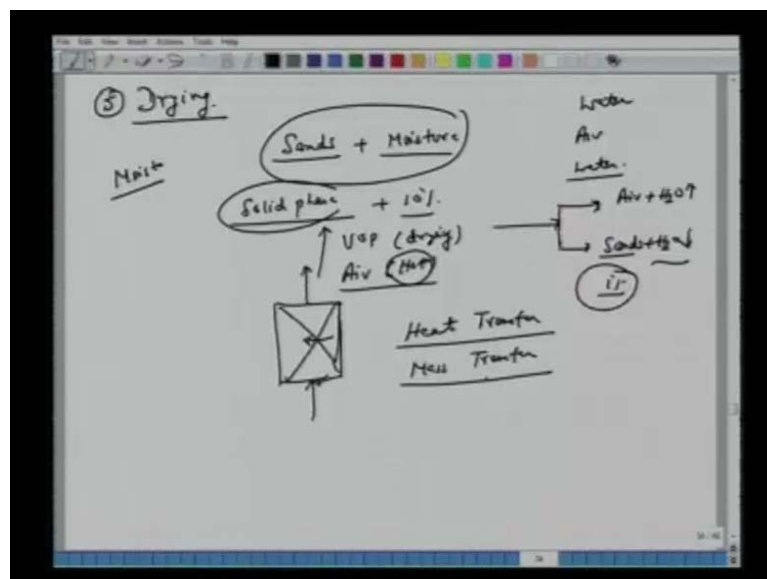
Then after that we will spend some time on this drying. What is that drier, you must have seen it you know even in household. We have sands, which contain moisture, some applications where sands contain moisture. Now, we are talking of solid phase sand, which we want to treat. We want to apply certain unit operation that this moisture, it contains a very large amount of moisture 10 percent. We want to apply this unit operation of dryer drying. So, what we will do now, one has to bring hot air. Look at the difference and similarity between the different unit operations. Here in the solid phase, but earlier we wanted to treat water containing VOC. We wanted to clean air from sulphur dioxide.

We had again water containing nicotine. We have the solid phase sands it is moist sand and we want to dry it that is called drier. Now what we will do, we will bring hot air and then still we will have separation hot air it will pick up moisture. Now, this air will contain moisture in very large amount slowly and slowly this will pick up as air will pass through some bed here you can have packed bed of sands. Let the air go through this, so moisture will be picked up by this air and, then whatever sands you have left in this stationary phase this will also contain moisture where this moisture amount will slowly and slowly decrease till it goes to the level of whatever acceptable may be one percent then your sands are relatively now drier.

Now again this unit operation, make a note of now we are bringing this hot air that means now we have to look at heat transfer. This is one unit operations, where we have both aspects of mass transfer as well as heat transfer. In the previous unit operations, for example; which we had absorption, extraction or adsorptions they can also be accompanied by certain release of heat or gain of heat or loss of heat, but generally for this course we are saying that this process is more or less isothermal that means the amount of heat released plus or minus exothermic or endothermic it is a negligible. Distillations if you notice very carefully, we started with air. We can also have liquid which we have to distil; whenever we have distillations there also we have energy considerations or enthalpy considerations.

These are the two unit operations drying and enthalpy, where you do have very exclusive discussion of heat transfer. Otherwise, the other three unit operations for this course you will have mostly isothermal process. Through this example what we have tried to know here that in all these unit operations we have some similarity and we have difference in

the mechanism. Now, what we want to achieve in this course or what are the other objectives that this course is about process design that means, if you choose absorptions what we will do in this absorptions that given the quality of air, how much sulphur dioxide it contains, given the flow rate of air, and given the temperature.

We will like to address questions like how much amount of water is required, solvent is required or how high what should be the height of the column or what should be the amount of this packing and what should be the diameter of this that is like process design mechanical design aspect, design of the flange, design of the disk head, you have some other course for this similarly, economy cost that play major role here. It should be take larger amount of solvent so that we have small column or should we have less amount of solvent and have a large column, there is a question of economy cost. Again, for that type of question to answer we have a separate course in chemical engineering may be at the fourth year level we have some at least one course on design.

Whether this is absorption, distillation or heat transfer we are exclusively discussing mass transfer and in that we are trying to address certain process calculations the amount of solvent required. Say in distillation column, how many trays we need 10, 20, 15, so that air which contains 21 percent of oxygen and 79 percent of nitrogen, now we have two products top product contains 99 percent of oxygen nitrogen and bottom product contains 98 percent of oxygen. Here, our discussion is confined to height for the amount of solvent given or amount of one phase required, how much is the separations, anything related to the separation mass transfer that is intension of this course. Mechanical design is not included here.

Heat transfer as I said we need to have certain knowledge of heat transfer, I am sure you have done in the second year we can say level fluid first law. Concept for even heat transfer coefficients may be will have some analogy here with mass transfer coefficient by that aspect, we will be addressing here. There is another thing here hydrodynamics and pressure drop. If you have flat column how much is the present drop. If you have the fluid or water flows through these columns will there be something called channelling have you heard of this channelling and mal distributions not necessarily water will be flowing uniformly through this. If it is non uniform that is not ideality, we have less separation.

Again for this course hydrodynamics is also not included. We have done some course at least one course in fluid flow at the second year or first year level, where you have addressed how much is the pressure drop. Some unit operations like absorption column we will be spending at least one lecture to address issues like loading and flooding. If you have the column air flows from the bottom and water flows from the top then you have that type of situations, where if the water flooded is very large entire column will be flooded with water. Certain hydrodynamics are very limited that we included in this course. Otherwise this course is exclusively about mass transfer, 90 percent can say mass transfer.

Some heat transfer energy balance we will have in the drying the last unit operations or in distillation, which we will take up after absorption. Approach all unit operations are different, yet there is one approach. If you have that type of approach then we can learn from one unit operations and we can apply to the second unit operations. In this course of mass transfer separation processes there are two approaches one is called rate wise approach and the second is called equilibrium approach. We have in a rate wise that there is finite rate transfer of this component one component B from one phase to another phase.

At one second 5 moles of a per meter square of interfacial area between two phases they get transferred from one phase to second phase that is rate based every time we are talking of rate. Second approach is equilibrium; here what will you say is, we have stages, cascades, certain devices, where we bring two phases in contact or two phases come in contact they spend some time. During that time there is rate finite rate, but at the end of that stage or the time we have two living streams which are equilibrium, it is equilibrium wise approach. From one stage, now we go to the second stages again bring the two components, two phases in contact again achieve this mass transfer then we have this equilibrium.

In the second equilibrium approach, we do not have finite or we do not have calculation at least for the rates. We work on equilibrium. We assume that there is equilibrium. The approach now again, it is our mathematical approach. In principle, we have the unit operations like absorptions, which are carried out in mostly in the packed column. In distillation we have trace, so you say physically trace most likely and very often we apply this approach of equilibrium approach. Similarly, when we see some equipment

where we have the two contacts in two phases in continuous contact like in a packed column then you will tend to apply this approach of rate.

In principle, it is possible the rate wise approach can also be applied in vary of trace or where we have continuous packed bed one can also apply the approach of equilibrium so that is also possible. What I am trying to say here that approach is one thing and the geometry the real configuration is the other thing.

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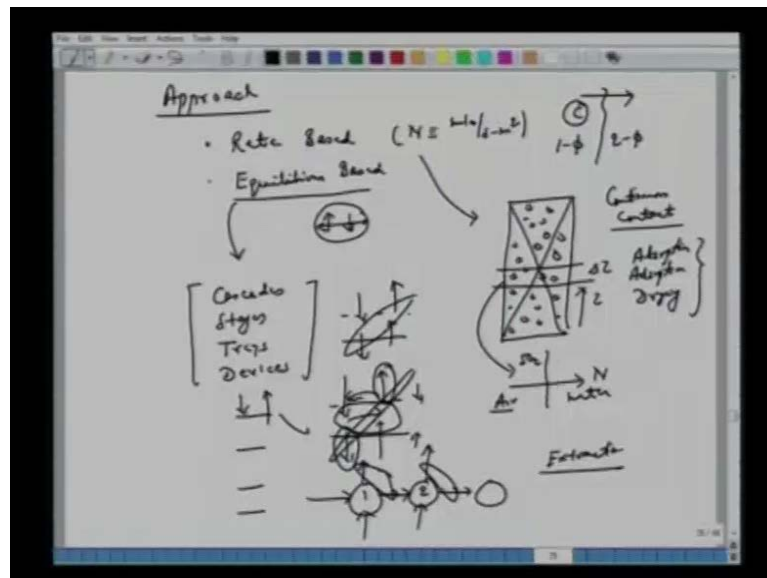
Let us make a note of this discussion here. Now we are talking of our approach to address different unit operations, each unit operations mind it is different. We have totally different treatment, but at least we can have a common approach. So, the two approaches one is rate based and second approach is equilibrium based. When we rate based say N, we are talking of certain moles per second per meter square is getting transferred from one phase to another phase. Let us say this is C component, which is transferred from one phase to another phase. Second is the equilibrium based; we are not talking in terms of rate, there are two phases and they have come in contact currently and they have reached equilibrium.

No matter how much time we spend to get that we cannot have separations, whatever has been achieved that is a maximum separation. So, again talking of some example of rate based is the most common example would be of this packed bed. We have packed,

bed packing. We have some solids, which provide very large interfacial area between two phases. We will come back to these aspects and details later in the class. Right now, we are saying that if you look at any distance let say z. we choose del z, here if you look at there is a finite rate of N at which sulphur dioxide is getting transferred from air to water phase.

This arrangement is continuous contact, which you can have in absorption and you can have in adsorption mostly and you can have in drying as well is just example. There you applied rate based approach. In equilibrium based approach what we do, now we are talking of cascades. We are talking of stages, trays, certain devices, contactors. So, we are looking at the trays like this. Liquid goes like this and vapors goes like this. If you look at one tray there is a pool of liquid, so water goes like this and air goes like this, so it makes very good contact for some time for some very small height in which one species has been transferred like this or this way.

So, here we are talking of equilibrium the phase which is leaving two streams, they are in equilibrium. You cannot have maximum transfer or whatever components, we have more than what you have achieved after this stream. Go to the second tray there you have the same situations here you bring in contact with liquids spend some time here then they leave equilibrium so it is a rate wise approach. You can also think of certain phases, in which one phase is brought in contact with the second phase. So, the two leaving streams they are in equilibrium they have spent some time to bring to the second stage. Stage two stage one and then bring in contact with some different solvent again if they get mixed and there they leave so notice the difference here. It is an equilibrium based approach.
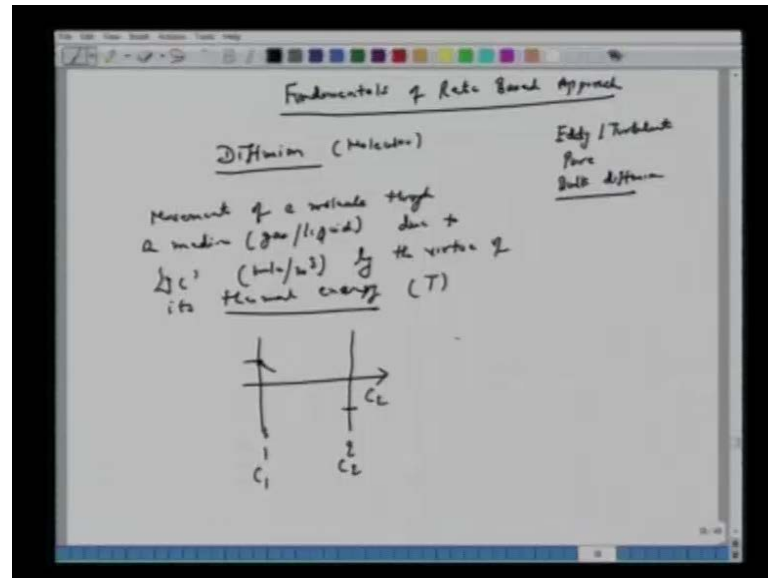
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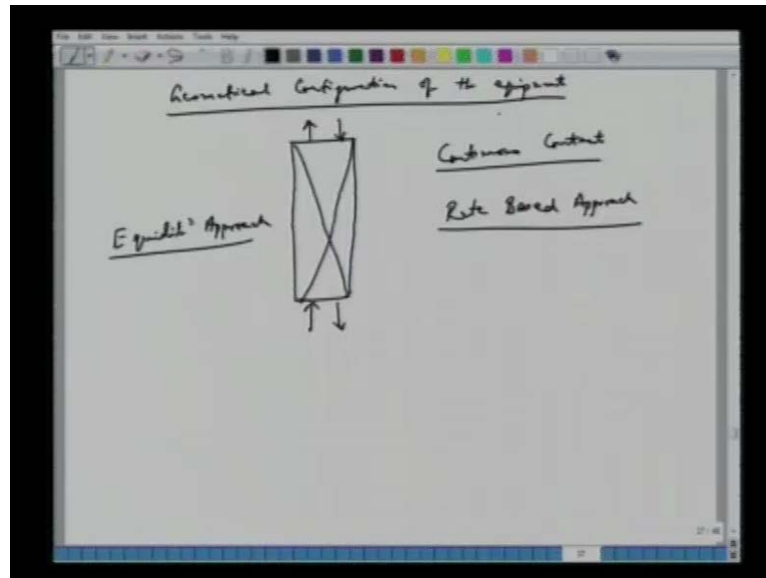
Here it is a rate based approach. You can give an example of extraction very commonly called is followed like this even drying can be done like this and adsorption can also be done by stage wise processes. Now, again we said that approach is one thing and actual geometrical configurations of the equipment is another thing, which means even if you have continuous packed bed like this, it is a real geometrical configurations air goes like this and water flows from this. We said that it is a continuous contact. There are no trays there are no stages, yet it is possible that we can still apply equilibrium based approach. This is also possible most commonly we apply rate based approach.

We want to conclude here that approach is one thing and real configuration is another thing. It is a critical approach how do we address, how many trays are required and what is the height of the column. One can in principle can apply any of the two approaches, in solving that type of questions whether it is a continuous contact vessel or there are cascades of trays, but in generally it turns out to be that if you have trays, sieves certain containers there you like to apply equilibrium based approach and if you have some continuous contact like in the packing packed bed column. you will have to apply rate based approach.

The second approach is: fundamentals of rate based approach. We talk of rate based approach the first thing is, we discuss here is diffusion and we are discussing molecular diffusion. When we say molecular diffusion, we are saying we are not discussing it is different from Eddy diffusion or diffusion in turbulent or pore diffusion or bulk diffusion. There are different classifications for this diffusion. What we are discussing here is molecular diffusion, we are referring to movement or transport of a molecule through a medium, which is be gas or could be liquid due to certain concentration gradient else so, for example: we are talking in terms of moles per cubic meter. Molecule is moving or getting transported because; of concentration difference moles per cubic meter by the virtual it is thermal energy.

Thermal energy is required for this movement of molecule from one plain to another plain that means the rate is going to depending on the temperature. We are talking of temperature. We have one and two and look at two planes; we have the concentration here at C 1 and C 2 if that happens that is oxygen molecule. There is a concentration gradient here, some level C 1 some level C 2 because of this will be transfer of the molecule from one plane to the another plane.
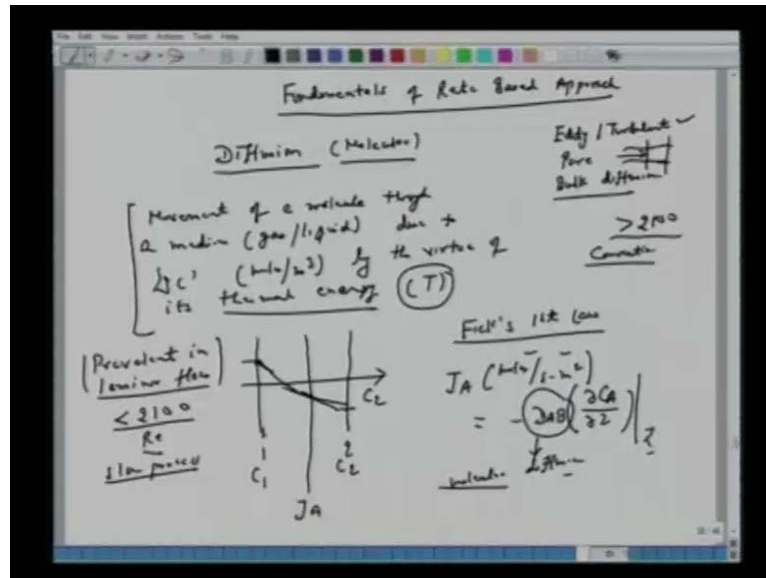
Now very commonly you have heard of this Fick's law first law. So, when we say application of Fick's first law, we are referring to transport or to this mode of transport, which is molecular diffusion, it is mostly will make a note it is prevalent in laminar flow. So, let us say in a tube if you have hydrodynamics as I said earlier the Reynolds number is less than 2001 it is a very slow process. So, we are talking of molecular diffusion unlike turbulent. Eddy diffusion then we are talking of very large Reynolds number in which this molecular diffusion is still prevalent, but still different but net rate of transport of this molecule is much higher in turbulent, so there is no defect of convention there. There are Eddy's there similarly, we need to talk of poor diffusion when molecule here also gets diffused that transfer from one plane to another plane, but by different mechanism. The presence of wall makes a difference.

We are talking of molecular diffusion where Reynolds number is less 2100 prevalent in laminar flow driven by this concentration gradient, but it depended upon temperature. Increase the temperature rate will also increase. It is most of revision you must check down some level here. Fick's first law is the one which gives us at what rate molecules or moles in one second will diffuse from one plane to another plane. We have given as minus DAB del CA over del C2. This is a gradient that means have a concentration profile like this. So, what is a flux here J A moles per second per meter square, you find a gradient at this plane.

So, at that plane what is the gradient multiplied by this molecular diffusivity. So, just go through certain textbooks or even Treybal they have first couple of lectures on this Fick's first law.

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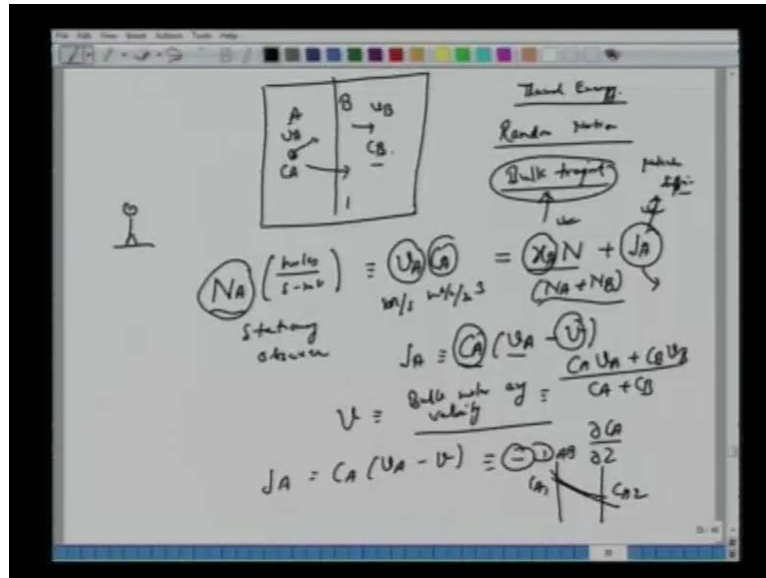
In reality what happens, let us say when we have some closed box here and let us say we have A and B two molecules each molecule of A, it moves with certain velocity V A. Let us say if absorber is stationary here he will notice that this molecule of A is moving in one direction with concentration at this location is may be C similarly, V B concentration is C. Why this molecules move in different directions one is thermal energy, we are talking of random motion. In addition to this random motion, it is also possible that may be there is a pressure difference and as a consequence this molecule can also move in some directions, that means we are talking of a transport or flux of A moles per second per meter square having two components.

One so most fundamental would be N A moles per second per meter square is equal to VA C A; it is velocity, it is the concentration meter per second. We are talking of moles per cubic meter so we have this flux. At any plane, if I notice draw here what is a flux I can major it by VA C stationary object, so this observer is stationary. We will measure VA C, but this will contain two quantities. One say the mole fraction of this species is X A of this plane, so X A into N. What is N, N is nothing but N A plus N B. There is one component when entire A plus B they move along with this and they also carry this X A

plus said that there is another component, which is Fick's first molecular diffusion, so this diffusion is over and above this N A.

In other words, what is J A flux how we will you measure this is nothing but C A V A minus V. So, what is V here, V is the bulk molar average velocity. We are defining C A V A plus C B V B over C A plus C B. We can try to understand, what we are saying what is distally observer will observe will measure two components. One by this bulk convention called bulk transport and another component is over and above this bulk transport. In other words, it is possible that N A plus N B is 0. There is no X A N equal to 0, but is still because of concentration difference by Ficks law one can measure this in J A, which is C A concentration of species at A velocity is V A over and above this bulk average velocity.

This J A we can rewrite as C A V A minus V, which we have defined here and this is equal to minus D A B del C A over del z. Y del minus sign it signifies that the gradient is negative. Species moves or transport diffuses from high concentration level to low concentration level so we have this negative but more important here is the definition or fundamental understanding of this molecular diffusion from bulk transport. The species gets transported why, because one is concentration difference this can adjust irrespective of whether there is a pressure drop or there is no pressure drop. There is a concentration gradient Fick's first law. The observer who is moving with the bulk average velocity so all species A and B they are moving in different directions.

We can always define a quantity as if the fluid is one, so it has a velocity V, which is dependent upon V A and B so if the observer moves with V so relative velocity is 0, he will observe certain move flux. He will major certain flux because of this concentration difference where we call J so two are different J could be 0, if there is no concentration difference. We can have V A into C A that means all concentration everywhere is C A, but there is a velocity may be because of natural convections, heat transfer difference and temperature difference. This is the first introduction to your very basic of mass transfer. We are talking of N A flux moles per second per meter square, which will have two components, bulk transport and this diffusion component, which is given by Fick's first law. We will again revisit this aspect in the subsequent lecture. Thank you.