Mass Transfer II
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Lecture No. # 24

In today's lecture, we start a new unit operation – extraction. This extraction is also known as liquid-liquid extraction. In some cases or some text books, you will see it is also known as solvent extraction. Here what we have? We have one phase – liquid phase; we add the second phase, which is also liquid. So, essentially, we are talking in terms of L 1 and L 2. One phase of liquid, say for example, contains A plus B or A plus C; one would be feed containing say contaminant C and we want to extract this C from A. To do that, we bring another liquid, which we call it solvent. So, we have the solvent phase; we have a feed phase; we add this solvent; agitate them; bring contact within two phases. Then, extract C into the solvent phase. So, when we have the mass transfer, at certain rate, allow this liquid to settle phase of A plus B plus C. Then, we will see phase separations.

There will be two phases; or, these two phases are liquids. So, we have L 1 and L 2. One is extract. So, essentially, solvent, which you have added B, has extracted C into this. So, that phase will contain very large amount of B solvent and most of the C from the feed phase has gone into that phase. You have the second phase – we will call it raffinate. Remember – if we use this word extract in raffinate, in the first introductory lectures, we had on this cascades or a stage wise. So, here now, we have the raffinate, which will contain like a residue that will contain small amount of C in A. So, essentially, try to understand the difference between these unit operation extractions with the previous two unit operations, which we discussed: absorption and distillation. In absorption, we also have A plus say B; air contains sulphur dioxide, two components and one phase.

What we did? We brought in this phase with a new phase – liquid, water; water does not contain any sulphur dioxide; it is for simplicity. So, we are bringing another component and another phase here. And then, sulphur dioxide is getting transferred. So, at the end of the day, we have two phases: gas phase and the liquid phase. Gas phase contains less amount of C, sulphur dioxide. And the bottom product, which is spent liquor – spent liquid in this case, contains large amount of sulphur dioxide. So, one phase brought in contact with the second phase new component and then we have these separations. The mechanism here is solubility. Then, we talked of distillations. We have liquid phase, feed or we can have vapor phase; we talked about in the previous lectures – q line, different values of q, etcetera. So, we can have a liquid or vapor – contains two components: A and B. How do we separate? We do not bring any third component. We give energy – heat. So, essentially, we have these distillations. Now, you have two phases. Top product – say it is vapor phase; it can be condensed as a liquid. And then, bottom – you have this liquid phase. Both contain A plus B and A plus B; there is no C here. But, in the top product, we have very large amount of A, very small amount of B; and, in the bottom, we have very large amount of B and small amount of A.

What is the mechanism of separation? Relative volatility. So, depending upon the volatility of A with respect to B or vice versa, we have these separations. So, the difference between absorption and distillations is one we can see that in case of absorption, we brought in a new component – C in the form of water. And, we have the two phases: gas and liquid. In case of distillations, we do not bring any third component; we bring energy and then we separate by some mechanism. In extraction, what we have? We have liquid – contains two components say A plus C carrier, bulk amount; and, we have C contaminants; and, we have been asked to separate. For some reason, we cannot use distillations, because when we give energy, first will that the mixture of A plus C degrade, decompose. So, distillation will not work. We do not have a new solvent, which is going to have different solubility for C. So, absorption will not work. So, what will work? Let us try extractions.

In extraction, what we have? A plus C. Now, we have A and C. Let us say C is soluble, miscible in A. How do we remove? We bring another solvent B, which is immiscible with A, but miscible with C. So, what B will do? Will bring A plus B plus C in contact, agitate, mix them, allow for the mass transfer, and then, allow them to settle. So, separations. When they settle, we will get two liquids – immiscible liquids. So, they will separate by the mechanism of density difference. That is only for the settling. But, C has been now distributed between the top phase and the bottom phase; both are liquid. So, one phase, but we are saying that it is L 1 phase and L 2 phase – extract and the raffinate. Now, C is getting distributed. What is the mechanism here? Different solubility, two phases – C’s solubility in A is different from solubility of C in solvent, which you are trying to add. So, mechanism of separation is solubility difference. But, still we have two phases: L 1 and L 2; may not be like liquid and vapor; not like liquid and gas; it is L 1 and L 2; two immiscible liquids. Very often, it happens in case of organic and inorganic solvents. We will talk about those examples later.

Let us try to understand again. We have A plus C; we bring B; C distributes. Maybe in the extract, it has very large quantities – 98 percent. And, in this bottom, this residue or this raffinate phase, we have very small amount of C. So, here we are adding a third component similar to absorptions. But, now, here the difference is that the C is getting distributed in A and B by different mechanisms; there is distribution coefficient; there is a partition coefficient, etcetera. So, let us see what will be our strategy to address this type of unit operations. We will take some examples – industrial examples, where you have separations. If you remember, in the first few lectures also, we talked about…; when we were discussing about cascades or a stage wise, we said nicotine, water and kerosene. So, water contains nicotine soluble; nicotine is injurious to health; carcinogenic compound. We have been asked to treat this waste water, potable water, whatever water. Maybe for some reason, we cannot use distillations; maybe for some reason, we cannot use absorptions or desorptions to desorb nicotine. But, we have this extraction; we bring solvent kerosene. This kerosene can extract nicotine, because nicotine has larger solubility in kerosene than in water. So, here there is analogy between different unit operations; and, there is a difference also between the different unit operations. So, let us just sum up here before we address these extractions.

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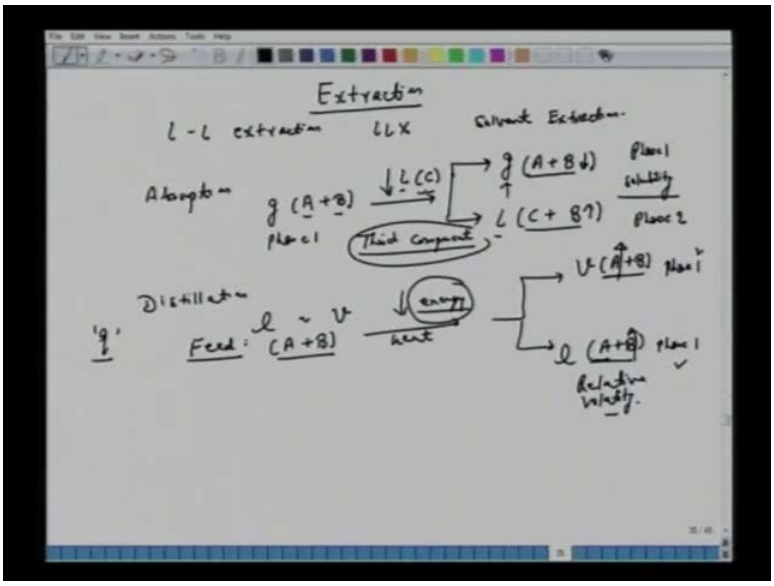

In today’s lecture, we begin a new unit operation – extraction. It is also known as liquid-liquid extraction or L-L extraction or just L, LX or in some cases, you will see, it is called solvent extraction. All of them are very similar. And, just for our record or for our understanding, absorption – we had typically gas phase. So, we have phase 1; two components system – A plus B – air and sulphur dioxide. We have been asked to remove, separate B from A; what we have done – we bring liquid different phase – say component C – water. Now, we have this separation – two phases by mass transfer: one phase is gas; one phase is liquid. Gas contains A and some B, but B is very smaller (( )) Liquid contains this C – water, but very large amount of large concentration of B – spent liquor. So, here addition of liquid – third component; here we have added third component. And then, we have mechanism here – you can write – it is solubility.

What happens in the case of distillation? We have say liquid phase or vapor phase; feed – we talked about q line, etcetera. And, both of them contains A plus B; either liquid or vapor. So, that is our feed. And, we want to separate B from A or A from B. What we do? We add energy; it is now different component. Here we are adding L; here we are add energy – heat. This heat causes separations: we have vapor phase and we have this liquid phase. Both vapor phases contain A plus B. We notice the difference: A plus B here and C plus B here (Refer Slide Time: 10:32). Now, water can also evaporate into this gas phase, but if you neglect this evaporation of water, which should happen, then you have this gas phase, liquid – A plus B and C plus B. In distillation, you have A plus

B and A plus B, except here A is more volatile; then, A will be very large. And, in this case, B will be very large. So, we have 99.99 percent; we saw those examples in the earlier class. And, here we have this liquid, which will be rich in B or very poor in this A (Refer Slide Time: 11:01). What is the mechanism here? Mechanism is relative volatility. And, we have phase 1, phase 2 – phase 1, which is a gas phase and phase 2, which is liquid. We have phase 1 for the vapor; phase 1 for this liquid. And, difference is here; we are adding energy. Here we are adding a third component – water.

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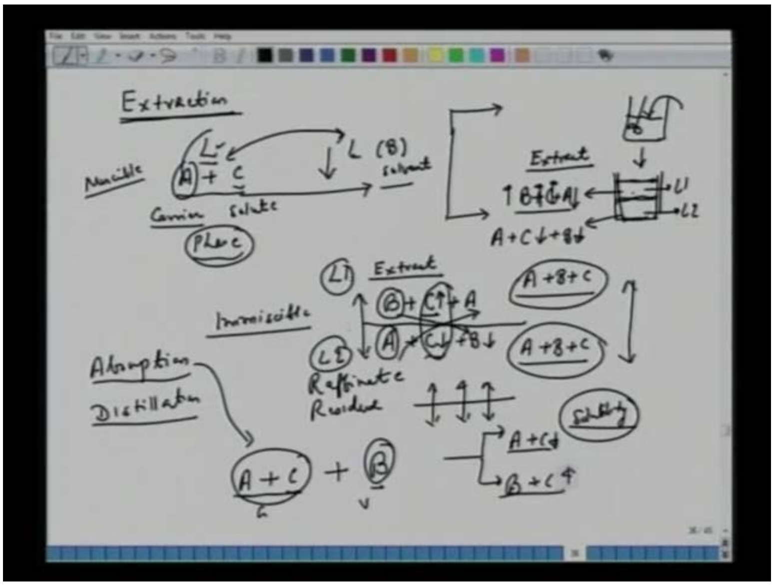

Let us see what happens in extraction. Very simple example – we have phase; phase is one thing and component is another thing. So, we have a liquid phase – it contains two components: A plus C. Typically, A will be large; C will be small. We will call this C as solute; A – we will call it as carrier. One more important is that we have phase; liquid phase here. And, we have been asked to separate C from A. What we do here? Now, we add another phase and another component. We are adding a liquid say B – different component – we call it solvent. So, one – this liquid is being added to this second liquid. Now, C and A – they are miscible, solubilized; but, the one we are going to add here – B must not be miscible in A; or it should be a partially miscible in this. So, we will talk about the phase diagram or the different systems: system one, type one, type two, etcetera, where it is possible; I know different (( )) situations are possible. So, right now, we are saying that we are adding a solvent to extract this C. Hence, this component B is insoluble in A. Now, when we do this, we bring in contact; we have agitation, etcetera.

Now, we separate and then allow them to settle. We will say we can visualize – we have taken A plus C; we have added B; we stir them for sufficiently long time; allow them to settle. We will have two distinguished liquids. They are separated now by densities. Heavier liquid will settle here; (Refer Slide Time: 13:45) lighter liquid will settle on top of it. Visually, you should be able to see that there are two phases: L1 and L2. This L1 typically will contain say B extracts solvent. So, most of B has come here and it will carry with it large amount of this C. There may be some amount of A here also. So, we said earlier that the different types of systems, etcetera – type one, type two; but, typically, what we are trying to say here that both L1 and L2 will contain B plus C plus A; all three of them – A plus B plus C. So, now, B is a solvent. It picks up C; very large amount of B, large amount of C, but small amount of A can also go in.

We will call this as extract (Refer Slide Time: 14:47). Extract because we have very large amount of solvents; B is extracting it as a solvent. So, very large amount of B and most of C has gone here. This L2 phase will also contain A plus B plus C. We will expect that now we have very large amount of A, which was our feed and very small amount of C here, because most of C has gone here. And, it is possible that some B will also get in, although very small amount. So, what we have? Extraction – at the end of this separation or equilibrium, we have two phases: both phases contain A plus B plus C – L1, L2. And, these two phases are immiscible. Altogether we have new types of a fluid mixture: A plus B plus C; A plus B plus C. But, two are totally distinct; they are different.

Other than this density difference, we have different amounts of A plus B plus C. L1 – we call it extract to signify that this contains very large amount of solvent. A solvent has picked up C – most of this C, but it contains A also. Similarly, this L2 – we call this as a raffinate or residue. So, this is the second product. This will contain… You will expect carrier, large feed and a very small amount of C, but some B will also get carried over here. So, both are A plus B plus C. But, in one case, we have extract solvent – it has taken away with it most amount of C; and, the second phase has feed A, which we wanted to purify, we wanted to remove this C out of this – it will contain some amount of C and there will be some carryover. So, there is a partitioning of A, B, C in both phases. So, this is a difference. Try to appreciate the difference between this unit operation extraction from the previous two, which we discussed: absorption and distillation. Here the mechanism is also about solubility, but makes a notice, the solubility is not just about C. We are talking of now solubility of all three components: A plus B plus C. To what extent there is a carryover of B in this; to what extent there is a carryover of A; and, partitioning of C – larger solubility in this extract phase and very small amount of carryover of C in this raffinate phase. So, the solubility is mechanism.

See the difference between these absorptions… What we did in case of absorptions? We had A plus B. For say A plus C, air and sulphur dioxide, we added B, water; two phase. And, this contains two components: (Refer Slide Time: 18:19) this is a pure component here – liquid, gas and vapor. But, look at the separations. We have A plus C; very small amount of C, but now, we have B and plus C. It is a gas phase; it is a liquid phase. Unlike here, we have clear partitioning between the two phases, which are liquids: L1 and L2; immiscible; we can see the difference. We are adding a solvent to liquid – one liquid to another liquid – to have a separation between two different types of liquid. But, both of them – L1 and L2 contain A, B, C; A, B, C. It is a very popular unit operations used in several industrial applications. So, this is the introduction for extractions.

Now, before we go many far, you must understand the difference between extraction and the previous two unit operations from mechanism point of view; or, from the phase – what phases we are talking; what components. By default, extraction is a ternary; it is a three components mixture we are talking of. We have two phases. Both contain A plus B plus C; A plus B plus C. Unlike in the previous two cases: distillation, absorptions, we talked of mole fractions of A and B; X A 1 minus X A; X B 1 minus X B; Here we have to talk in terms of X A, X B and one minus X A minus X B for C for both phases – extract and the raffinate. So, there is a difference; there is a similarity in both cases.

Now, let us take some examples – industrial examples of extractions. This is also very quite popular especially in petroleum or refining industries. In refining industries, you have distillation column. If you happen to visit one of the refinery industries, you will see heart of the plant is distillation column. You have feed crude oil liquid; and then, you distill and you fractionate. You have different types of products. At the top, we have very light gas – methane, ethane coming out of it – C 1, C 2; then, you have naphthene; you can have kerosene; kerosene, naphthene; then, maybe heavier liquids like paraffins, lube oils. So, there you are trying to separate by distillation, change in the relative volatility. But, to the bottom products, which is lube oil; very heavily, its extraction becomes very popular here. There you have to extract by making use of this change in the solubility of one component in another components.

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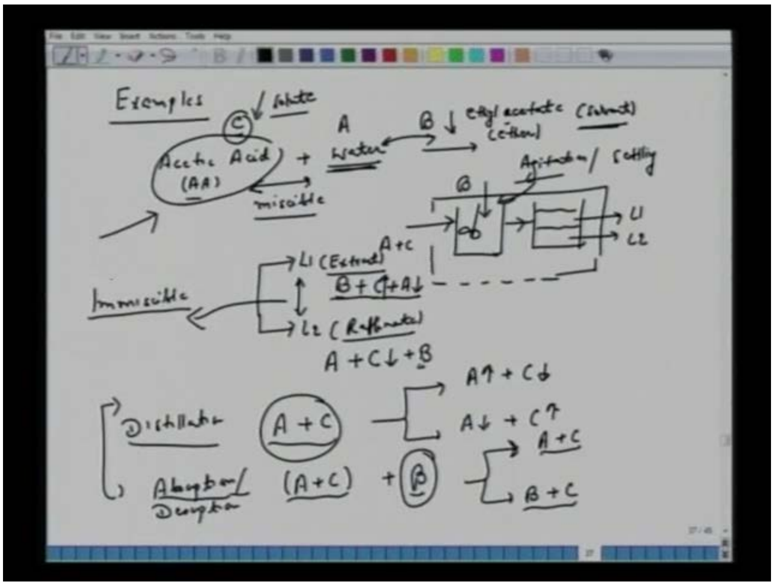

Let us just note down one or two examples of extraction. The examples – We have acetic acid (AA) and we have water. So, these two are miscible. Let us call this A; let us call this as C. So, typically, we have solute represented by C. So, water contains some amount of C; small or large; that is not important right now. All we are saying that they are miscible. We add ethyl acetate; ethyl acetate – also known as ether. So, we add B – ethyl acetate; A is insoluble or partially miscible in B. So, we mix the two; we have agitation; allow for settling. So, typically, this extraction – you will see it is represented by tank for agitation and then you say that you have a settled just like this.

For entire extraction, from the principle of operation, contains two large vessels: one for agitation; one for mixing; where you have this A plus C and you have added B. Allow them for some time. Then, bring to the next vessel, where you allow them to settle, where you will have two phases: lighter and the heavier. So, going back to this example of acetic acid in water and you are adding ethyl acetate or ether, you have two products: L1, L2; both are liquids, but they are immiscible. L1 – we call it extract; for the reason, we are using this ethyl acetate as a solvent (Refer Slide Time: 23:54). So, you will expect most of ethyl acetate; ether will come here. This will contain very large amount of C, acetic acid, which is the solute; you wanted to purify this water from acetic acid. So, very common example – water contains acetic acid in some applications. So, B plus C – very large amount of C, but there is a very small amount of A as well. So, water has now also partitioned into this – B plus C plus A; you have L2 – call it raffinate or residue for the reason that this feed A – most of water has come here, from which we wanted to remove this C. So, there is some amount of C; very large amount of C here (Refer Slide Time: 24:53). But, there is some amount of B, ethyl acetate or solvent here also getting carried out. It is a very good example, typical example of extractions.

How do we separate acetic acid from water? We use ethyl acetate and separate them like this (Refer Slide Time: 25:11). We cannot use distillations, because there is a risk of this acetic acid getting decomposed there. Although it is possible that there is a relative volatility, a difference in the volatility between the two components… (( )) We are trying to say that if we use A plus C in distillation, then what we will get? There is no B there; we do not have to add any B. If we can do that, we will have a vapor phase that will contain large amount of A, small amount of C; we will have another phase – it will contain small amount of C of a very large amount of this. If we will have absorption, if we can use absorption, then again we will add. So, this is one phase – liquid. So, actually, instead of absorption, we should use the word desorption. If we can find solvent like a steam we used in the previous examples for absorptions, this A plus C; maybe we add another component B and then we will have a (( )) situations – A plus C; but, you will have also B plus C. So, you notice, it is not A plus B plus C nor this is A plus B plus C. So, in this case, because of the limitations or whatever relative volatility or finding a new type of solvent, we have extractions – works very nicely for this.

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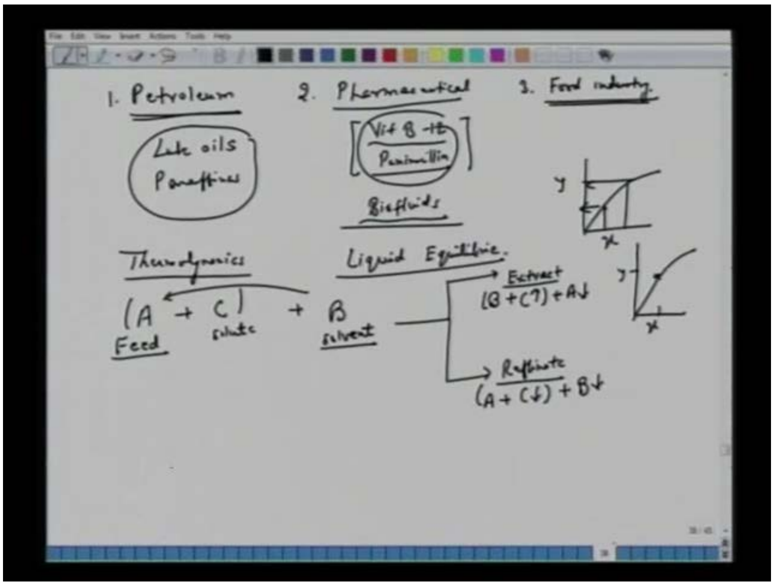

As said earlier, there are several examples. Petroleum – for your understanding, it is recommended that you go through the text book Treybal or the book by Dutta. And, go through some of the very common typical examples, which you find in petroleum industries or pharmaceutical industries or even food industries. These are some of the examples you will find. For petroleum, like I said, there were very extensive use of extractions in separating a number of components from lube oil or paraffins to waxes, etcetera. It is very extensively used in such applications. Pharmaceuticals – species compounds – let us say, vitamins B 12, maybe penicillin, erythromycin, amoxicillin, etcetera. One can make use of this extraction to extract vitamins B 12, all these pharmaceutical compounds from bio fluids. So, it is used very extensively. Food industries – extraction of certain juice, etcetera; you cannot use distillation, because all these count, all these items, quantities will decompose. So, extractions work very nicely. It is recommended you make use of several examples in the text book by Treybal or by Dutta.

We begin first with thermodynamics. Our approach is same for p had adapted for absorption and distillation column. One has to establish liquid equilibrium. Just like in case of absorption, we started with absorption – Henry's law. So, there has to be some equilibrium curve – y versus x. Given this y; so much is x. Given this x; so much is y. Here also, we have liquid equilibrium. For case of distillations, we also have y versus x based on Raoult's law. We fix the temperature, fix the vapor pressure and then fix the two compositions. So, here also, we need to have liquid equilibrium. So, essentially, we have A plus C; feed, solute or carrier; C and A – if they are completely miscible, we bring in contact B solvent. B is immiscible or partially soluble in A. We have this mixing; then, settling; we separate as two phases – two immiscible liquids: extract... But, both of them are ternary mixture unlike we have handled barrel mixtures. So, here we will expect extract – B plus C – very large amount of C and small amount of A. In this case, (Refer Slide Time: 30:06) you will expect feed, small amount of C and some small amount of B as well.

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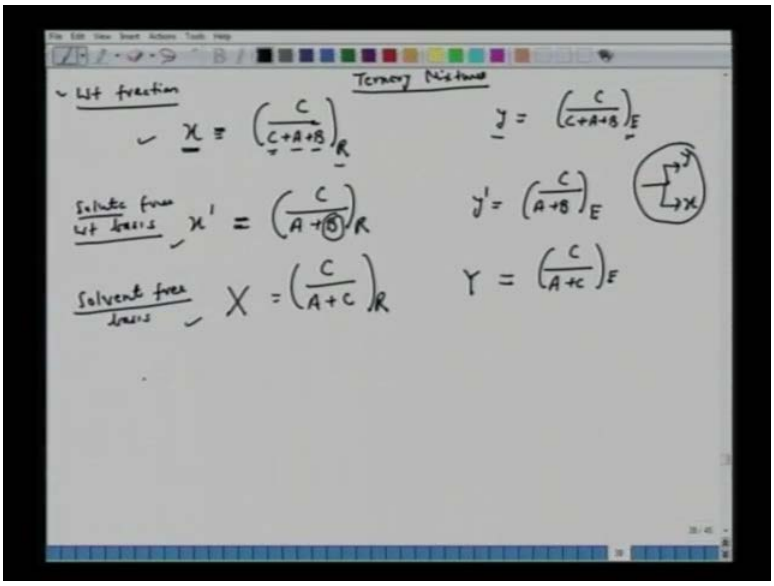

Ternary Mixture

Wt fraction

$$x = \left(\frac{C}{C+A+B}\right)_R \qquad y = \left(\frac{C}{C+A+B}\right)_E$$

Solute free wt basis

$$x' = \left(\frac{C}{A+\textcircled{B}}\right)_R \qquad y' = \left(\frac{C}{A+B}\right)_E$$

Solvent free basis

$$X = \left(\frac{C}{A+C}\right)_R \qquad Y = \left(\frac{C}{A+C}\right)_E$$

And, what mole fractions we use here or what nomenclatures we use here is – first is x or we work on mostly weight fractions. This becomes more convenient in extractions than on the mole fractions. Of course, mole fractions will also work. But, generally, typically, we have this weight fraction. We have x defined as C over C plus A plus B. So, now, you should be able to notice the difference between the extractions and previous absorption or distillation as far as our mathematical treatment is concerned. And, we make a note here that therefore, this is a ternary mixture. Both phases: raffinate and extract – they are ternary mixtures. So, we have x C over C plus A plus B in raffinate; we will use y as C over C plus A plus B in extract. There is no obvious reason why we are using x for raffinate and y for extract. But, traditionally is vapor phase, which is lighter, we use y, the one which is liquid; heavier – we use x. So, maybe there is a reason that extract in all the text book is represented by y and raffinate – we have represented with x as weight fractions. So, we are going to use x and y.

Similarly, one can also use x prime, which we will call it as a solute free weight basis. So, again here notice – this is not the first time we are using this solute free basis; in previous also, we had this type of representations when we discussed absorption. Then, we also discuss solute free or solvent free basis. So, now, we have x dash, which is solute free basis. That means this is C over A plus B raffinate. So, notice the difference here – solute free basis; some of the computations becomes quite simpler if we work on this solute free basis. Similarly, we will have y prime, which is C over A plus B; no C here in the denominator and we have this extract (( )).

There is one way of representation – also by solvent free basis. Here we use capital X. We should recall discussion on absorptions, which is C; now, (Refer Slide Time: 33:02) this will be A plus C. So, no solvent. Remember – we had B as a solvent; A as a feed; C as a solute contaminant, which you want to separate; and, we added B as a solvent. So, this is solvent free basis nomenclature; capital X as C over A plus C. So, corresponding to this, we have Y as C over A plus C. So, we have extract and this is also this is a raffinate. So, these are the three very common phase of representing these weight fractions: one is the simple x; another is solute free basis; and, the third is solvent free basis.

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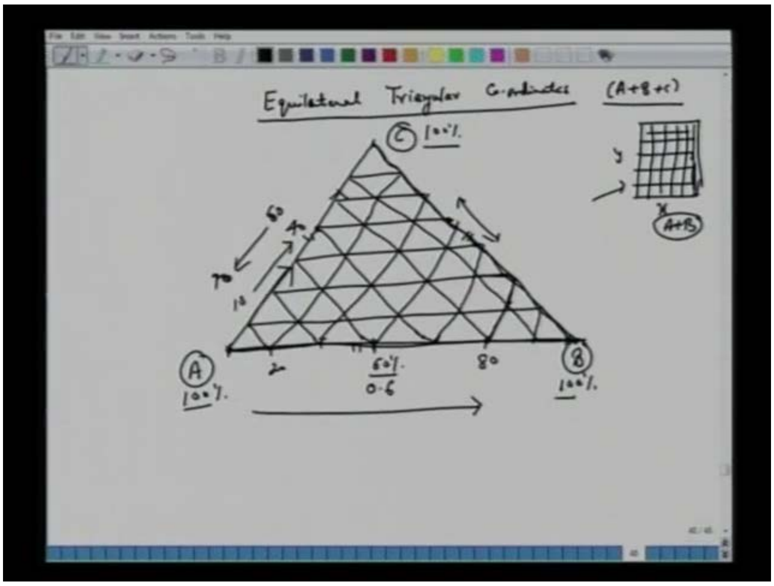

More important here – now, I should realize that, appreciate that now since we have three components, we require a different special type of graph, which is based on equilateral triangular coordinate system, because now, every time, we have to discuss in terms of three components: A, B and C. So, this is default of these extractions. So, if you go to your nearest book store or you can download for the internet, your equilateral triangular coordinate system or the graph for extraction will look like this. And, the reason is only one – it is A plus B plus C. The traditional coordinate system or the graph, which we had x verses y like the lines like this, like this, like this, and the vertical lines like this, like this, like this, will not work or may not work, because here we had only two components: A and B. But, now, we are talking in terms of A plus B plus C – three components. So, as I just said earlier, you go to your next book store and go to the internet and also download this type of graph. This graph – you will see lines like this. So, equidistant lines like these (Refer Slide Time: 35:30). And then, if here, you will see lines like this. This is also equidistant; qualitatively, we can draw like this; all parallel lines to each other. And then, we have now, third line going like this. These are also parallel lines. So, these are all angle lines connecting like this. Here also, we will make connections like this – all parallel lines like this (Refer Slide Time: 36:25). And then, we have the representations: say we have the apex for A, for B and for C. So, before getting into the details, when we write A, B, C like this, here we have 100 percent A; we have 100 percent B; we have 100 percent C.

Now, let us stay away from the extractions or this partial miscible or immiscible or phase separations; just try to understand the physical representations of different coordinates on this space equilateral triangular coordinate system. So, equilateral means all these equilateral triangles’ three sides are the same. And now, we will see the exercise like this unlike here; now, this Cartesian coordinate system. And, when you write here 100 percent A, 100 percent B, then you will see some scale here say 10, 20, 30, 40, 60, etcetera. So, this will be level say 20 or you have 60, 80; equally distanced like this. So, when we say 60 here, 60 percent or 0.6, we are saying that it will be written like this. That means B is 0.6 here. So, A is 100 percent. As you go along in this direction, amount of A decreases and B is 100 percent. There is no C on this. Similarly, on this, (Refer Slide Time: 38:00) you will see the level say 10; say here, if you see 40, all it means… or, this could be in some text books; you will see that it is a reverse like 60 or 90. So, you should be careful that when you writing like this, A is 100 percent here. So, when you march in this direction A is less and C is more till C becomes 100 percent. So, this 40 represents 40 percent of C and 60 percent of A. So, A increase in this direction and C decrease in this direction; similar argument for B and C. So, it is required that it becomes familiar (( )).

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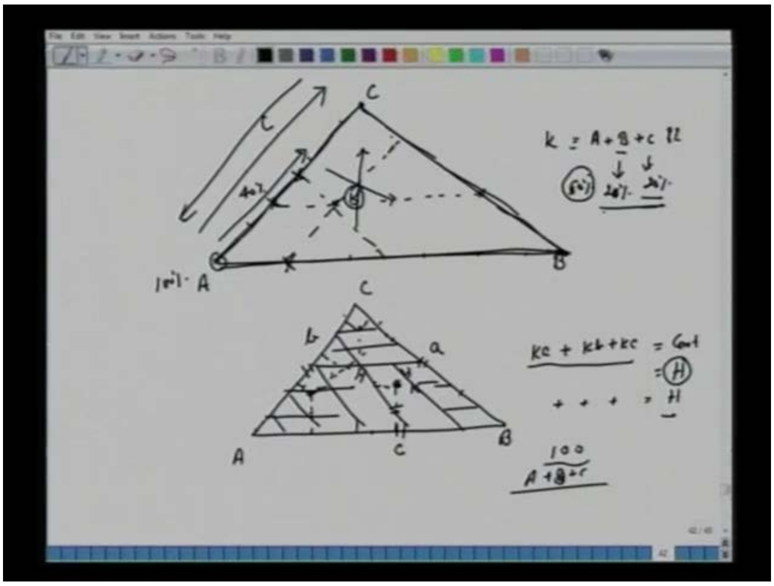


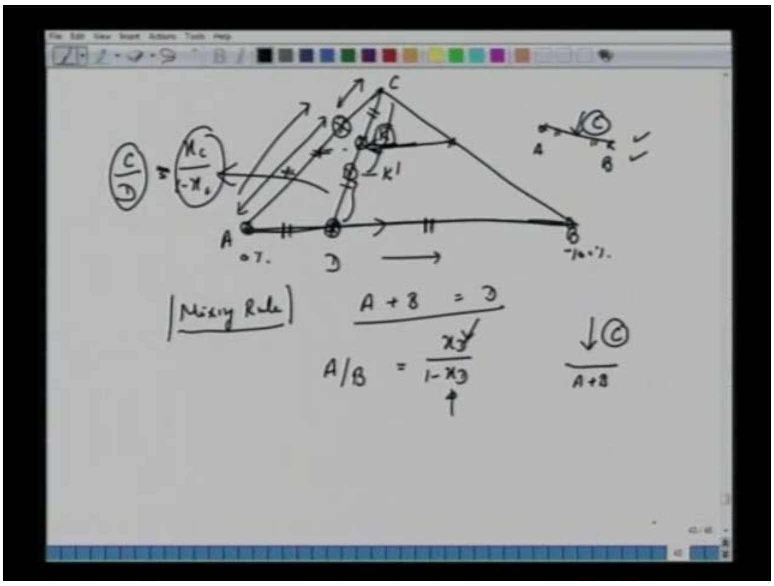
Take this example – a general example of A, B and C here – equilateral triangle. So, we have say this graph for A, B, C; it is level. And, we choose arbitrarily positions here – K. And, if we are asked to find out what is A, B and C in this case, what should be the representations? A here is 100 percent; B here is 100 percent; C here is 100 percent. On this line, there is no B; on this line, there is no C; on this line, there is no A. So, in this graph, how much amount of A, B, C – we take this horizontal line and read either from here or from here. This C increases in this direction. Whatever we read the reading from here, that will we given by (( )).

Let us say C is 20 percent. How much amount of B? Just parallel to this, we take line passing through this P; read from here – this will be given by B. Let us say this is 25 percent or 20 percent. So, all we are trying to do here is we are trying to read this graph. If we are asked to find out what is B here, take a line parallel to this AC. What is C here? Take a line parallel to this AB, because C is 0 here; B is 0 here; and then, B increases in this direction; C increases in this direction. How much is A? A is 0 here (Refer Slide Time: 40:24). So, treat the line passing through this on this scale. So, whatever we read here, that we will represents C. So, how much is A? 100 minus this; 20, 20 – 40; this is 60. Here also, we read 40, because the rest would be 60 percent here for A. So, be careful with the reading sometimes as I said earlier, they increase; so, this A is 100 percent here. So, we will see A reading in this increasing order; that means it is about C.

If you see the reading in this that it is about A. So, since B is 20 percent, C is 20 percent, A is 60 percent; 100 minus 20, 20. On the graph also, we will be able to read the same numbers. So, what is the amount of A? We have taken this line here (Refer Slide Time: 41:11). For (( )) B, we have taken a line like this. So, here you will read for this 60 percent, this would be read as 40 percent, because as for the C – 100 minus 40 is for the C. Before we take another example here, we must to try to understand that how this graph has been prepared; just for our understanding. And, the way this graph has been prepared, it is actually based on the principle of equilateral triangle. So, recall your knowledge from your coordinate geometry or some elementary geometry that if we have equilateral triangle and we choose any coordinate here and draw the perpendicular on this, on this, on this, (Refer Slide Time: 41:58) summation of all three altitudes will be constant. That means, if this is K and we represent here say as c, for this is a, because a is 0 here. And, for this, if we use b and then segment Ka, Kb and Kc, summation of all these will be constant and same as the altitude of this triangle.

We choose any point here and draw the perpendicular for the three sides; measure the three segments. Summation of all three will again be same as H. That means, it is telling us that since we have 100 percent, we want to distribute A, B and C; equilateral triangle can be used to represent the different amounts of A, B and C. Why, because anywhere amount of A plus B plus C is 100 percent, A plus B plus C is 100 percent, A plus B plus C is 100 percent, because sum of all three altitudes is same as H. Then, based on this, one can construct the graph; one can prepare the graph; you can take parallel line – this; (Refer Slide Time: 43:13) distribute BC into equal number of segments; distribute AB integral number of segments; distribute AC integral number of segments to prepare this kind of equilateral diagram. So, this also maybe you can try as an exercise to convince yourself that altitudes are the same; as a consequence, one can draw this equilateral equal amount of these segments here.

(Refer Slide Time: 43:44)

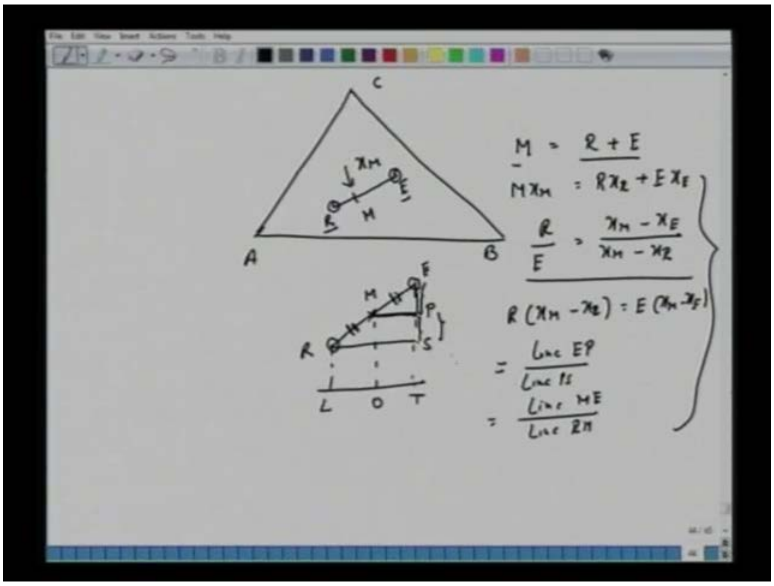


Now, let us do something more here. Again, let us start with this equilateral graph or this equilateral triangle here. A 100 percent here; apex of B representing 100 percent of B; apex C representing 100 percent of C. As we said, any amount, any point if we choose here D, C is 0; in this line, C is 0. How much is A and B? That depends upon the segment ratios; it is all about mixing rule, which we have done so many times in case of distillations, even absorptions. A plus B we add – D. How much is a mole fraction of B or A 1 minus x B? That depends upon how much amount you have added. So, in this locus for D, if you recall previous A by B, this is nothing but x D over 1 minus x D. So, how much is the amount of A and B in this mixture of D? Is these segments. So, the way the graph has been plotted, this a 100 percent here; this is 0 percent here. So, increasingly going with this direction D increases, A decreases. So, amount of A and B, which have been added to prepare this mixture of D will contain mole fractions or the weight fractions of D in the ratios of this length BD, which is 1 this x D (Refer Slide Time: 45:11). And then, we have this AD here. Similarly, if I use, add this A and C and obtain this mixture here of A and C, how much amount of C and A is here? C will be the ratios of this segment to this segment. So, all about mixing rule or the tie rule we applied here.

Now, let us say that we connect this line CD (Refer Slide Time: 45:36) and we say that in this mixture of A and B, we have added certain amount of C, and we obtained this mixture. Let us not worry about the phase separations whether miscible or immiscible; just the species balance or the mixing rule. In a mixture of A and B, we add C to obtain this locus here. So, what does this K represent? K represents that whatever mixtures we have prepared of A and B, is now like say represented by D hypothetically. Mixture in D we have added. The resulting mixture of K has to lie on this operating line. This is what we said in the case of enthalpy absorption. Any space we apply this mixing rule of A and B, the resulting mixture of C has to lie on this straight line connecting between A and B. You directly apply the total balance; you apply this species balance to convince yourself that the locus of this line is a straight line; and, on this, C will fall depending upon how much is the amount of C we have added here. So, if we take this point K here, all it means how much amount of C is added; the ratios of this to this (Refer Slide Time: 46:45).

If I have the locus here, I choose suppose this point here, K prime, how much of C is added here in this ratio? About this segment; it is all about as if we have A and B mixture and we have added A component C. We go all along this line; here now, C becomes 100 percent; A and B is 0 here. We come all the way here; now, C is 0 and we have mixture of A and B. Again, all these understanding come from one mixing rule; you add the two mixtures. How much is C by D in this case? All about x C and 1 minus x C. So, from this line if you read, draw a horizontal line; C is 0 here. We will read from here. Say we read from here – this x c. So, C by D is x C by 1 minus x C, because C increases in this direction. So, this coordinate is x C; (Refer Slide Time: 47:47) this segment is 1 minus x C. So, amount of C by D will be equal to x by 1 minus x C. By writing all these species balance, the total balance, you should be able to convince yourself the meaning of this.

(Refer Slide Time: 48:07)



$$\underline{M} = R + E$$

$$M x_M = R x_R + E x_E$$

$$\frac{R}{E} = \frac{x_M - x_E}{x_M - x_R}$$

$$R(x_M - x_R) = E(x_M - x_F)$$

$$= \frac{\text{Line EP}}{\text{Line PS}}$$

$$= \frac{\text{Line ME}}{\text{Line RM}}$$

We take one more example here. Again, we start with this equilateral triangle; or, this equilateral graph, ternary graph, we have A, we have B, we have C. Again, it is all about the mixing rule. If we choose R and E here, let us call it R; let us call it E; R basically may signify for raffinate; E for extract. But, let us not worry about how we are talking in terms of (( )) We are trying to understand the meaning of this A, B, C, the coordinates on this A, B, C; what does it reflect? So, if we take R and E and we say that the mole fraction of this mixture R is x E, x R, mole fraction of C solute in this extract or E is x E; if we add the two, we have them new mixture M, which will have the mole fraction for C as x M and this has to be on this straight line connecting between R and E. That is about the mixing rule. M equals R plus E. Anytime you have addition, the equations like M equal to R plus E; M x M equals R x R plus E x E, one can show that the ratios of R by E will be equal to x M minus x E over x M minus x R.

Let us try to understand this; we have E here; we have R here. Take the line here say L; say this M here; we have O here. Let us take these projections here as T. Connect this; call it S; call it P (Refer Slide Time: 49:54). So, what we have written is R by E; the amount of raffinate to the ratios of amount of E is nothing but the ratios of x M minus x E. So, x M minus x E and we have x M minus x R, is like a tie rule; R x M minus x R equals E into x M minus x E. So, essentially, we are saying is nothing but the line EP; x M minus x E – it is a line EP over line PS; this is the PS (Refer Slide Time: 50:42). x M minus x R – this has to be the same as line ME over line RM.

There is similar argument about this mixing rule. Add E and R; you get B. How much is the ratios of R and E in this phase? It is about this segment; ratios of RM over ME. And then, this will also be equal to the ratios of these two segments (Refer Slide Time: 51:17) based on the property of this to a rectangle with two parallel lines. These small calculations given in the text book Treybal also – you should be able to convince yourself. But, it is all about the mixing rule irrespective of the state of the two phases whether miscible, immiscible. If I choose any two coordinates here R and E with the composition of x R and x E and mix and ask for what is the mixture composition x M, this x M will be given by the ratio of the two segments; or, given the ratios, given the mole fractions, the amount of R and E will be decided by this ratio of the two segments. And, this line has to be on this straight line connecting R and E. The same argument we had in the case of distillations. Here also, we say that for this ABC phase, we have similar applications.