Mass Transfer II
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Lecture No. # 25

So, in the previous lecture we started with the new unit operation extraction alright, and what we did there? We wanted you to be familiar with the equilateral triangular or equilateral graph here for the triangular system. So, because we said that, we have three components say A, B, C, and it is possible that all three components, they are miscible or partially miscible with each other; that means we can have a mixture which contains A plus B, another mixture contains A plus C plus B, and the third component contains only B and C.

So in those cases, when we want to represent the mole fraction or weight fraction of one component in the mixture then, this kind of graph - equilateral graph becomes quite handy here; alright and we have, I also said that, you know, you should become... You should buy this this kind of graph or you can download from the internet and become familiar with this; essentially, all these graphs are plotted depends upon, you know, in the property of this equilateral triangle, we said that if you chose any coordinate on any point in this equilateral triangle A, B, C and draw three perpendiculars, some of all three perpendiculars are constant means 3 constant here. So, which means you make use of this property; if you have 100 percent say, 100 moles and all we are talking of distribution of A, B and C in out of 100 hundred moles.

So, if you choose one component here or one locate one coordinate, then it contains as 60, 40, you know 60, 40, 0 that is also possible and then, we have 20, 80, 20. So, this three - sum of all three components, weight fraction is a constant here. So, by making use of these properties you have, you know parallel lines along all the three sides, and then, you have marked in the axes with 0 to 100 percent for A, B and C etcetera and then, try to monitor or does the point move when you add two components.

So, let us just quickly go over this equilateral graph, before we start, you know the first thing is the thermodynamics phase diagram for tannery systems; just like you have the phase diagram for liquid vapour or you have the phase diagram or the solubility curve for absorption system.

Similarly, we have a phase diagram for tannery system in case of extractions.

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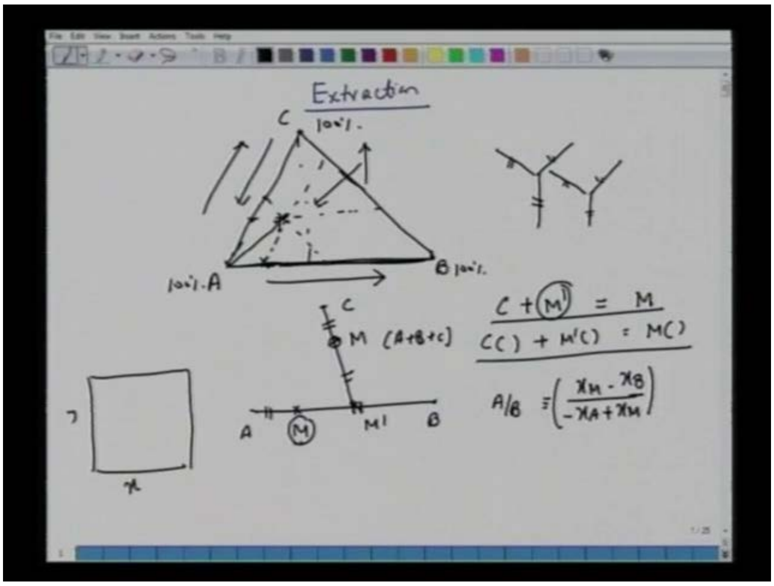

So, we continue our discussion with this extraction. So, we said that we have say equilateral triangle or graph traditionally we put the solute, see here on this apex and we have A and B here. So, if we choose any mole fraction here any any coordinate here, then we are trying to say that, amount of C presents; so, C is 100 percent here, A is 100 percent here and B is 100 percent here. So as you go in this direction, the amount of C increases from 0 on this horizontal axis - horizontal side AB and it becomes 100 percent.

So, if you go here, we can note down - what is the reading on the graph paper, that reading will correspond to the amount of C. Similarly, we take a parallel line like this - line parallel to this BC, in which case A is 100 percent here and A is 0 on this line, and if you go in this directions and read the graph, you know say on AC, then 100 minus this reading for 1 minus this reading will tell you how much is the amount of A in this. So, A does not forget that A increases in this direction, C increases in this direction. So, you have to be careful how they have reported in all the graph for this.

Similarly, if you do not to find out how much is the B in this components; of course, 100 minus C at A will give you this, but that the same time we have at read this graph or read the line which is parallel to this AC, then the whatever reading you have that will represent the amount of B - the weight fractions; so, B increases in this direction. And all this, because of you know the rule of this equilateral that summation of the three perpendiculars from the three sides is constant. So, if I choose here, then I draw the three perpendicular on the three sides, sum of the three will be also be constant, same as what we have the altitude you know, C to AB or A to BC or B to AC etcetera.

So making use of this property, one have this equilateral graph for extraction system here; then we said that, if you choose say side AB again and if you have say some point here M - we call it M, all it means the amount of A and B, they have been added in this mixture and the amount is proportional to the segment here.

So, you can you apply the mixing rule here, A by B will be equal to x M minus x B - so other side of this segment over x A minus x M alright from minus x M plus x M to make it positive; so no C here, which if we add certain amount of pure C, and I draw a line like this, and I have the mixture, so you call it M here, so I have M and M prime here. So again, what is amount of C in this – now, we have both A plus B plus C; so, the fraction of C again will depend up on how much is ratios of this these two segments here; again we are applying a mixing rule for C added to this M dash to give us M here. So, this M dash is now, a initially we had the mixture of A and B in that ratios is to be given here. So, every time we are applying this mixing rule C and then, we have this mole fraction of C plus M dash mole fraction of this and there is editing mixtures mole fractions.

So, these are the two main things we discussed, you know this is different traditionally we have this xy graphs here y versus x. So, it is recommended that you become familiar with this graph.

So, now what we start here is phase diagram.

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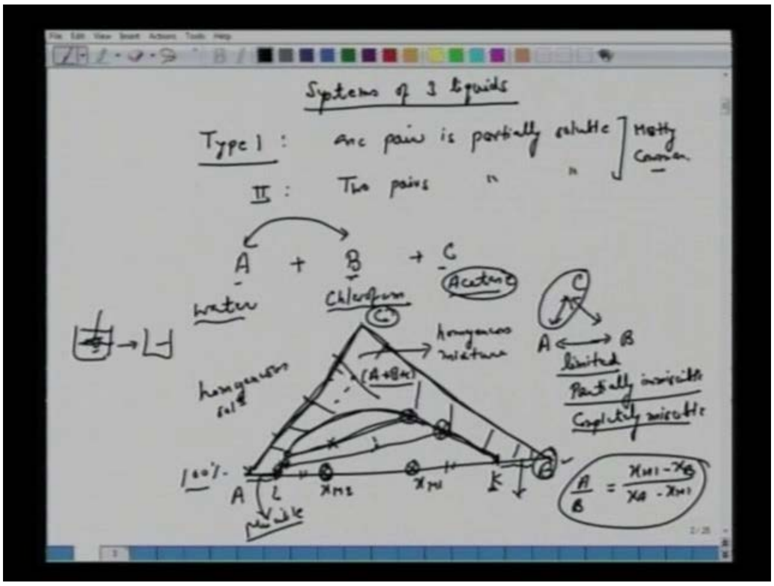

Systems of 3 liquids

Type I : One pair is partially soluble] Mostly Common
II : Two pairs " "

So, essentially we are talking of now systems of three liquids alright and then, if you go through the hand books of extraction or even the text book they will talk of several types of systems here. We are concerned with mostly two types of system in our case. So, we call it Type I where we say that one pair is partially soluble; alright then we will discuss different Type II - different system called Type II, in which we have two pairs partially soluble alright; of for the first one is mostly common. So, most of the example you will take in this course will be related to Type I.

So again, let us try to understand, and that we have three components or three liquids A plus B plus C; let us say we have water, we have chloroform and we have this acetone. So, when we are saying that A, B they are partially miscible or B and C are partially miscible alright or A and C you know they are completely miscible, then you must be you should be able to plot accordingly on this A, B, C; now this equilateral graph when it should be consistent with our earlier understanding of how to mark the coordinates in this plot here.

So, now we let us assume that, we are saying that A and B alright water and chloroform they have limited solubility or they are partially immiscible. So, their solubilities are limited or we can say that they are partially immiscible; now everything here is relative here. So, let us try to understand that we are saying that water and chloroform they are partially immiscible, but C, which is acetone it is completely miscible in A, and C is also completely miscible in B, which is true acetone and water may be under certain conditions is completely miscible; C is also - acetone is also completely miscible in chloroform, but when you mix water and chloroform then we see that you know it small batch experiment we will get they will get separated of like this. So, we are using this word partially immiscible or completely miscible.

And then, we are trying to make a phase diagram here. So, going back to this equilateral graphs, there are parallel lines to AB, parallel lines to this AC, parallel lines to this BC. So now, when A and B are limited - very partial limited then, we have the phase diagram like this. So, let us first mark you know it for be discuss for the and we have the phase diagram like this.

Now let us see, we say that A and C they are completely miscible; so, here if you choose any coordinates, you do not see any phase diagram; all it means all mixtures of A and C with whatever proportional used, large amount of C or large amount of B if you add and mix, stir it then, you have say certain mixture composition x M, but it do not you have a homogenous solutions.

So, you have a homogenous solutions or you have completely miscible; similarly, if we add B and C and stir them properly, then we have a completely homogenous solutions or we have partially miscible partially sorry completely miscible system; on the other hand if you mix A and B and look at this; now we have this phase diagram, they will be a separations. So now, here also we see some segments between A and L, and K and B, in which we can say that the mixture of A and B they are miscible. So all it means, suppose I choose a mole fraction or weight fractions, here x M, stir them and allow them to settle; you will have two phases: one phase will have content, some amount of A; mind you this is 100 percent here.

So, we have very large amount of A here, but very small amount of B in this, and we will have the second phase, in which we have very large amount of B which is mark here K, and in which we have very small amount of A. So, further from this apex we have large amount of B, and further from this we have large amount of A, and there is no C in this. So, this is the meaning that A and B there are limit they have limited solubilities; if I choose another say amount of this mole fractions or mixture here, and they allow them to settle. So, when I say that we have choosen x M1 and x M2, I can should go back and apply this mixing rule that we are saying the amount of A and amount of B, x M 1 is different from amount of A and B in this x M 2, but we are adding pure 100 percent A and we are adding pure 100 percent B here. So, only the amount is ratio, so again the amount of A and B, you can apply this, you know mixing rule this should be equal to let us say, x M 1. So, A by B minus whatever you have x B over x A minus x M 1.

So, the ratios of these two segments here, and if we choose any component here, now this will also contain A plus B plus C given by what reading you read like this, what reading we read like this and what reading we read like from here. So this contains A plus B plus C except here we have this homogenous mixture. So, this is phase diagram we have got like this for turning system A, B and C we have homogenous solutions - mixture in this range, if you hatch it like this and if you choose now a component or a mixture here of A plus B plus C within this region here and allow them to stir, now you will see a separation like this, there you will be two phases: one phase will contains this amount coordinates given by this, another coordinates - another phase will contain the weight fraction of C given by this coordinate.

So, here we are talking of this phase separations, here similarly if we choose x A, A plus B C mixture of given by this coordinate. So, certain amount of A, certain amount of B certain amount of C, stir them and allow them to settle; in that case there will be phase separations and experimentally, if we measure will be two phases: one phase will contain so much amount of A, B and C, another phase will contain so much amount of A and B C. So, let us again try to understand here, you know this extraction.

So, if you recall, you know we started this, before this extraction we discussion we are a discussion on distillation. So, we had liquid vapour of course, we had only binary components. So, when we we had this phase diagram, liquid and vapour and there if you choose fix the temperature and then, you draw this horizontal line and you have a mixture of liquid and vapour, allow them to come to equilibrium then, we have this M certain there is separations, vapour is rich in one component, liquid is rich in one other component.

But you have both A and plus B, and A plus B in the liquid as well as this vapour phase. So that is the phase diagram, beyond the upper limit you know due point, you have super heated vapour, one comp one phase; underneath this you have another phase, in the regions of liquid and vapour if you take any component fixed temperatures, there will the separations there will be A plus B in the vapour phase, A plus B in the liquid phase.

So similar to that, we also have this, you know solubility diagram for A plus B plus C now we have three components. So now, we have a phase diagram which is you know, it has a mark such regions, you have solute C, A, B then, we said that if you choose any components of... In any mixture of A plus B plus C in certain regions above this phase diagram stir them so you mixing, allow them settle, there still be one phase; however, if you choose mixture which contains A plus B plus C within that region, stir them properly, leave them allow to them settle; now, you will see two phases, this one phase lighter, underneath you will see another phase which is denser, you know while larger density and both phases will contain A plus B plus C, A plus B plus C.

So, if you are call earlier we have said that extract and we have this now raffinate. So, both that there is a phase separations in certain regions, in which we have a distribution of A plus B plus C; it is one thing that in one case C will be larger, another case we have C smaller, in one case A is larger, another case you have B is larger, but there is a phase separation.

So here, we are talking of system Type I there two components A and C they are partially miscible. So, there is no phase diagram, there is no line there right; any mixture between A and C in what proportion you mix it, no B it is one phase, choose C mix with B, no matter what proportion you know, you add them you will get one phase how much is the amount right that will be decided by how much amount you added or the mole weight fractions you have started here.

So, suppose you choose now A and B that case we have saying that a and B are partially soluble or they have limited solubility or they have partial partially miscible you cannot completely miscible in that case if you choose A and b say somewhere you know in 40 percent 50 percent or 60 percent stir them allow them to settle now they will be 2 phases 1 phase will contain A plus B sorry A plus B second phase will also contain A plus B 3 is no C, because this you are picking up a solutions on the horizontal axis of a and B C is 0 3.

Now, you have phase separations A plus B here A plus B here recall you know liquid vapor that type of argument we gave both A plus B I choose here and here in one phase

A will be larger and another phase B will be larger . So, now, let re plot here and will sub give them the names like extract raffinate will call them tie line will have the operating line etcetera.

So, let us revisit this aspect of Type 1.

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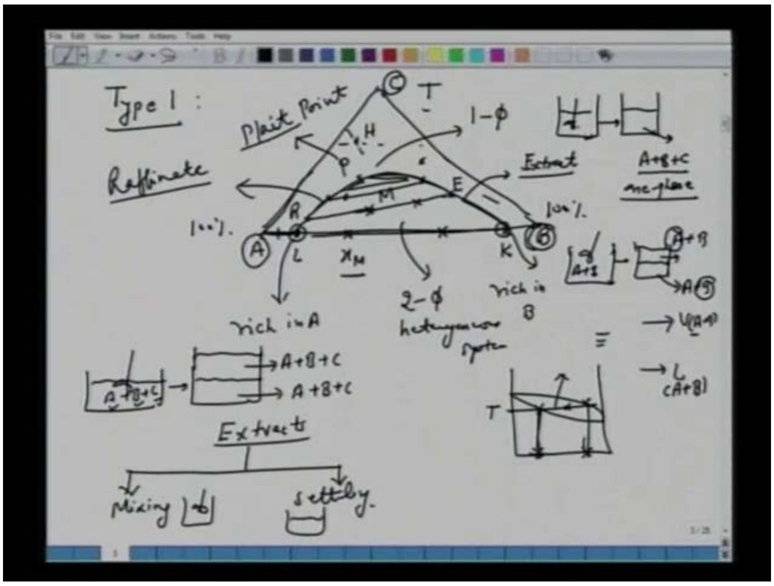

So, we have Type 1 system; let us redraw this equilateral triangle, which is the graphical representation of three components system; and we are saying that now, we have this phase diagram right, this phase diagram intersects the axis A and B, let us say it L and say this K, and notice there is no intersection; here there is no intersections anywhere, all it means, anywhere if I choose say component coordinate H this will contain A plus B plus C, we know how to read this, will read take the reading here, you will take the reading here, 100 minus this will give the other components, so from this you have A plus B plus C. So, I had I have this mixture of A plus B, I stir them and then, I allow them to settle; I will just see one phase and this phase will contain A plus B plus C all miscible; I choose another component it has certain percentage of A plus B plus C, stir them, allow them to settle, it still they will be one phase.

So, this is one phase system here, so called one phase, because A and C are the completely miscible here, B and C are the completely miscible.

Now, let us look at horizontal line of this coordinate in a triangle A, B, C; now here if I choose a component of A and plus B, a mixture of A and B in that ratios - certain ratios giving this mixture density mixture mole fraction or weight mole fraction as x M, now I take this AB; I stir them; allow them to settle; now there will be two phases, both phases will contain A plus B; this phase will also contain A plus B, but in one case A will be larger, another case B will be larger. So, recall our analogy between liquid and vapour for the top product say vapour, bottom product we had the liquid both contains A plus B, but in one case A is larger, another case B is larger - bottom product.

So here we have the same story, if you take this, allow them to settle; now I have L and K represented by this, this guy closer to this apex, so it is rich in A; this coordinate closer to B, it is rich in B. So, we have 100 percent A this apex, 100 percent B and allow them to settle; now we have this region. So, this is nothing but a tie line; this tie line a very close or very similar to this liquid vapour tie line; you fix the temperature, then mole fractions of vapour and the mole fractions of liquid they are mixed; fix the temperature here, mole fraction of A and B in this, mole fraction of A and B in this surface; start with another mixture, stir them; settle; you will get back to the results, there you get back L and K; start any mixture here, settle allow them to settle, you know equilibrium, we have the fix mole fraction; you start with here allow them to settle at this temperature, equilibrium you get the fix. So, we have this tie line essentially.

Now, what happens here? Suppose I choose component this. So, it is another experiment now, I am choosing coordinate where I have three A plus B plus C. So, I have chosen three components A plus B plus C; water, chloroform and acetone; mix them, allow them to settle; now if you do this experiment, now they will be two phases; just like here. So, here also we have two phases: except one phase both the two phases will contain now A plus B plus C; here C was 0, but now you have C so; that means, if this is a phase separations equil equilibrium there is a tie line.

So, now we have tie line like this; and we give them the name here, one phase which is rich in A, we calling it raffinate. So, this is raffinate; this any point here will be called as raffinate phase, because this contains large amount of A and large small amount of C here; similarly this side, this line any point here will call them is as extract, which means we have B is acting as a solvent and this contains large amount of larger amount of C than this.

So, we have the tie line positive with the positive slope; let us try to understand the meaning of this, A we are using as a feed, C is a solute and B is a solvent; take any mixture of A plus B plus C, anywhere within this easier, stir it. So, extraction always contains consist of two steps: one is mixing, and one is settling.

So, you represent like A, you know like a C S T R reactor and here you very simple, settle, no no mixing. So, we have taken this, we have mix them A plus B plus C; temperature is fixed; allow them to settle; we get two phases: raffinate and extract; raffinate phase contains certain amount of C which is a smaller than, what we have in case of extract that what we will also expect. So, this vapour and liquid phase you can make the same analogy more volatile as gone here, less volatile has gone.

So, one which has more soluble in this B as a solvent as gone here and this is...So, there is a phase separations; you can call them as R and we call this small phase E, R for raffinate and E for extract, this is your x M were M 1. Let us take another point here. So, we have another mixtures allow them to mix them first; settle them; you get another tie lines not necessarily you know with the same slope. So, again we have another x R, we have another x E; typically, there is a point here called P, which denotes as plait E L i. So, it is a plait point; there is a point you know where no there is no tie line. So, this is a limit of this separation.

So, we have this line here, after this, there is another tie line here. So, every time below this point B, you will see that this extract phase has larger mole weight fractions than this raffinate; beyond this B points now tie line slope changes and then y this weight fraction in this raffinate is now larger than this extract; we will come back to this, but the idea here is about this two phase system - heterogeneous system alright, unlike in this range we have one phase system right here, even here if you choose a component of A and B, mix them; allow them to settle; there is no phase separation; phase separation occurs in this ratio that is a solubility curve.

So, I choose let us say another M here and allow them to mix them; allow them to settle; again you will get the weight fraction or any says equivalent, very much equivalent to just the a liquid and vapour diagram which we discussed.

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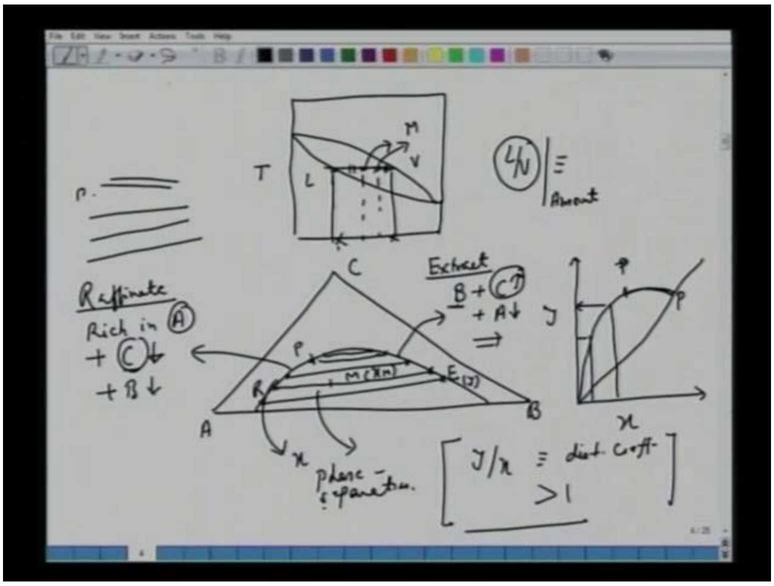

So, we have L and V to this temperature, you have vapour phase and liquid phase composition of x or you start with some mix feed here and then, at this temperature if (( )) them in equilibrium, allow to come to equilibrium, you have this is fixed here I choose another weight feed here in some batch experiment, you can allow them to settle, I still I get the same L and V; it is only the amount of L and V will be different. So, only the amount which has different here depending upon the ratios of the two segments across this mixture point M or V.

So, we have the same situation here, there are tie lines; the phase and there is a tie line like this, this is E here extract, we have raffinate; we have A, we have B, we have C; it is closer to this A is larger here, C is B is a smaller here and C is a smaller than in extract phase that what you will expect large amount of solvent has taken most of the solute much larger than what you have here; similarly, you have another tie line different slope, different slope, you have all R, R, R; you have all extract, extract, extract; till you have this P platelet points at which the slope now changes.

Now, you have raffinate extract phase, composition smaller than this raffinate phase, which means if you take this projections and plot just like y versus x. So now, we are going from this triangular diagram, so this coordinate - cartesian coordinate system with y and x. So, just take this y here we call it extract with the weight fraction y and all the raffinate as extract, this is a P plait points and plot y versus x with this as a 45degree line;

you will expect curve like this, this with this should be the most general; so that means, beyond P now x has become you know this is y larger than x y larger the x right; now we will start seeing things getting leveled here below this.

So, this is now you P point platelet point x, beyond certain point you will see the tie lines slope have change. So, the amount of y has started becoming less and less. So, we have this y versus x diagram; for our understanding you can call it y versus x as distribution coefficient; at the platelet plait points, there is no separation so, it always greater than 1 above this 45 degree line, below this both P we have there is no phase separations here; alright we calling this, let us just level it between R and between this point and this point, this is the raffinate phase.

So, it is a raffinate, it is rich in A; essentially, you have a feed right and we have small amount of C now, and very small amount of B also. So, it is a three component system except it is rich in A, small amount of C; because most of the C has gone into this extract phase. So, we are comparing one to one so, it is gone to extract phase that also contains A, B and C except it is larger amount of solvent closer to this apex.

So, large amount of solvents C is larger; see this is closer to the C, closer than this point. So, anyway tile line this is closer than this, y is greater than x, except beyond this platelet points now the slope is start decreasing. So, if the slope like this or you like this, like this slowly and slowly beyond this p, now slope starts decreasing.

So, it is closer to our C here. So, we have B plus C away from A, so very little amount of A here, and you say C is large there is we are trying to compare with this C in this extract raffinate phase and anywhere we choose M m we are seeing that this is x M; we have mix them; we have settle allow them to settle; now there is R n phase separations for any of this R and E, we can also apply mixing rule.

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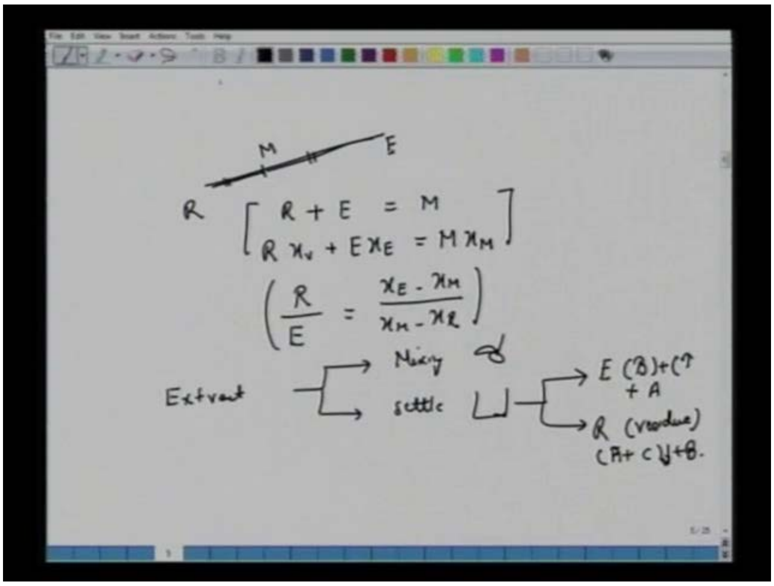

$$R + E = M$$

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

$$\left(\frac{R}{E} = \frac{x_E - x_M}{x_M - x_R}\right)$$

So, we have essentially R and E; if you take this M right and you want to write down how much is amount of extract and how much amount of raffinate is formed still you apply R plus E as M, R x r E we have x E, generally we like to use y for the extract phase and there has this is y into x M. So, you have you can write down the amount of raffinate over extract; applying this tie rule so R by E, you should able to show that this is x E minus x M and extract this is x M minus x R. So, again we have the same tie rule material balance or we are trying to distribute here.

So, extract fundamentally, it consists of two steps: one is mixing and one is just settle, and when we settle there is a phase separations: extract phase and raffinate, which is nothing but we call it residue also sometime.

This extract will contain we have extracted using the solvent right, a raffinate is a feed which will also contain a solvent, but C is smaller here, C is larger here, some A will also go here alright, this is A here and some solvent B will also going. So this is your introduction to your phase diagram for extractions; fundamentally of course, in the two or different operations - one is a absorption we had, then we had distillations, then we have this extractions; but the approach in all the three cases are same; first we have to understand the thermodynamics; in case of absorptions, it is a Henry’s law - solubility that decides how y and x that is how the solute is distributing between the 2 phase air phase air, gas phase and in water; in case of distillations, we have two phases: liquid and vapour; and now both A and B they are distributed, one which was more volatile went to the vapour phase, one which was less volatile went to the liquid phase, but here also we have phase separations.

Now, the mechanism is depend depends upon its determine by relative volatility; in extraction is also we have phase separation, but now we are talking of distributions solubility right, and we have now three components A plus B plus C, one we call it as a feed alright, one is a solvent and the C is a solute. So, feed is contaminated with some C may be there is no B that is also possible in one limit. So, we have A and C; so, recall our triangular diagram A, B and C; no B there, just feed contains some C so we are somewhere here, where is amount that depends upon, where is the coordinate that depends upon the amount of A and C, which have added we want to remove C. So, we add a solvent - pure solvent it do not be a pure; it may contain some amount of C, it is possible; it may also contain some amount of A; but the most simplest case of B that we have a pure amount of solvent.

So, it is we are on the apex B - 100 percent B, you add mix the two so, essentially you are mixing in a beaker where you have A and C. So, hypothetically you have a mixture where the mole fraction is given by that M. So you add, connect M to this B; apply the mixing rule again; somewhere on this straight line, you will get x M mixing mole from weight fraction right, where we with the location, you write down your material balance; write down your feed balance; you know a species balance in terms of weight fractions to find out how much is the amount of your you have the solvent, how much amount of you have your feed and you have this solute.

So, now when you add like, this stir them; mix them; there is a phase separations; you have the tile line very similar to what had in case of liquid vapour. So now, you have to rely on this phase diagram; all this phase diagram for all the ternary system or the binary system they are available in text book, in the hand book you know, very there is you know several types of systems you have, trey bal text book we can also go to other book that the and you know look for this type of phase diagram or the solubility diagram.

So, essentially now you have a phase separations and all we are saying that when we have the separations, one is called raffinate phase, one is called extract phase. So, you are extracting it. So, raffinate is nothing but your residue; feed contains now a small amount of C that is what you wanted, you wanted to remove C from B. So, your feed F A plus C; So, C will be very small, but there is a possibility that there will be carryover of solvent also; so, you have A plus B plus C.

You have the extract phase where most of C has gone here, at least at one stage larger amount of C has gone here, but there will be some carryover of feed as well. So, it is still there, you have A plus B plus C here, but C is larger, A is a smaller, and B is a larger, because that the solvent there; again you apply the mixing rule, we have the tie line all this three lines will will lie on the tie line - straight line; you have some other mixture compositions, you have another tie line. So, there is a phase separations for depending upon what where fraction, we choose here.

We go to the point P plaited plait, there you have no separations; all the tie lines have reduced to 0 line and when you take the projections of all these phase diagram on y x again you get a y versus x solubility curve. So, for separations in a y versus x diagram should be over 45 degree line or the distribution coefficient y over x or y star over x should be larger than 1.

So, now let us take, understand this temperature reflux, you know very similar to the earlier case also; whenever we have the solubility then, they are they become a strong function of temperature. So, whatever phase diagram we have, now we are saying that two mixtures like A and B they are partially miscible; A and C are completely miscible; but it is possible that at high temperatures we have larger and larger solubilities for most of the systems and this phase diagram will actually shrink. So, let us draw this here.

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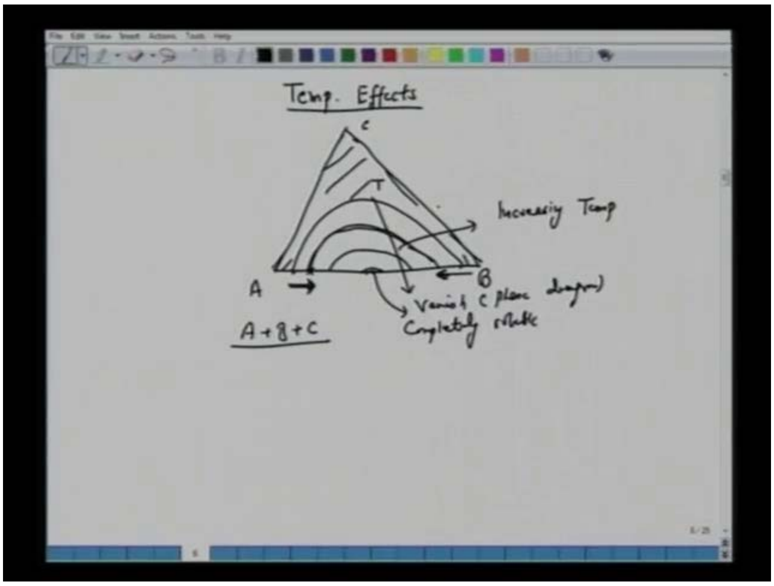

So, you drawing this qualitatively, you can go through the book text book to see you know, exact locations or exact numbers for the different systems; again we have A, B and C so at certain temperature we have drawn this phase diagram. So, this at one temperature, here we are saying that, A and C completely miscible; B and C completely miscible; this is a range; this is a region where we have this homogenous system including here and here, and on this when you have A and B then, they are partially miscible or where they have limited solute. So, you will expect that when you increase the temperature, then this region will shrink here.

So, now you can see that, now the region has increase and this region of partially miscibility has decreased here. So, this point moves towards this, this point moves towards this, you have large amount of B here, earlier you have very large of amount of A, small amount of B; now this locus proves this point moves this in this way and this point moves this way. Similarly, we have at the high temperature this will shrink and it is possible that at a very large temperature now only the bottom line is that is A, B and C that three components must not decomposed.

So, at a very large temperature is possible that we have now completely miscible and this point will vanish. So, we have this increasing temperature, and at this point now we have completely soluble. So, essentially they will all phase diagram will vanish and we have perfectly homogenous solutions of A and B and C.

So, this what you will also expect here. So, this about the temperature effects and we are discussing about this Type I system.

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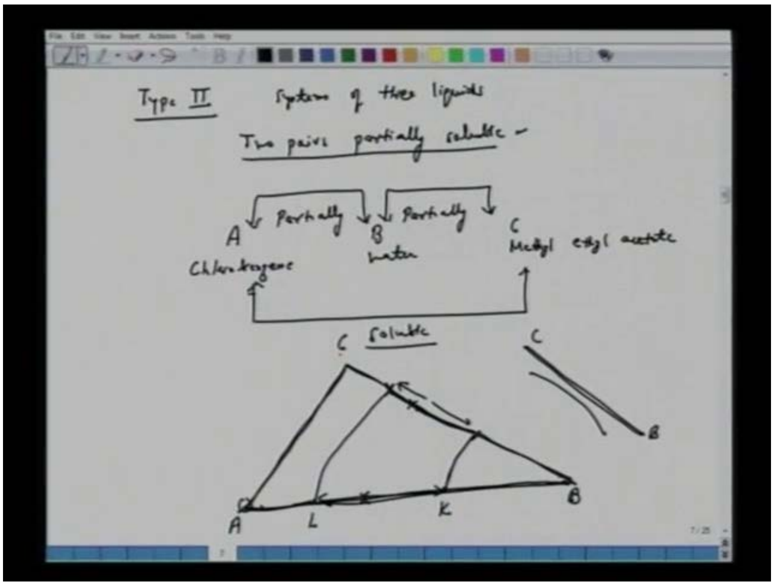

Type II System of three liquids

Two pairs partially soluble -

Now, let us discuss this Type II system, now you can here, we have systems of three liquids, same as before; except now we are saying the two pairs are partially soluble. So, you are saying two pairs are partial soluble; let us taken look at A, B, C as an example, let us say, we have chlorobenzene, we have water and we have this methyl ethyl acetate; petroleum industry is one of the industries where you will get several of such examples.

So, now we are saying that A and C they are soluble, which is true chlorobenzene is soluble in methyl ethyl acetate, then it depends up on the temperature, but let say that normal temperature - room temperature we have this chlorobenzene soluble in methyl acetate, but A and B they are partially soluble, and B and C they are also partially soluble. So, we are talking of two pairs which are partially soluble, that is the Type II system and more important here is to draw this type of phase diagram or understand what do you mean by two pairs beings soluble.

So, again we start with the equilateral graph, we have A, B and C; now, we are saying that, if A and C they are partially they are completely soluble, so we do not have any phase separation; but B and C as well as A and B they are partially soluble. So, you will expect phase diagram like this.

Let us again try to understand what we are saying here; there is a region over which A and B, they are partially soluble.

So, any mixture between this and this line here, if you mark it L, and say K, we allow them to settle, they will separate; here we have homogenous mixture of A and B here you have homogenous mixture of a and b; similarly, if you have take B and C, no amount of A here from along this side here, then there is a region at which over which if you choose any weight fraction, any mixture of B and C and allow them to settle, they will separate into this.

So, we have two pairs of B and C, which are partially soluble this what the meaning of partially soluble; here you have a large amount of C, here you have a large amount of B; if B and C they become totally soluble then you will not see any phase diagram here. So, they will be a curve like this; see no intersect; intersection of this phase diagram over this line B and C. So, this is the meaning of two pairs partially soluble as you have represented on this curve.

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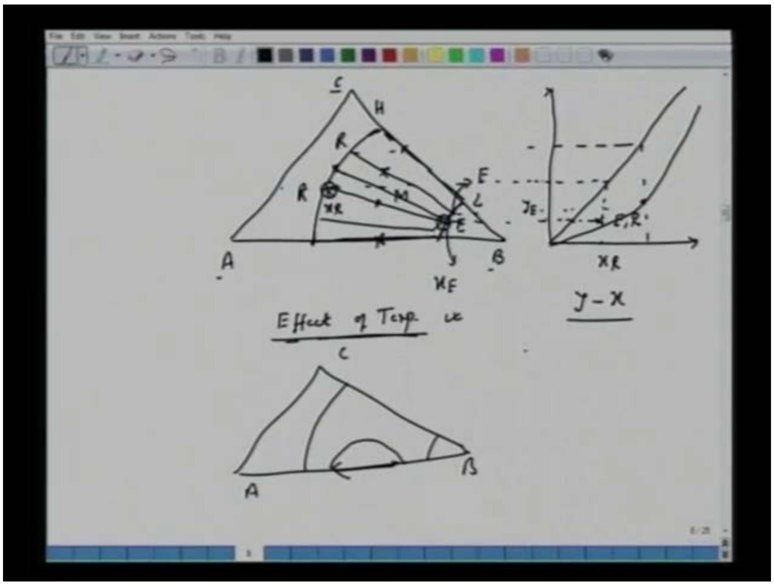

Let us redraw again; so, we have A, B and C; we have this phase, call it H; just mark a line here say this L, and very similar to the previous case, now we have, we choose any mixture here which will contain A plus B plus C all three allow them to settle; there will be a tie line or there is a separations tie line represents equilibrium; so, they will be a tie line; this phase we call it R raffinate, this phase we call it extract so, E.

So, again if you choose M, mark this coordinate as M, and say that you have there is the equilibrium, raffinate will contain certain mole fractions say x R of C, extract will contain certain weight fractions of C again here in this, if you choose any other mole fractions here, again there will be a allow them to settle; there will be a tie line, then need not be parallel; again you can apply the mixing rule to obtain how much is amount of R and how much is amount of extract, by choose here all it means, if still there is a tie line, except there is a no amount of C.

If I choose any amount here, any mixture of B and C all it means, there is no A here and we have this tie line. So, there is a tie line like this, like this, this, which represents equilibrium between the raffinate phase and extract phase; one can plot this, you can take x actually, a projections. So, if you take a projections, suppose this a 45 degree line here, and we have this x R, and let us say this E is represented by x E. So, you are reading with in all the time it is C, you are reading it from this graph, line like this parallel which goes through this, which goes through this . So now, if you take these projections along this so, 45 degree line, take C here. So, one can show that you will get one coordinate; so, again you do the same thing what we did earlier when you have taken a projections like this and extend this component here. So, this will it represent your E and R.

So, this is coordinate, which comes from here is x R and what we are reading here is your y E. So, this y E is extract phase compositions, x R is your raffinate, and you get this line, similarly you take any other points any other tie lines and take a projections extend it here, take a projections here, take it is corresponding extract phase, mark this point here and then, it draw this line, you have a solubility curve.

So similarly, so, essentially, we have plotted same equilibrium curve, now we have plotted as y versus x here; similarly all of this you know, we can discuss about this effect of temperature, if you increase the temperature, it is possible that B and C may be becomes solubilise at high temperatures; in that case, you will expect there will be a phase separations so, we have A, B and C alright is possible that at certain temperature A and B may be they become miscible. So, all this phase diagram, now they will change like this. So, this region has now shall decrease. So, again you can go through you know the text book to see that if different types of system and you have different effect of temperature.

Now, what we do here, before we go to the next stage of course, we said that for A plus B plus C three system, by in a ternary systems we require equilateral triangle, but you must not forget that if you fix the amount of A and B or weight fraction of A and B then the C is fixed; 100 minus A and B or if you fix the amount of B and C the third component is fixed.

So, there are other coordinate systems including this rectangular systems which can also be used to represent this ternary system; of course, all three values you would not be able to read directly; right in case of you know equilateral trai equilateral triangles, you have any coordinates you take you read on the readings from you know all three sides of equilateral triangle to obtain this A and B and C, but if you have this coordinate system, traditionally you have this Cartesian coordination system, there also you can work on mole fractions just two component systems here, the third will be 100 minus this. So, that is also quite frequently used and we will just draw qualitatively here to the type coordinate system.

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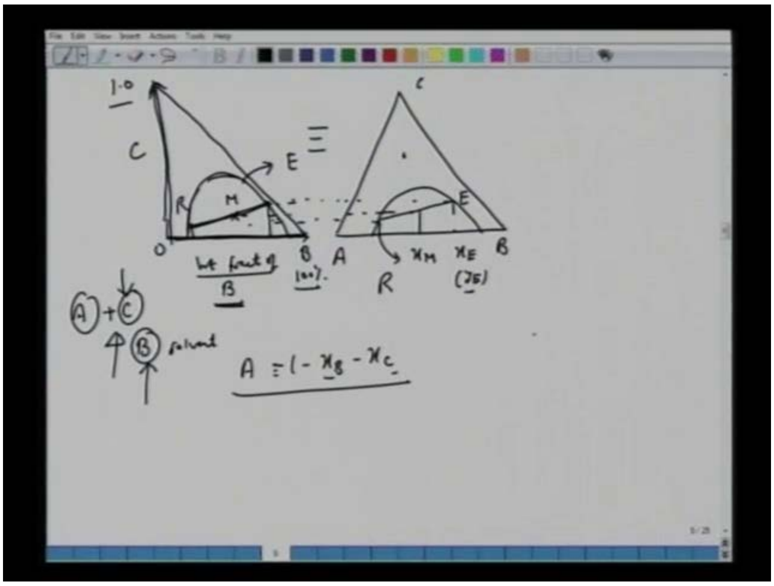

So, suppose we have this A, B and C; A, B and here you have C. So, let us say this phase diagram; you have says it is a tie lines like this, extract and let us say this is your raffinate. So, we have x R and we have this x E or y E, generally for extract we use y nomenclatures, here you have x M, one can also take a projections.

Suppose we have this you know, you can plot different ways here. So, now we plot weight fraction of B, because the same amount of solvent one uses. So, generally the standard problems would be that you have A, it contains some amount of C and you are adding we B solvent. So, same A plus B and C, one can also represent in a different way of coordinate 90 degree perpendicular system here. So, you have plotting weight fraction of B on the x system OB, so B would be here 100 percent or 1 and 0 here same plot; now, if you take a projections of E, you take this projection of this R, you will also get a phase diagram like this.

So, what we essentially you are plotting amount of C; so, this is one here. So, this is a most common way, another common way of plotting here; of course, here if you choose any coordinate we get we can read all the three readings here. But the most important is that what is amount of contaminant, solute you have been in the system and how much amount of solvent here adding it to remove this; generally on the x axis, you replot weight fraction of B and here you plot weight fraction of C here, the A would be 1 minus B and C anywhere. So, we do not need to plot exactly on this equilateral triangle.

So, still you have the phase diagram, you have a tie line; so, you have extended this here as extract, you take this raffinate of this all the way till here, you have this the tie lines, you have this M, M as this. So, this will also work as as a representation of this extraction system with this as raffinate phase here, here you will have extract phase, you will have x R, you have x E, except now the amount of A, we have to calculate now 1 minus whatever B you have, whatever you have C here.

So, the two are quite analogous that is very similarity here, here there is a convenience of calculating or readings are A B and C directly, here of course, one has to obtain the amount of A by simply you know subtracting B and C. So, essentially we just plot weight fraction of B and weight fraction of C, because we know that A will be 1 minus this. So, both of them are equally popular and most of the text books you know on the give importance to both of the different style of plotting here.

So, this was our introductions to two different types of systems we have, in one case C is soluble in both A and B, but A and B are immiscible or partially soluble or they have limited solubilities.

So that we call it Type I, then we discuss Type II, which had two pairs insoluble. So, we have a different type of phase diagram; again as we said earlier they are different types of systems and all kinds of possibilities possible, especially when you notice or when you absorb, this temperature effects. So in this course, we will take a simple case of Type I, Type II systems and we will see you apply the mixing rule, apply this equilibrium phase diagram to determine how much is amount of solvent is required to remove say if this amount of C from say 10 percent to 0.1 percent.

So, now we are talking of stage operations. So so far we had thermodynamics alright now we are talking of this stage operations; let us continue with these operations very simple with single - stage contact.

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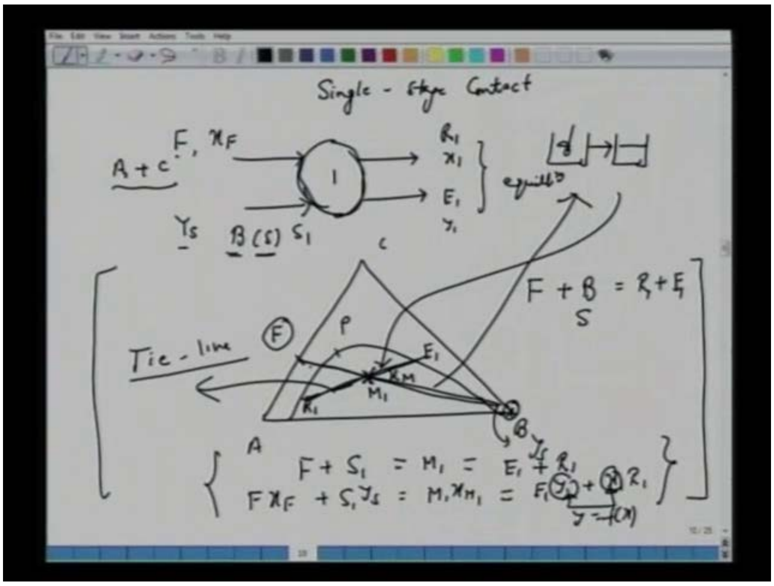

Single - stage Contact

$$F + B(S) = R + E$$

$$F + S_1 = M_1 = E_1 + R_1$$

$$F x_F + S_1 y_s = M_1 x_{M_1} = E_1 y_1 + x_1 R_1$$

$$y = f(x)$$

So, we have single - stage contact. So, you have stage one; let us say we have F, composition is x F, let us say for our simplicity that we have A plus C only. So, there is no B, although we will we can extend our discussion to say that is also contains B.

So, now we have A plus C, C is a solute; we want to remove this solute by bringing B, which is a solvent; it has mole fractions y S; this solvent can also be pure; this may also contain some amount of A and C as B. So, all possibilities are there, for simplicity let us see, let say that we have very small amount of A or C in this.

So, it is very closer to this apex B of this equilateral triangle; now we allow them to settle. So, they mix first; then you allow them to settle. So, generally this is stage one; experimentally you will have you will have to show with the two unit operations; in one case you have mixing take over this product and then allow them to settle.

So, when you do this, now there is a phase separations, you have raffinate phase 1, we have this x 1 we have extract phase, we have y 1 they are in equilibrium. So, single stage operations we come to this ABC diagram - the equilateral triangle: A, B, C; we look at the hand book for the system, you have this same diagram there is a P platelet point.

Now, we have to mark on these points. So, we have F A plus c. So, this A and C; that means F is here; there is no B, although in principle is possible that we can have feed here also. So, all the components possibilities are there, for simplicity let us assume that feed contains only A and C.

Now, we add the solvent you want to remove this C from this, you can add a pure solvent 100 percent or we can have some a small amount of solvent y S. So that possibilities are also there. So, now I have added these two settle, you know stir them and then, the allow them to settle; first thing is that if you connect this straight line, the mixture has to fall on this, because this is a mixing rule F plus B equals R plus E alright or A plus solvent equal R plus E, you have R 1, E 1 and S so, you get x M; this is a first unit operation for this; once you allow them to settle, now you have this tie line, this represents this tie line.

So, you have R 1 raffinate and you have extract here, all we have done; now we can write F plus S 1 say amount of solvent required, S 1 here instead of B will equal to M 1 which is this. So, that is one unit operations, but when you allow them to settle, now you have E 1 plus R 1 and you have species balance F into x F plus S 1 into y S will be equal to M 1 into x M. So, that is a mixing, but when you allow them to settle they will separate as E 1 y 1 plus x 1 into R 1. So, we have similar situation have one mixing rule we are apply in in two contents; one is mixing of feed with the solvent and then separations between R E, all of this they have to intersect at one line, because this M satisfies that mixing as well as M satisfy this separations that is the tie line y 1 and x 1 they are connected with the equilibrium or some equilibrium curve. So, this becomes our basis for our discussion for a stage operation.

So, what we have done, we started with this course extraction, first thing was the familiarity with this equilateral triangle with the graph, how do we represent ternary systems A, B and C that is number 1, number 2 we talk of thermodynamics, the way we talk thermodynamics in absorption and distillation.

So, we have this phase diagram; phase diagram depends upon what type of systems we have system 1, system 2, which two of them are partially miscible, which two components are partially immiscible etcetera; then we talk of this mixing rule which we apply in both cases when in mixing feed with the solvent. So, we have one mixing rule and now, we talk of separations tie line equilibrium where we separate into extract and the raffinate phase. So, the same common principle what we did if you remember the third or fourth lectures when you talk of the cascades and we said that you know cascade they could be in co-current cross-current or counter current they are making the same analogy earlier that example was for binary system.

Now, we are doing actually for ternary systems, but our principle you know our approach is the same we have to start with the thermodynamics certain phase diagram then make a material balance species balance see how much is amount of you know that applying the tie rules what amount of component is separated about amount of extract and the raffinate they are formed here.

So, next class we will continue with the multiple stage contacts, very good.