Mass Transfer Operations I
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Module - 2
Mass Transfer Coefficients
Lecture - 7
Interphase Mass Transfer and Mass Transfer Theories
Part 2

Welcome to seventh lecture of module two. The module two is on mass transfer coefficients. So, in this lecture, we will continue our previous lecture which is interphase mass transfer. In the previous lecture, we have seen that to calculate the flax for interphase mass transfer, we need to know the interfacial concentrations. But the interfacial concentration is not an easy task to measure by simple device or we can say the interfacial concentration is not measurable by simple device.

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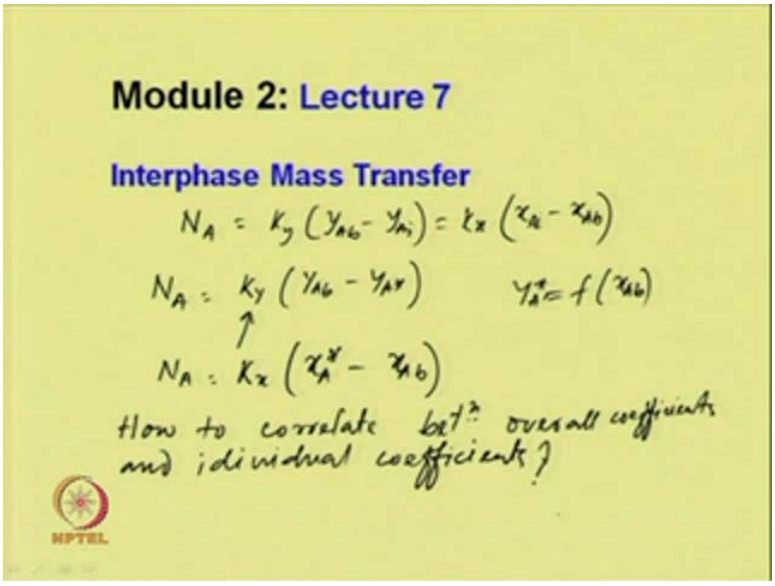

So, we cannot calculate the flux using say k y into y A b minus y A i interfacial concentration or K x x A i minus x Ab. We have seen that we can use the overall mass transfer coefficient concept to calculate the flux.

So, N A will be capital K y y A b minus y A star; where y A star is in equilibrium equilibrium with x A b, and K y is the overall mass transfer coefficient. Similarly, we can use NA is equal to capital K x x A star minus x A b x A star is the equilibrium concentration with y A b, then how to correlate or the relations between the overall coefficient and the individual coefficient, how to correlate between overall coefficient and individual coefficient?

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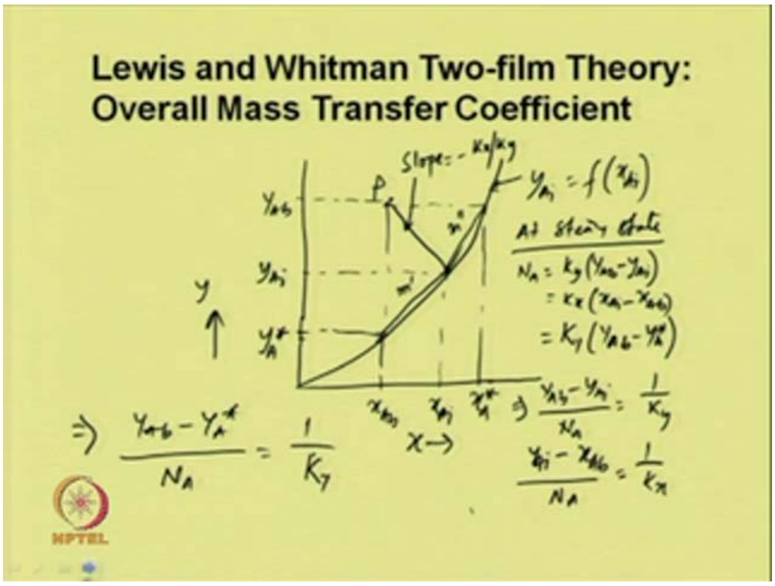

So, this we will discuss by graphical method. We now know that, so this is the equilibrium line and say this is y A i is a function of x A i is equilibrium line. And suppose, so this is the operating line are we this is the slope of this equations as we know, slope is minus k x k y. Suppose, this point is P and this location is x A b and this is y A b bal concentration and this is the interfacial concentration, where this line meets on the equilibrium line. This is y A i and this is x Ai. This y A b, if we draw a line on this, so this is the equilibrium with x A. So, this is x A star and similarly this is x A b equilibrium with y A star from this point. See, this is the slope of the line, suppose the slope of this line is m double dash and this is m dash, then at steady state at steady state, we can write NA is equal to k y y A b minus y A i is equal to k x x A i minus x A b. And also we can write is equal to capital K y y A b minus y A star.

So from this we can write y A b minus y A i by NA is equal to 1 by k y y A i minus x A b by NA is equal to 1 by k x. Similarly, y A b minus y A star by NA is equal to 1 by capital K y.

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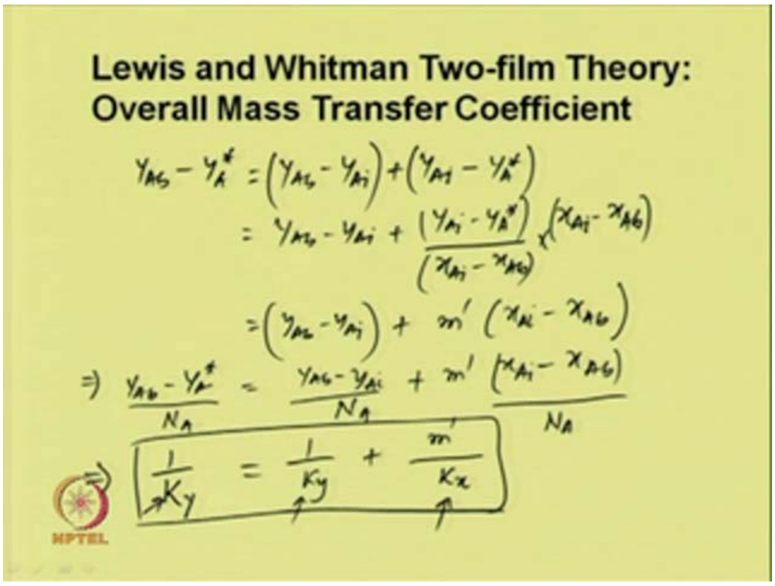

Now from this figure, we can write y A b minus y A star y a b minus y a star. We can write sum of y A b minus y A i plus y A i minus y A star. So, we will write y A b minus y A i plus y A i minus y A star. So, which is equal to y A b minus y A i plus y A i minus y A star. If we multiply by x A i minus x A b, both denominator and the numerator, so this is the slope of this line. The slope of this line is y A i minus y A star divided by x A i minus x A b.

So, we can write y A b minus y A i plus m dash x A i minus x A b. Therefore, we can write y A b minus y A star divided by NA is equal to y A b minus y A i divided by NA plus m dash x A i minus x A b divided by NA. So, this is nothing but one by capital K y is equal to y A b minus y A i by N A, which is one by small k y plus m dash by k x. So, this is the relation between the overall mass transfer coefficient and the individual mass transfer coefficient.

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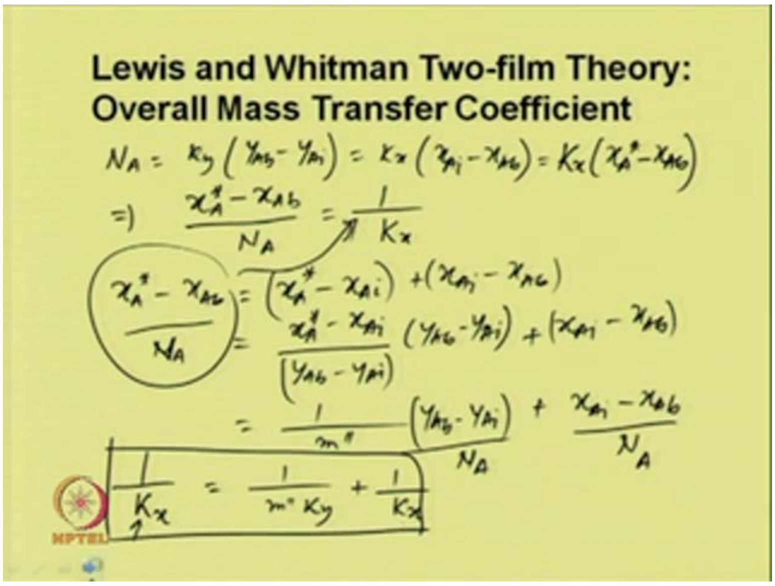

In the similar fashion, we can write NA is equal to k y y A b minus y A i is equal to k x x A i minus x A b is equal to capital K x into x A star minus x A b. Or from this, we can write x A star minus x A b divided by N A is equal to one by capital K x.

From the geometry of the figure, we can write x A star minus x A b. This is the overall driving force for mass transfer. So, this will be equal to x A star minus x A i plus x A I minus x A b. So we will write, is equal to x A star minus x A i plus x Ai minus x A b. So, we can write it. This equals x A star minus x A i divided by y A b minus y A i into y A b minus y A i plus x A i minus x A b. So, this is one by m double dash and this will be into y A b minus y A i plus x A i minus x A b. Now if we divide both side by NA, this will be NA and this will be NA. So, this is nothing but one by K x, capital K x, is equal to one by m double dash k y, small k y, plus one by k x, small k x. So, this is the relation between the overall mass transfer coefficient in terms of the liquid phase with the individual mass transfer coefficient.

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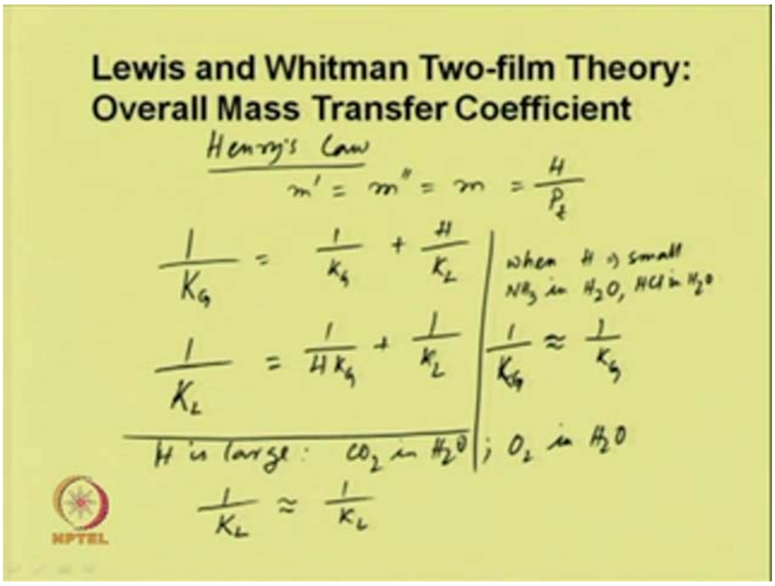

If the concentration of the solute in the system is very low and if it obeys Henry's law, in that case m dash will be equal to m double dash; which is equal to m and which we can write H… the constant by total pressure P t. And this relation between the overall mass transfer coefficient in the gas phase will be one by capital KG is equal to one by small k G plus H by k, small k L, and one by capital K L will be equal to one by H k G plus one by k L.

So, when H is small in case of absorption of ammonia in water or HC l in water, in that case we can write one by capital KG will be approximately equal to one by small k G. And similarly, when H is large as in the case of CO 2 in water, it forms carbonic acid or oxygen dissolution in water, the H is large. So, from this we can write one by capital KL approximately equals to one by small k L.

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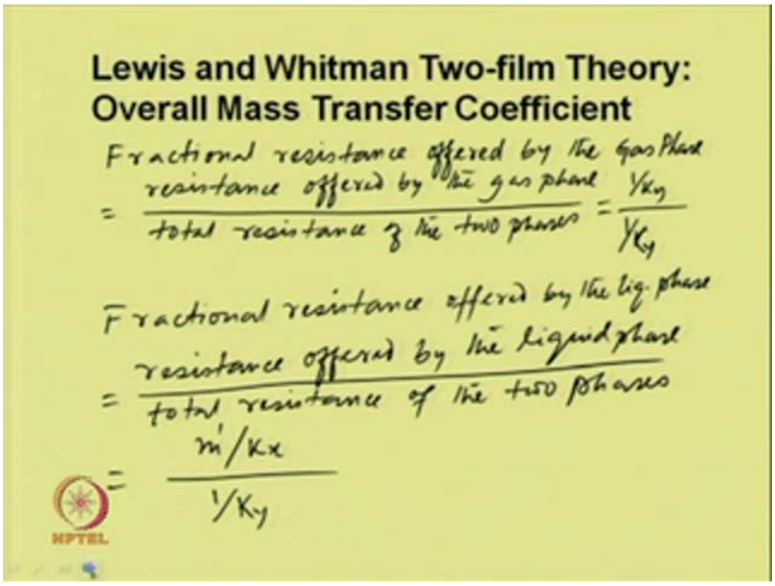

Now, the fractional resistance offered by the gas phase offered by the gas phase will be equals resistance offered by the gas phase divided by the total resistance of the two phases; which is equals to one by k y, this is the resistance offered in the gas phase divided by the total resistance offered by both the phases is capital K y. Now, fractional resistance offered by the liquid phase can also be defined. It will be equal to resistance offered by the liquid phase divided by the total resistance of the two phases, which is equals to m dash by k x, small k x, divided by 1 by capital K y.

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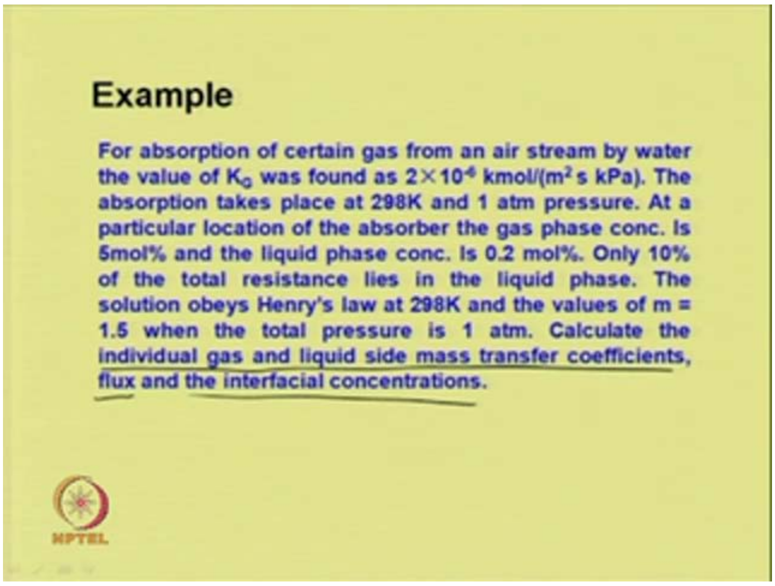

Let us take an example to calculate this individual coefficient flux and inter facial concentrations for a particular system. For absorption of certain gas from an air steam by water, the value of K G was found as 2 into 10 to the power minus 6 kilo mole per meter square second kilo Pascal. The absorption takes place at 298 kelvin and at one atmospheric pressure. At a particular location of the absorber, the gas phase concentration is 5 mole percent and the liquid phase concentration is 0.2 mole percent. Only ten percent of the total resistance lies in the liquid phase. The solutions obeys Henry's law at 298 kelvin and the values of m is equal to 1.5, when the total pressure is one atmosphere. Calculate the individual gas and liquid side mass transfer coefficients, flux and the interfacial concentrations.

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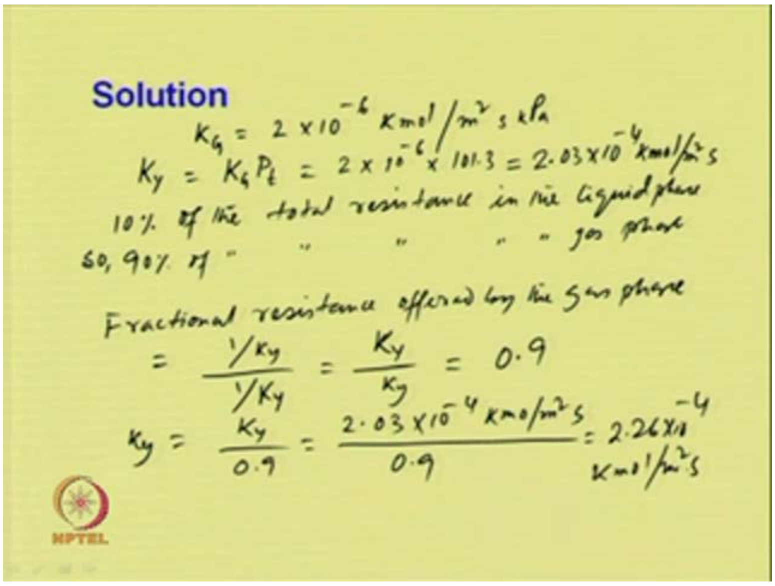

Now, the data which are given is k G is equal to 2 into 10 to the power minus 6kilo mole per meter square second kilo Pascal. And we know that capital K y is equal to capital KGP t, which is equal to 2 into 10 to the power minus 6 into 101.3 kilo Pascal, one atmosphere is 101.3 kilo Pascal, which is equal to 2.03 into 10 to the power minus 4 kilo mole per meter square second. And it is given that ten percent of the total resistance resistance in the liquid phase, so ninety percent of the total resistance should be in the gas phase.

Now, we know that fractional resistance offered by the gas phase is equal to one by small k y divide by one by capital K y. So, which is capital K y divided by small k y. This is given 0.9, 90 percent. So, small k y will be capital K y divided by 0.9. If we substitute capital K y, 2.03 into 10 to the power minus 4 kilo mole per meter square second divided by 0.9, which is equal to 2.26 into 10 to the power minus 4kilo mole per meter square second.

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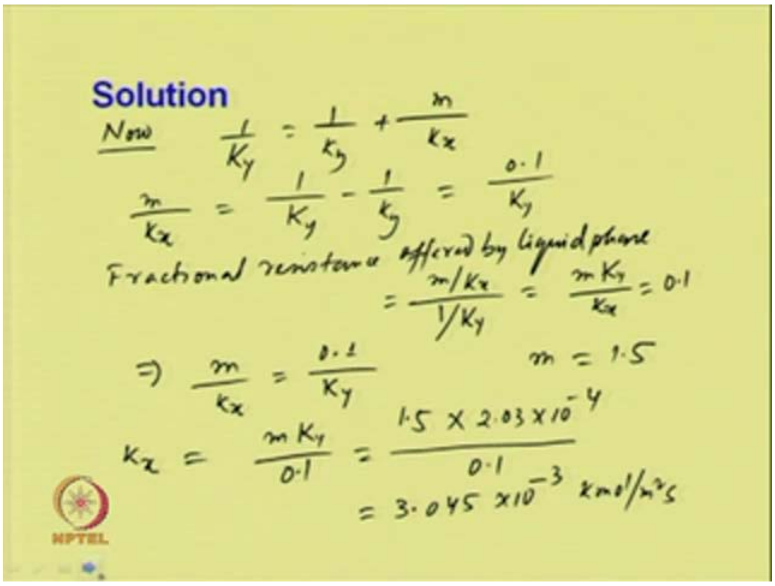

We know that, one by capital K y is one by small k y plus m by k x. So, m by k x is equal to one by capital K y minus one by k y. And we know that fractional resistance offered by liquid phase is equal to m by k x divided by one by capital K y, which is equal to m capital K y by small k x. So, this is given as ten percent, which is 0.1.

So, from this we can calculate m by k x is equal to 0.1 divided by capital K y. So, this will be equal to 0.1 divided by capital K y. So, from this we can calculate k x will be m capital K y divided by 0.1 is equal to, m is given 1.5 into, so m is given 1.5 into 2.03into ten to the power minus 4 divided by 0.1, which is equal to 3.045 into 10 to the power minus 3 kilo mole per meter square second. So, these are the individual mass transfer coefficient. Now, we will calculate the flux.

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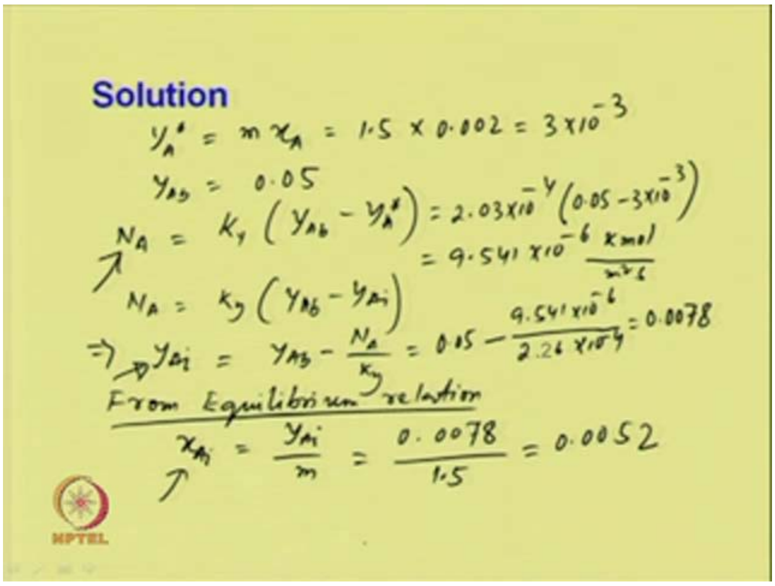

To calculate the flux, we know the equilibrium compositions y A star is equal tom into x A. m is given 1.5 and the concentration in the particular location is given 0.002.So which is equal to 3 into 10 to the power minus 3.And, y A b is given 0.05 mole. So, NA will be equal to capital K y y A b minus y A star, which is equal to 2.03 into 10 to the power minus 4 into 0.05minus 3 into 10 to the power minus 3, which is equal to 9.541 into 10 to the power minus 6 kilo mole per meter square second.

We know that, NA is equal to k y into y A b minus y A i. So, from this we can calculate the interfacial concentration y A i will be equal to y A b minus NA by k y. So, we substitute. It is0.05 minus 9.541 into10 to the power minus 6 divided by2.26into 10 to the power minus 4, which is equal to 0.0078.And, from the equilibrium relations we know that x A i will be equal to y A i by m. So, which is equal to 0.0078 divided by 1.5, which is equal to 0.0052.So, these are the interfacial concentration and this is the flux and we have calculated the individual mass transfer coefficient.

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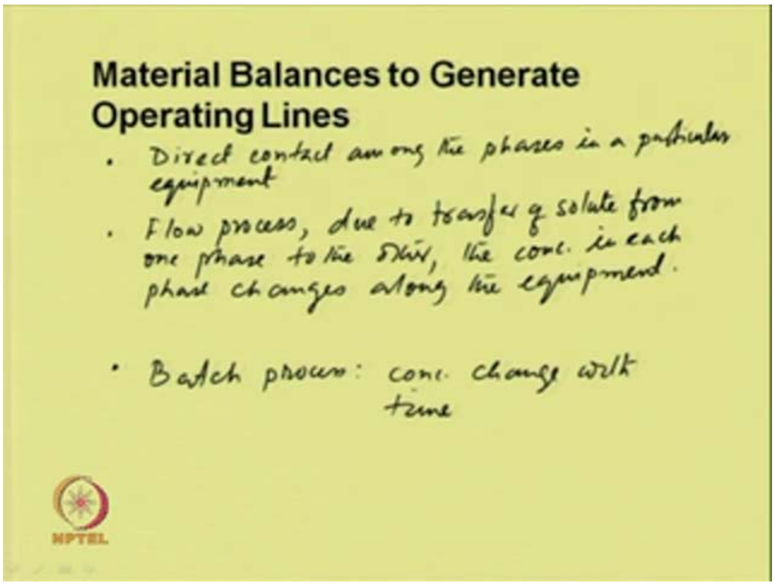

So, now we will discuss the material balances to generate operating lines. In general, when there are two phases are in contact, they are in direct contact between the phases in the equipments.

So, direct contact among the phases in a particular equipment. In case of flow process, due to transfer of solute transfer of solute from one phase to the other, the concentration in each phase changes along the equipment. So, if it is a batch process in this case also, the concentration changes with time. Since the concentration changes with time, there is a variation of driving force for mass transfer along the equipments.

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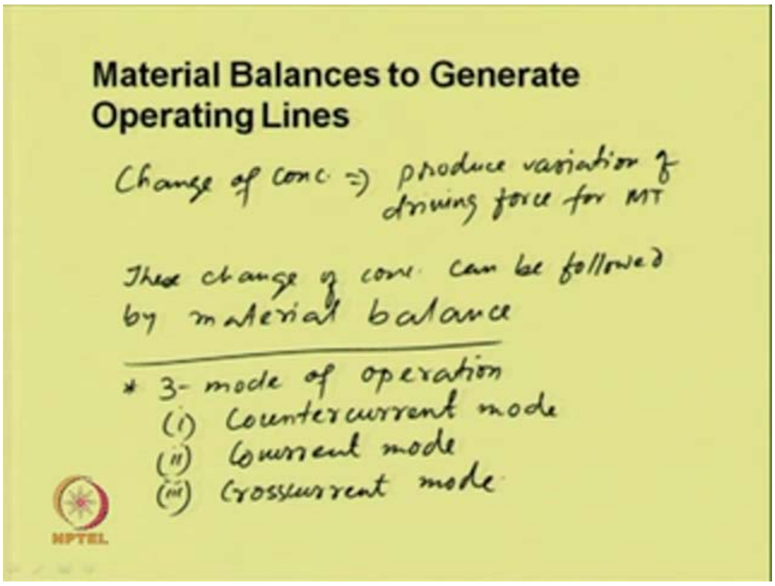

So, change of concentration produce variation of driving force for mass transfer. How we can follow these changes of concentration through the equipment, as the phases flows from one into the other. And this can be followed; the change of concentration can be followed by material balance. There are three mode of contact three mode of operations. We will discuss three mode of operations. One is counter current operations; second is concurrent and third one is crosscurrent.

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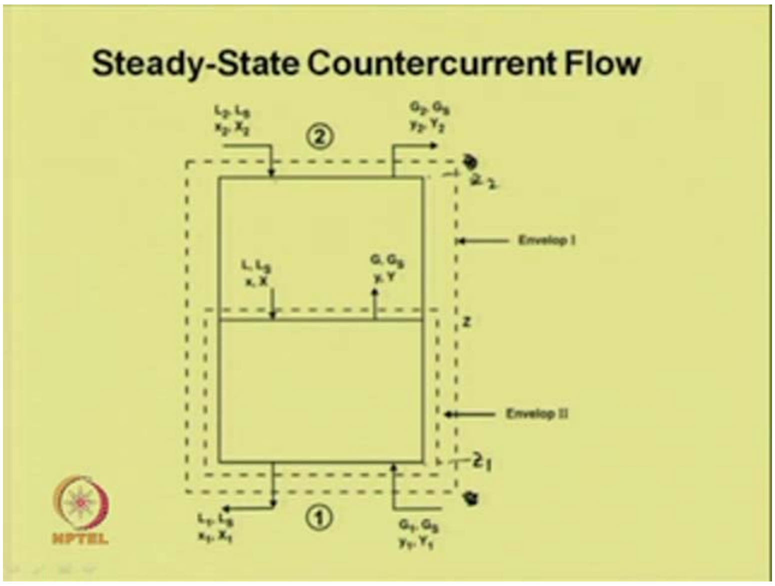

So, let us consider steady state counter current flow. A steady state countercurrent flow; consider there are gas and liquid phase, they are in contact. And gas being a lighter component compared to the liquid phase, they flows from bottom to top and the liquid flows from top to bottom. So, this is location at Z 1 and this is some intermediate location, any plane and this is at location Z2. So, at one the gas flow rate is G one and G s is solute free vases and Y one is the mole fractions, small y one and capital y one is the mole ratio basis. So, these are the nomenclature which is given. So gas, there is an inlet at the bottom and outlet at the top and liquid in at the top and out at the bottom.

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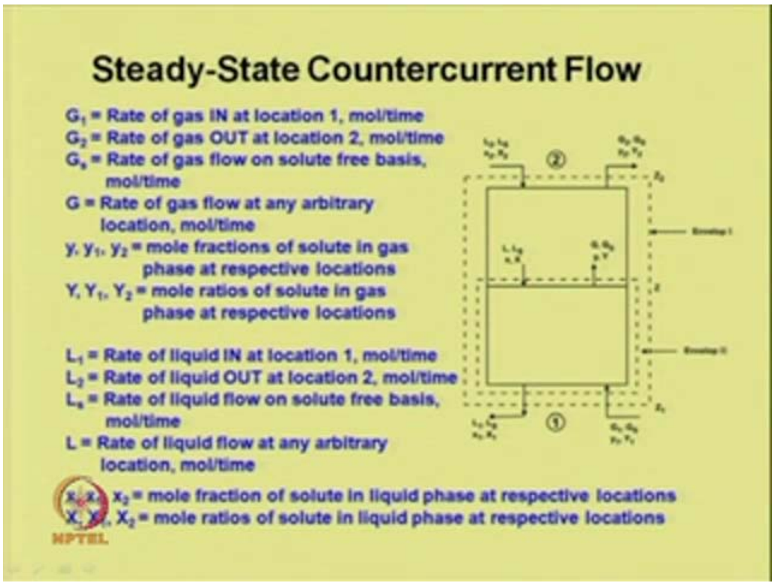

So,G1 is the rate of gas IN at location one, in mole per time;G2 is the rate of gas OUT at the location two and mole per time; G s is the rate of gas flow on solute free basis in mole per time; G is the rate of gas flow at any arbitrary locations inside the equipment; and small y, small y 1 and small y 2, these are the mole fractions of the solute in the gas phase at respective locations and capital Y, capital Y1, capital Y2, these are the mole ratios of the solute in gas phase in their respective locations. L 1, L2 and L s, these are the liquid flow rates. And L, these are the liquid flow rates at respective locations and small x is the mole fractions of the solute in the liquid phase and capital X is the mole ratios of the solute in the liquid phase.

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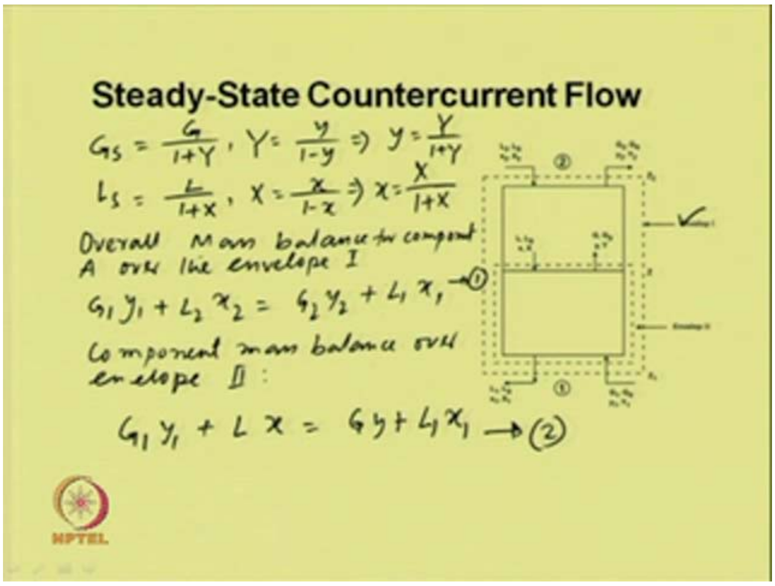

So, with these convention if we do the material balance, we can define like G s as we said, which is solute free basis. G s can be written. It is equal to G by one plus capital Y and capital Y is equal to y, small y, by one minus small y. Or, from this we can write small y is equal to capital Y divided by one plus capital Y. L s is L by one plus X, capital X. Capital X, we can write x, small x, divided by one minus small x. From this we can write small x is equal to capital X divided by one plus capital X. The overall mass balance if we consider the envelope one, the overall balance over the equipment which is envelope one, overall mass balance for envelope one for component A, for a particular component A over the envelope one.

This we can write, G one small y one plus L2 x 2, which is equal to G2 y 2 plus L1 x 1.So, this is equation 1. The component mass balance over envelope two we can write, G1 y 1plus L x is equal to G y plus L1 x 1.This is equation 2.

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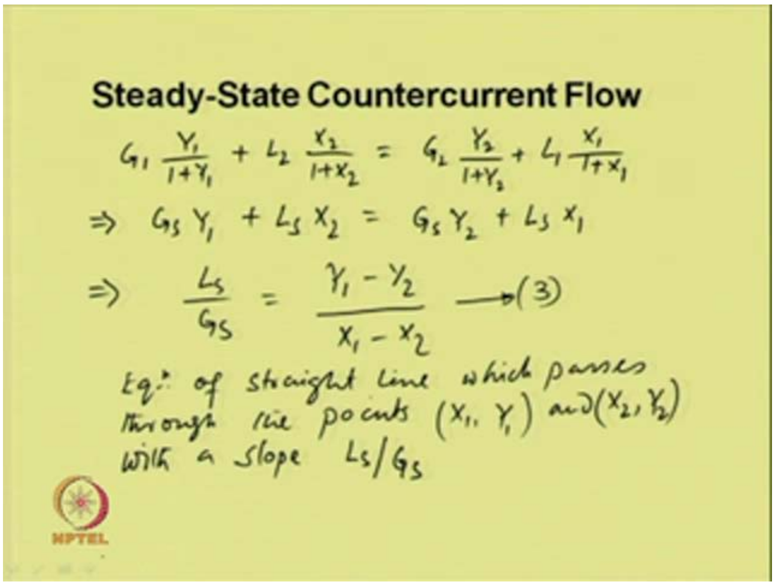

Now, if we write these equations in terms of the solute free basis, we can writeG1 into y 1, small y 1, is capital Y1 by 1 plus y 1 capital Y1 plus L2 into x 2 by 1 plus x 2 is equal to G2 y 2 by 1 plus capital Y2 plus L1 capital X1 by 1 plus x 1.

So, this will give G s Y1 plus L s X2 is equal to G s Y2 plus L s X1.From this, we can write L s by G s is equal to Y1 minus Y2 divided by X1 minus X2.Say this is equation 3.So, this equation is an equation of a straight line which passes through the points capital (X1,Y1) and (X2,Y2) with a slope L s by G s.

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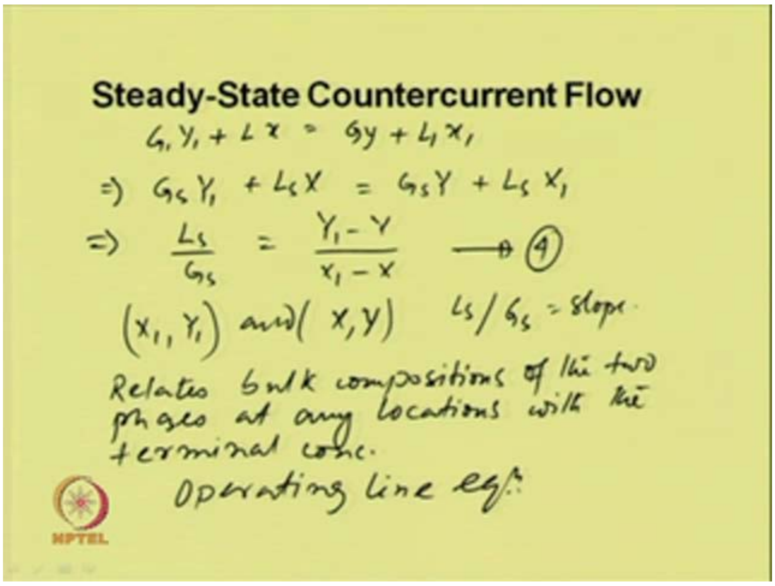

Now the equation 2, this equation also we write in term of the solute free basis, so that is G1 y 1 plus L x is equal to G y plus L1 x 1.So, this also will give you G s capital Y1 plus L s capital X is equal to G s capital Y plus L s capital X1.From this, we can write L s by G s is Y1 minus Y divided by X1 minus X.

So, this is also equations of straight line and passing through the points X1, Y1 and X, capital Y with a slope L s by G s. This equation is in general relates bulk compositions of the two phases at any location with the terminal concentrations. So, this is called as operating line equations or equation of operating lines.

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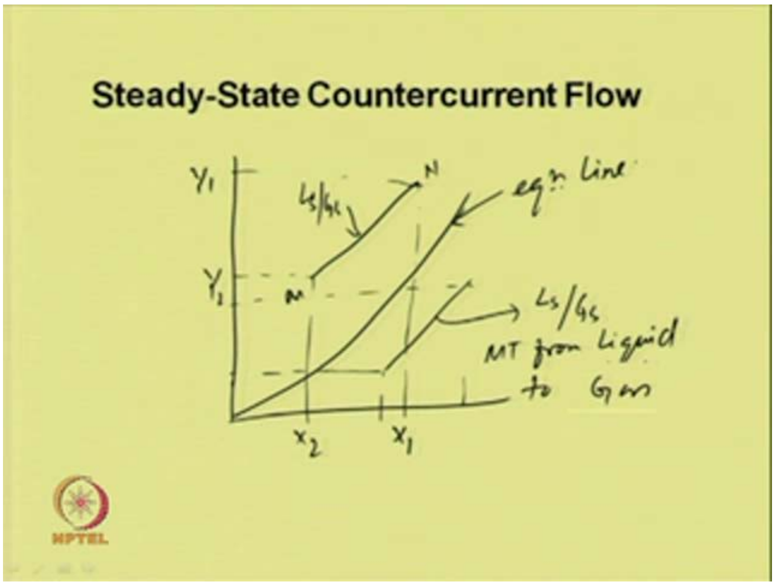

If we plot for the case we discuss, so this is the equilibrium line and this is the operating line with a slope L s by G s and this is the concentration, this is x 2, y 2 and this is y 1, x one and suppose this is M and this is N, so this is the equation of operating line and this is the equilibrium line.

So, if the solute transfers from the gas phase to the liquid phase, then the operating line is above the equilibrium line; if gas is transferred from liquid to gas, then operating line will be below the equilibrium line. So, this is also with the slope L s by G s and mass transfer from liquid to gas phase, if we plot the difference between the mole free basis and on mole basis.

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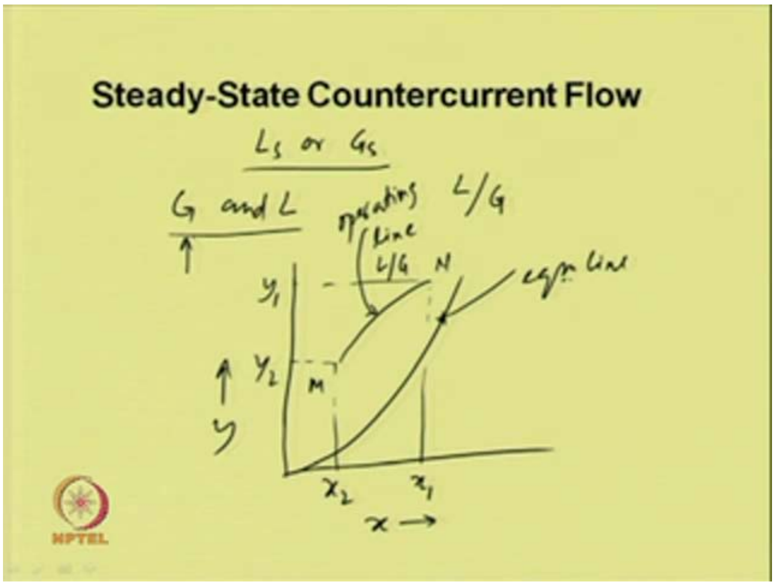

When we plot solute free basis, the operating line…, as we have seen; because it is based on L s or G s which does not change along the path of the travel of the phases in the equipment, whereas if we take the quantities G and L, these are change as it flows from one location to the other in the equipment, since there is mass transfer from one phase to the other, this G and L changes and hence L by G ratio changes. So, the equations of operating line will not be a straight line. So, it will be curved line like this. And if we plot, this is x 2 and this is y 2, this is x 1 and this is y 1. Suppose this is M and N two points and this is the equilibrium line and this is the operating line with a slope L by G, the slope is changing if we plot in terms of mole fraction basis. So, the equilibrium line and the operating line both will be curved. Since L and G, they are changing along the flow paths of the phases.

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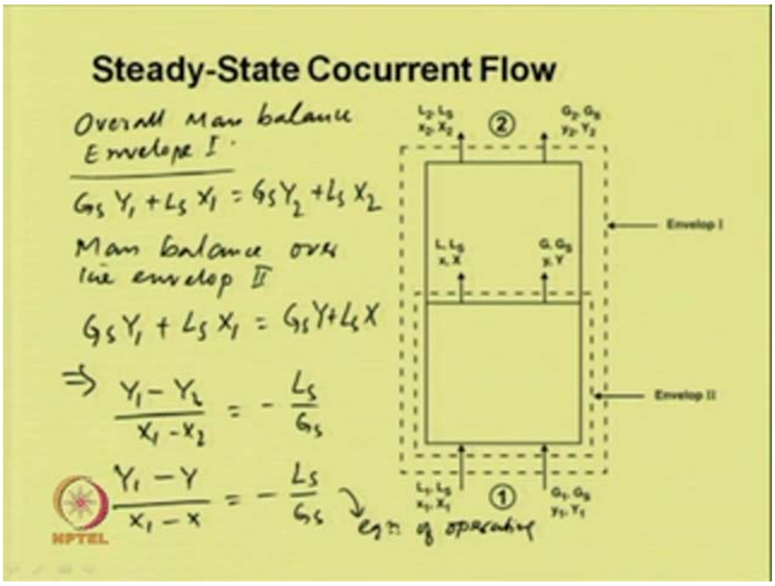

Now, let us consider steady state co current flow. The notations have their usual significance as we have discussed earlier. In this case, if we consider envelope one, in this case the flow is in the same directions; both the gas and liquid flows in the same direction from 0.1 to 0.2. The overall mass balance for component A over the envelope one we can write, G s capital Y1 plus L s X1 is equal to G s Y2 plus L s X2.And, mass balance over the envelope two we can write, G s Y1 plus L s X1 is equal to G s Y plus L s X. And if we rearrange these equations we can write Y 1 minus Y2 by X1 minus X2 will be minus L s by G s and also Y1 minus Y by X1 minus X will be minus L s by G s. So, the slope is negative and this is the equation of operating line with a slope; operating line with a slope minus L s by G s.

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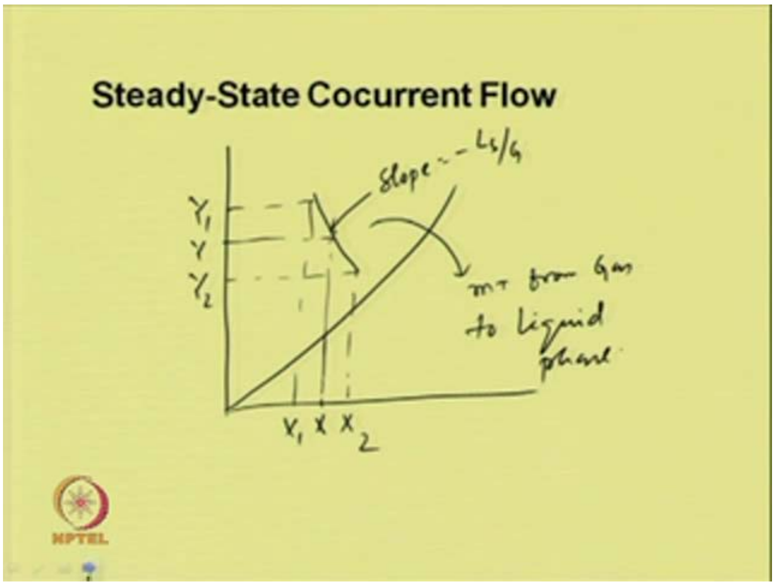

And if we plot, this is the line and this is the slope minus L s by G s and this is X2, this is y 2, this is y 1 and this is x 1 and in between this is, suppose x and this is y. So, the operating line will be above the equilibrium line, if this is mass transfer from gas to liquid phase.

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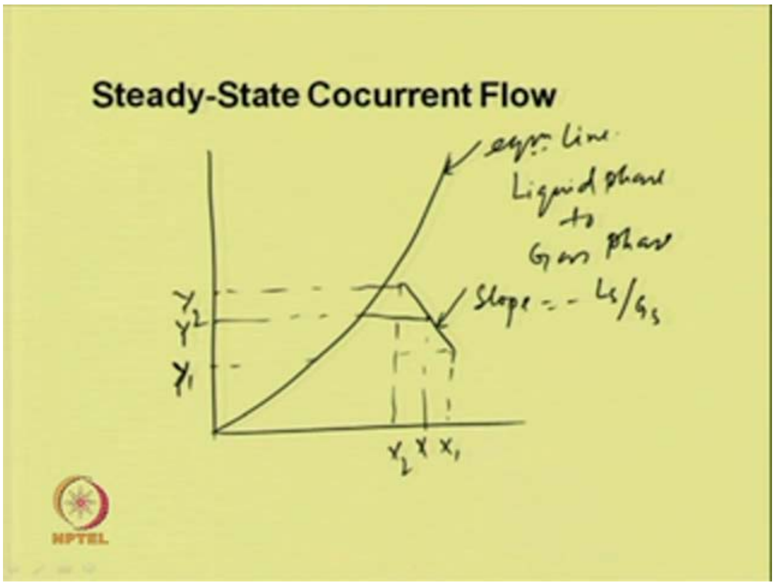

So, if the mass transfer is from from liquid phase to gas phase, the operating line will be below the equilibrium line and this is x 1, this is y 1, this is x 2, this is y 2 and some point in between, this is x and this is y. So, the this is also the same slope of minus L s by

G s. Now, among these two cases we discussed, that is, countercurrent operations and co current operation mode, which one is better or which one is preferred?

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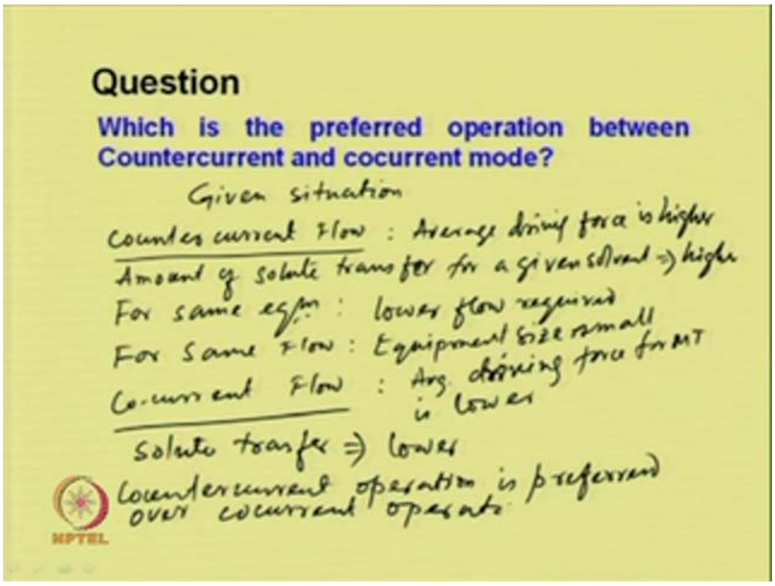

If we consider a given situation for counter current flow, average driving force is higher compared to co current flow; average driving force force for mass transfer is lower compared to counter current flow. So, the amount of solute transfer solute transfer for a given solvent is higher; solute transfer in this case is lower compared to the counter current flow. And if we consider for the same equipment, the lower flow is required required in case of counter current flow compared to the co current flow or if we keep the same flow, then the equipment size size required is small. So from all these points, we can say that counter current operation is preferred over co current operation.

Thank you.