# Transport Phenomena in Biological Systems
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## Lecture-64
## Gas-Liquid Interphase Transporta

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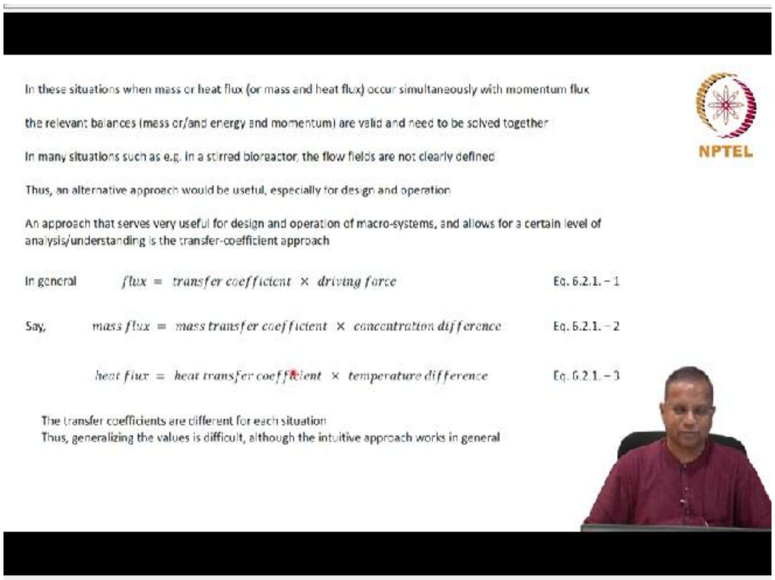

In these situations when mass or heat flux (or mass and heat flux) occur simultaneously with momentum flux

the relevant balances (mass or/and energy and momentum) are valid and need to be solved together

In many situations such as e.g. in a stirred bioreactor, the flow fields are not clearly defined

Thus, an alternative approach would be useful, especially for design and operation

An approach that serves very useful for design and operation of macro-systems, and allows for a certain level of analysis/understanding is the transfer-coefficient approach

In general $flux = transfer\ coefficient \times driving\ force$ Eq. 6.2.1. – 1

Say, $mass\ flux = mass\ transfer\ coefficient \times concentration\ difference$ Eq. 6.2.1. – 2

$heat\ flux = heat\ transfer\ coefficient \times temperature\ difference$ Eq. 6.2.1. – 3

The transfer coefficients are different for each situation
Thus, generalizing the values is difficult, although the intuitive approach works in general

Welcome back, in the last class we looked at flux being expressed as the product of a certain transfer coefficient times, a certain driving force. This driving force was the difference in amounts rather than the gradient of that amount okay. For example the mass flux was given as a product of the mass transfer coefficient and the concentration difference and heat flux was given as the product of the heat transfer coefficient and the temperature difference okay 6.2.1 - 3 and so on.

And then we said the limitation is that this the coefficients are specific for certain situations. So, generalization becomes difficult. Let us take things further in this lecture.

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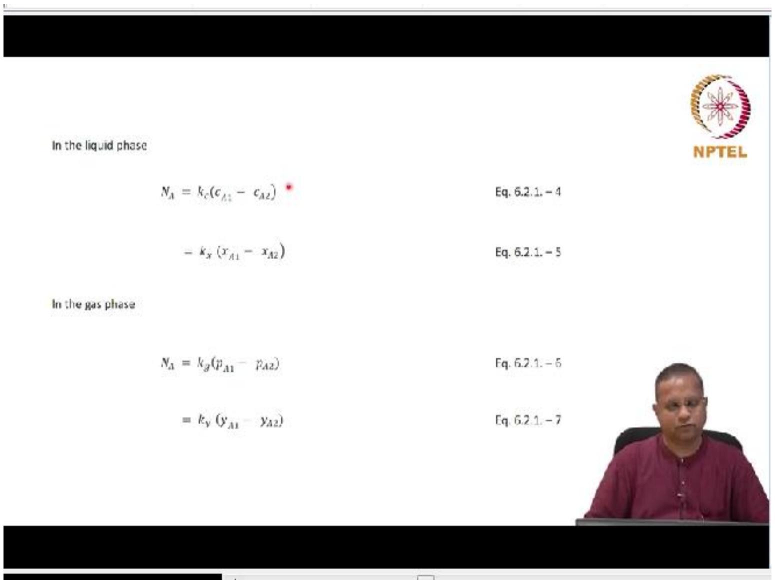

In the liquid phase

$$N_A = k_c(c_{A1} - c_{A2}) \quad \text{Eq. 6.2.1. – 4}$$

$$= k_x(x_{A1} - x_{A2}) \quad \text{Eq. 6.2.1. – 5}$$

In the gas phase

$$N_A = k_g(p_{A1} - p_{A2}) \quad \text{Eq. 6.2.1. – 6}$$

$$= k_y(y_{A1} - y_{A2}) \quad \text{Eq. 6.2.1. – 7}$$

Now we are looking at the transport of oxygen from the gas phase to the liquid phase, we have the gas bubbles through which the transport occurs or from bits the transport occurs. So, we are going from we are looking at the oxygen transport from the gas bubble to the liquid surrounding.

In a liquid phase

$$N_A = k_c(c_{A1} - c_{A2}) \qquad (6.2.1\text{-}4)$$

$$= k_x(x_{A1} - x_{A2}) \qquad (6.2.1\text{-}5)$$

6.2.1-4 which can be written, this has been written in terms of concentrations, we can write them in terms of mole fractions also, it becomes easy and many times to work in terms of mole fractions. So, we write this as k x the transfer coefficient in it is based on mole fraction times the mole fraction at equation 6.2.1 - 5.

In a gas phase

$$N_A = k_g(p_{A1} - p_{A2}) \qquad (6.2.1\text{-}6)$$

$$= k_y(y_{A1} - y_{A2}) \qquad (6.2.1\text{-}7)$$

So, these are the flux definitions from our formulation transfer coefficient times certain difference in the driving force.

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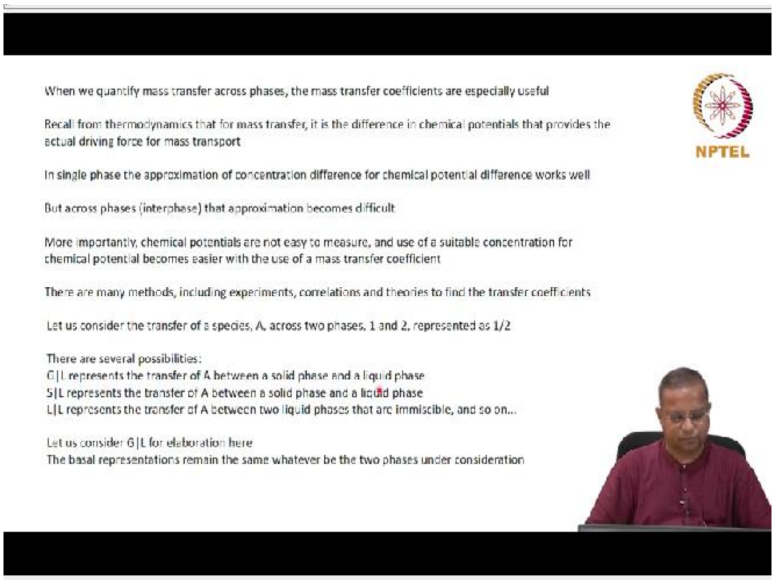


When we quantify mass transfer across phases, the mass transfer coefficients are especially useful

Recall from thermodynamics that for mass transfer, it is the difference in chemical potentials that provides the actual driving force for mass transport

In single phase the approximation of concentration difference for chemical potential difference works well

But across phases (interphase) that approximation becomes difficult

More importantly, chemical potentials are not easy to measure, and use of a suitable concentration for chemical potential becomes easier with the use of a mass transfer coefficient

There are many methods, including experiments, correlations and theories to find the transfer coefficients

Let us consider the transfer of a species, A, across two phases, 1 and 2, represented as 1/2

There are several possibilities:
G|L represents the transfer of A between a solid phase and a liquid phase
S|L represents the transfer of A between a solid phase and a liquid phase
L|L represents the transfer of A between two liquid phases that are immiscible, and so on...

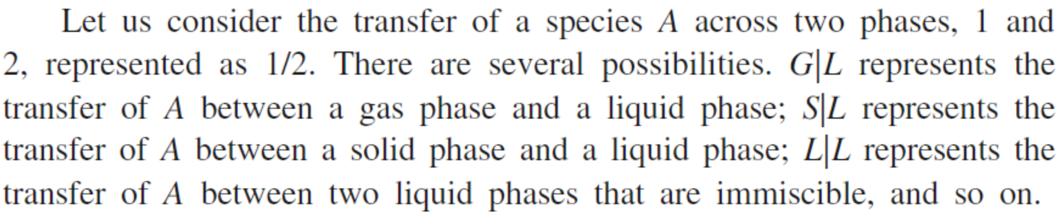
Let us consider G|L for elaboration here
The basal representations remain the same whatever be the two phases under consideration

Now when we quantify mass transfer across phases okay from a gas phase to a liquid phase, from one liquid phase to another liquid phase maybe in the immiscible liquid phase, from liquid back to the gas or liquid to the solid whatever it could be. The mass transfer coefficients are especially useful okay and recall from thermodynamics there for mass transfer it is the difference in chemical potentials that provides the actual driving force of mass transport.

This is true okay, however chemical potentials are a lot more difficult to measure on a regular basis, concentrations are far easier to measure, therefore we would like our formulations to be in terms of whatever we can measure easily right to be directly used and therefore we try to overcome this need for chemical potential by some sort of a roundabout method which uses concentrations okay.

And however, retain the use of the concentration and thereby the ease of application. In a single phase the approximation of concentration difference for chemical potential difference that works well, it does not matter, when they use the difference input, chemical potential or the difference in concentration as long as you couple it with an appropriate transfer coefficient, this will work, the flux will perfectly work.

But across phases or interphase from one phase to another interface that approximation of course becomes difficult and more importantly chemical potentials are not to measure that I just mentioned and use of a suitable concentration for chemical potential becomes easier with the use of a mass transfer coefficient. There are many methods including experiments, correlations and theories to find the transfer coefficients.



> Let us consider the transfer of a species $A$ across two phases, 1 and 2, represented as 1/2. There are several possibilities. $G|L$ represents the transfer of $A$ between a gas phase and a liquid phase; $S|L$ represents the transfer of $A$ between a solid phase and a liquid phase; $L|L$ represents the transfer of $A$ between two liquid phases that are immiscible, and so on.

If they are miscible a death just one liquid phase right so and so on okay. So, we are going to look at gas liquid because we are looking at the transfer of oxygen from the gas bubble to the liquid broth, the gas and liquid transport. The basal representations remain the same whatever be the 2 phases under consideration okay. So, it does not really matter for the applicability of our formulation. What the 2 phases are, it could be G|L, it will be S|L, L|L, so okay.

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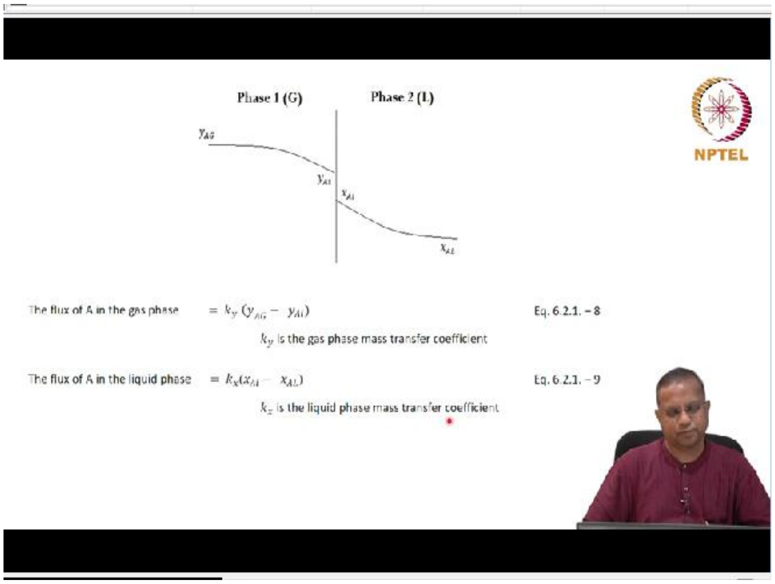


The flux of A in the gas phase $= k_y (y_{AG} - y_{Ai})$ Eq. 6.2.1. – 8

$k_y$ is the gas phase mass transfer coefficient

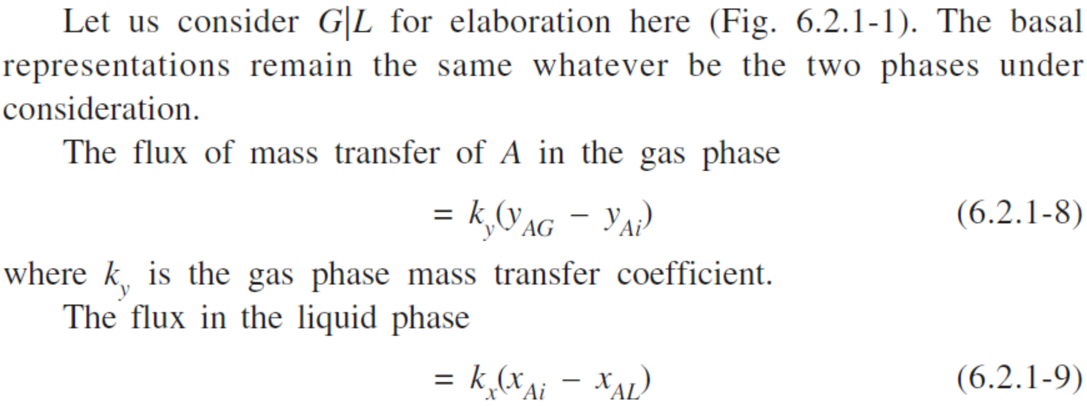
The flux of A in the liquid phase $= k_x(x_{Ai} - x_{AL})$ Eq. 6.2.1. – 9

$k_x$ is the liquid phase mass transfer coefficient

Now let us consider this to be the interface between phase 1 and phase 2, phase 1 happens to be a gas, phase 2 happens to be a liquid in this case, this is the gas bubble, this is the in liquid broth, the oxygen concentration at the middle of the gas bubble is taken as $Y_{AG}$ and it is expected to be higher evidence if the bubble is not well mixed. The bubble is very mixed probably there is going to be a flat line here.

And let us assume the reasonably general case where the bubble is not well mixed and therefore the concentration away from the interface of course is going to be a spherical interface, is going to be greater than the interfacial mole fraction of A. Similarly in the liquid phase this is the interfacial mole fraction of A and this is the bulk mole fraction of A, recall equilibrium $Y_{AI}$ and $X_{AI}$ are related in a certain way.

The approximated relationship for a short range and so on so forth, it is a linear relationship $Y_{AI}$ equals M times $X_{AI}$ can be used here, the overall thing is a lot more complex you recall the Y versus X graph the equilibrium curve and go or something like this okay. So, if you do a piecewise consideration of that curve then that variation could be considered as a linear variation that we look at in detail in a little bit.



Let us consider $G|L$ for elaboration here (Fig. 6.2.1-1). The basal representations remain the same whatever be the two phases under consideration.

The flux of mass transfer of $A$ in the gas phase

$$= k_y(y_{AG} - y_{Ai}) \qquad (6.2.1\text{-}8)$$

where $k_y$ is the gas phase mass transfer coefficient.

The flux in the liquid phase

$$= k_x(x_{Ai} - x_{AL}) \qquad (6.2.1\text{-}9)$$

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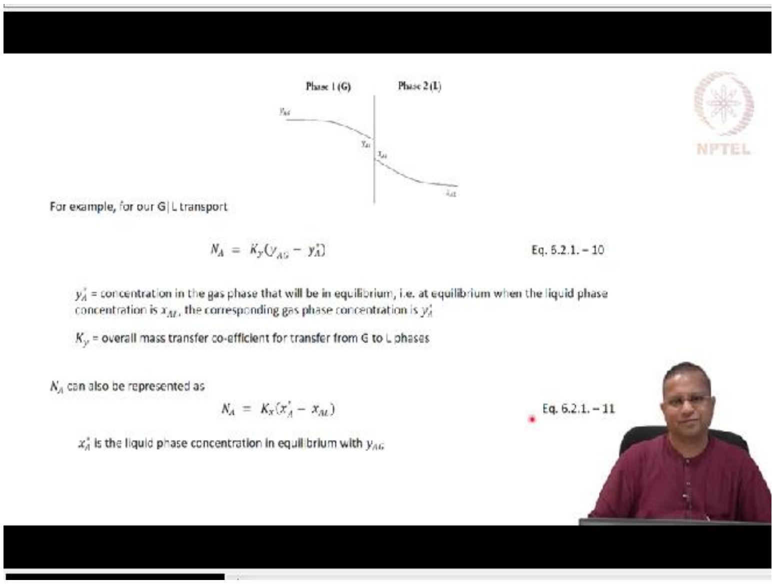


For example, for our G|L transport

$$N_A = K_y(y_{AG} - y_A^*) \qquad \text{Eq. 6.2.1.} - 10$$

$y_A^*$ = concentration in the gas phase that will be in equilibrium, i.e. at equilibrium when the liquid phase concentration is $x_{AL}$, the corresponding gas phase concentration is $y_A^*$

$K_y$ = overall mass transfer co-efficient for transfer from G to L phases

$N_A$ can also be represented as

$$N_A = K_x(x_A^* - x_{AL}) \qquad \text{Eq. 6.2.1.} - 11$$

$x_A^*$ is the liquid phase concentration in equilibrium with $y_{AG}$

Lewis and Whitman way back in 1924 proposed that the resistances to mass transfer reside only in the phases and across the interface or at the interface there is no resistance to mass transfer okay. That is what they said, what does this mean the change in concentrations will happen more slowly here, it will happen instantaneously here. Because of that at the interface this gas phase and the liquid phase can be considered to be in equilibrium.

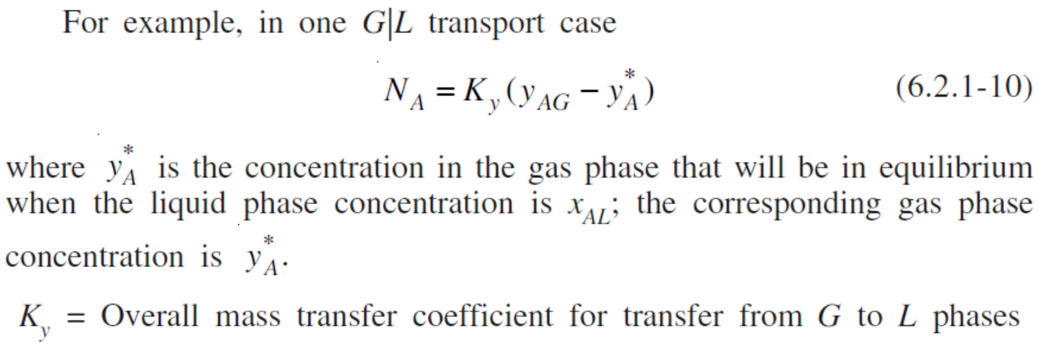
That is what they said okay, it is a very powerful thing to say, this is what they proposed and consequently the concentrations $Y_{AI}$ and $X_{AI}$ at the interface are equilibrium concentrations that I just mentioned and this is actually been verified by very careful experiments okay at the interface it is indeed at equilibrium. The gas phase concentration and the liquid phase concentration are at the equilibrium values.

However, the interface concentrations are not easy to measure, it calls for very fine instrumentation very careful measurements to measure at the interface, bulk far easier to measure. So, we need our formulation in terms of the bulk concentrations. So, we use bulk concentrations and an overall mass transfer coefficient and overall mass transfer coefficient that goes from here to here.

Note that these 2 are different, these are apples, these are oranges, but let us see how to formulate them, x and y are concentrations in different phases, they are different quantities and the denominator volumes are also different okay gas phase volume is different from liquid phase volume. So, the concentrations you know which are normalized with respect to volume there are lot of difficulties.

And hence algebraic operations cannot be done with them, we cannot put them together. The way around that difficulty is to use the concentration in one phase that is supposed to be in equilibrium but the bulk concentration in the other phase. So, you use the concentration in one phases there is supposed to be in equilibrium with the other concentration with the bulk concentration the other phase.

In other words we are trying to relate the flux in terms of the bulk concentration here and the bulk concentration here. $Y_A^*$ is not an actually concentration it is a conceptual concentration, $Y_A^*$ is the concentration that is an equilibrium with $X_{AL}$ okay. So, it essentially converts this into an equivalent concentration here.



For example, in one $G|L$ transport case

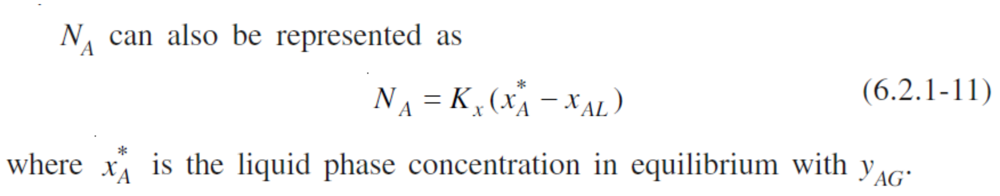
$$N_A = K_y(y_{AG} - y_A^*) \qquad (6.2.1\text{-}10)$$

where $y_A^*$ is the concentration in the gas phase that will be in equilibrium when the liquid phase concentration is $x_{AL}$; the corresponding gas phase concentration is $y_A^*$.

$K_y$ = Overall mass transfer coefficient for transfer from $G$ to $L$ phases

And thereby we could do algebraic operations, it converts an apple to an orange and thereby we can subtract apples add apples, whatever it is okay, that is what happens here and this is the equation 6.2.1 - 10. $Y_A$* is the concentration in the gas phase that will be in equilibrium, that is at equilibrium when the liquid phase concentration as $X_{AL}$. The corresponding gas phase concentration is $Y_A$*.

So, that is what I mentioned here. I think and $K_Y$ is the overall mass transfer coefficient from the gas phase to the liquid phase. Let me just say this thing and let you soak this in for a while we said we will do this lecture in very many different or we would do this topic in very many different pictures short lectures. So, that it will help you understand further. So, let me mention this and take a break.



$N_A$ can also be represented as

$$N_A = K_x(x_A^* - x_{AL}) \qquad (6.2.1\text{-}11)$$

where $x_A^*$ is the liquid phase concentration in equilibrium with $y_{AG}$.

This flux can also be represented as the other thing you could write the overall mass transfer coefficient in terms of the liquid phase also. $X_A$* is a conceptual concentration it is not something that can be measured. However, what this represents is the liquid phase concentration in equilibrium with $Y_{AG}$. So, we have represented $Y_{AG}$ through an equivalent concentration in the liquid phase and thereby we could do these manipulations, we can do these algebraic manipulations.

and let me take a break here for you to internalize this and then when we come back and reemphasize this further, see you in the next class bye.