Mass Transfer Operations I
Prof. Bishnupada Mandal
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Module - 3
Equipment for Gas Liquid Operations
Lecture - 1
Agitated and Sparged Vessels

Welcome to the first lecture of module 3. In this lecture, we will discuss the equipment for gas liquid operations. In the previous lecture, we have discussed the interface mass transfer, under module 2, and we have seen for mass transfer among the phases, we need to have a very good contact among, among the gas and liquids.

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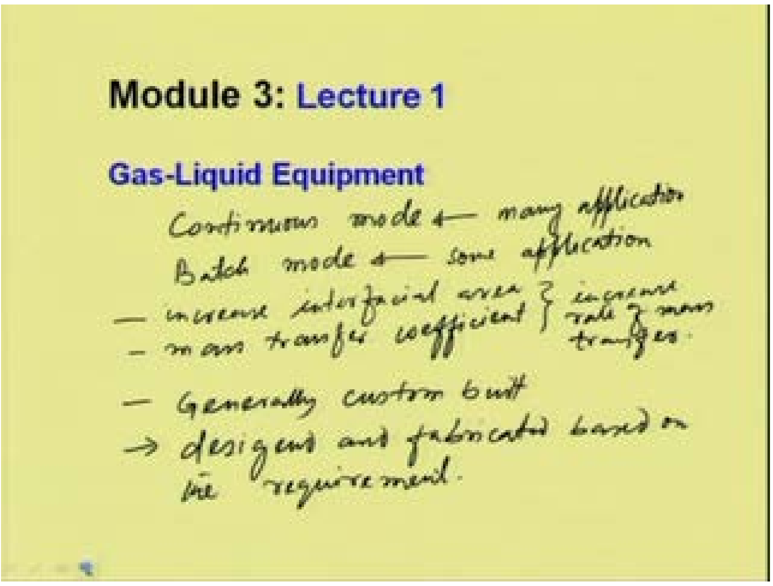

So, the equipments for gas liquid operations are basically serve this purpose, the intimate contact among the two phases. So, there are two types of operations; either continuous mode or batch mode. Most of many applications are based on the continuous mode, and there are some applications which are in batch mode. So, this equipments are basically, bring the gas and liquid to have a high turbulence among the phases, and this way helps to increase, increase interfacial area, and hence the mass transfer coefficient as well. So, increasing interfacial area and mass transfer coefficient will increase rate of mass transfer. The mass transfer equipments are generally custom built, custom built. So, it is not generally, readily available, like palms, heat exchangers, valves, blowers. Those are readily available, but these are designed and fabricated based on the requirement. There are variety of gas liquid contact equipments are available, and we can classify the gas liquid equipments in two categories.

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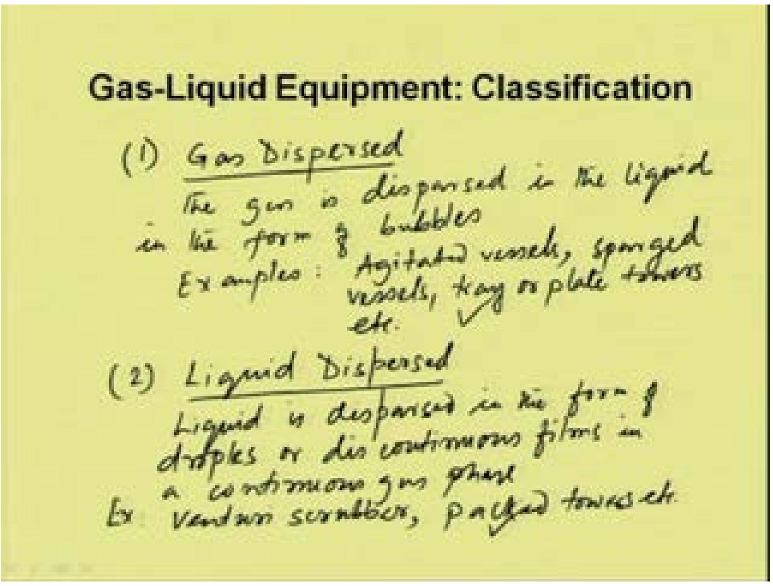

One is, gas dispersed. In the gas dispersed, the gas is dispersed in the liquid in the form of bubbles; for example, agitated vessels, sparged vessels, tray or plate towers, etcetera. And the second category is the liquid dispersed. In this case, the liquid is dispersed in the form of the droplets, or discontinuous films, films in a continuous gas phase; for example, Venturi scrubber, scrubber, packed towers, etcetera. This tray towers or plate columns and the packed columns are generally, most widely used equipments for gas liquid operations, particularly, for gas absorption, stripping, distillation operations.

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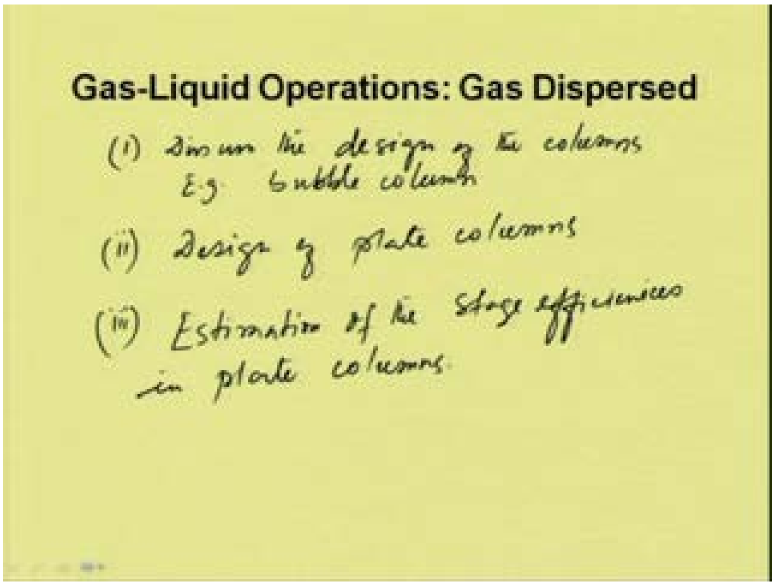

So, first, we will consider gas liquid equipments for gas dispersed. The main objective here is to discuss the design of the columns; particularly, for example, bubble column; and second, design of plate columns, which are widely used, and third is estimation of the stage efficiencies in plate columns.

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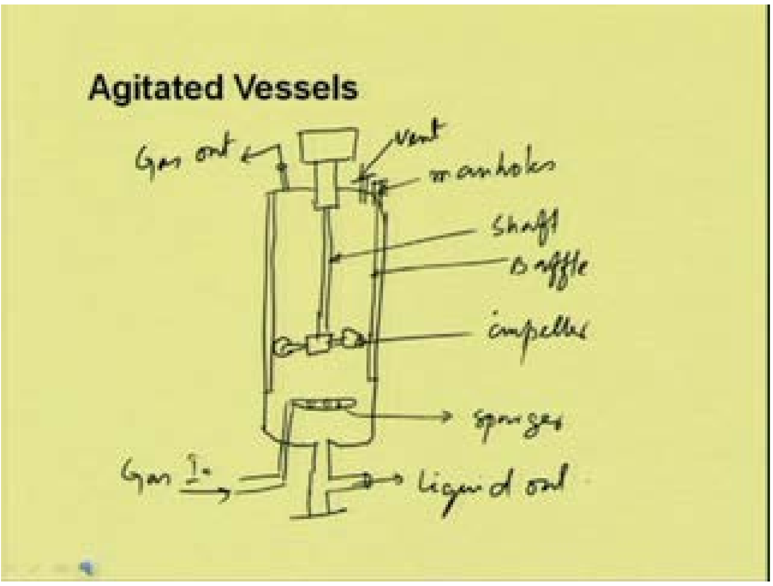

So, let us discuss, first, the simple equipment for gas dispersed, which is agitated vessels. The schematic of the agitated vessels, we can draw, sorry. So, this is a simple vessel, which is fitted with impellers. So, this is the stirrer shaft and this is vessel, installed with baffle; this is impeller and this is, the gas is dispersed, the gas in; this is sparger; liquid out and gas out; this is the vent and there are manholes for cleaning.

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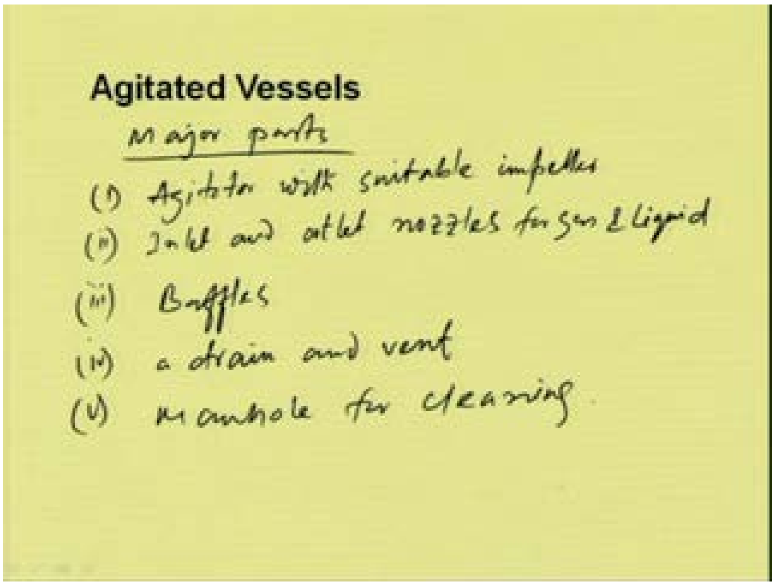

So, the major part for this agitated vessels are agitator with suitable impeller, inlet and outlet nozzles for gas and liquid, baffles, a drain and vent, manhole for cleaning. So, these are the major parts in mechanically agitated contactors. The impellers are available in different designs.

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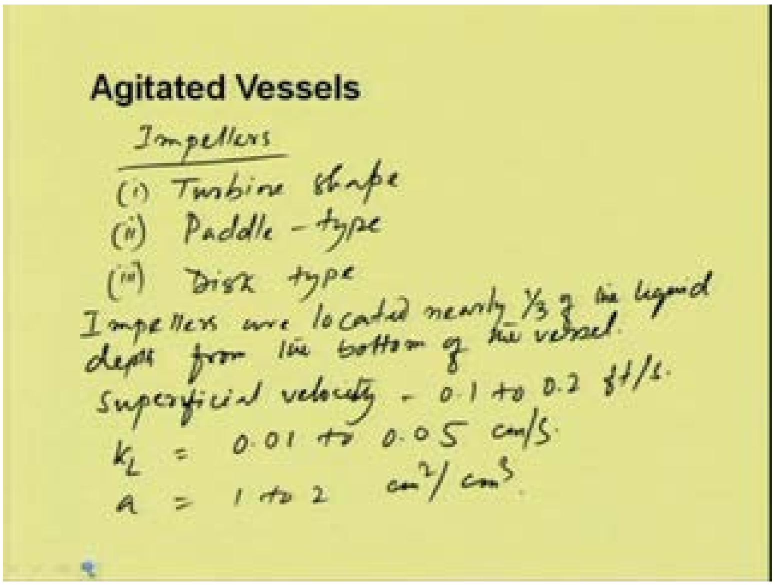

So, impeller, generally available in turbine shape, paddle shape, paddle type or disk type. So, these are the major applied impellers, and the impellers are located, nearly one third of the liquid depth from the bottom of the vessel. The superficial velocity is usually kept low; is in the range of 0.1 to 0.2 feet per second and the mass transfer coefficients generally lies between 0.01 to 0.05 centimeter per second and the interfacial area, in general, is around 1 to 2 centimeter square per centimeters cube. So, these are the specific parameters, which is usually maintained in the agitated vessels for gas liquid operations.

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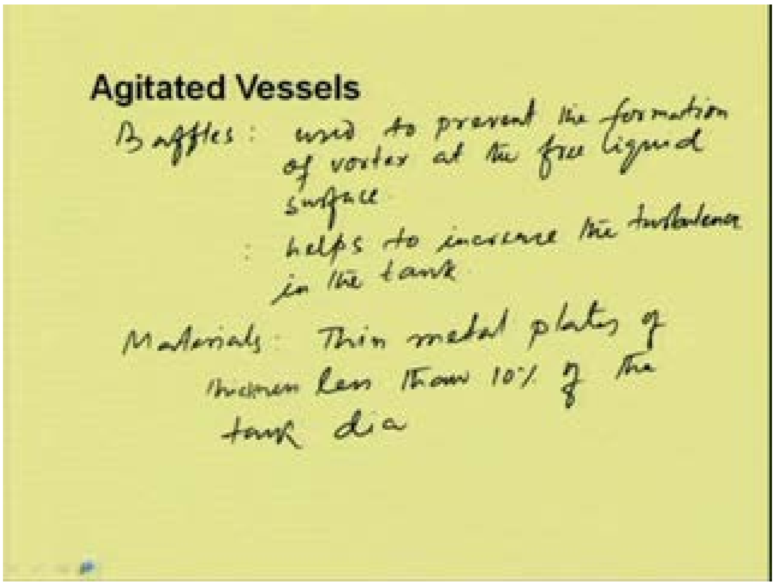

The baffles are generally used, baffles used to prevent the formation of vortex at the free liquid surface, and it also helps to increase the turbulence in the tank; and, the materials, generally, for the baffles, we can use thin metal plates of thickness less than 10 percent of the tank dia can be used as the baffles; generally 4 to 6 baffles are usually used for the agitated vessels.

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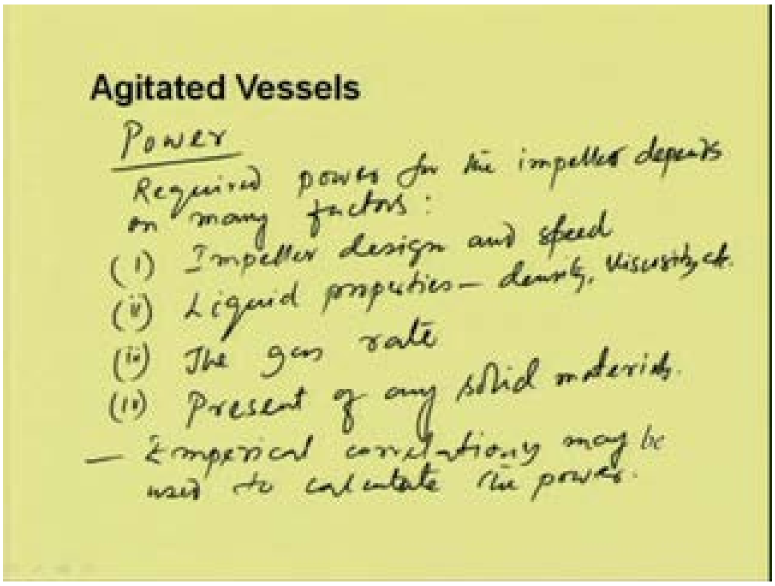

The power, the required power for the impeller depends on, on many factors. One of them is impeller design and speed, liquid properties such as density, viscosity, etcetera, the gas rate, or if any suspended solids are present, any solid materials. So, to calculate the power, there are several empirical correlations are available. Correlations may be used to calculate the power.

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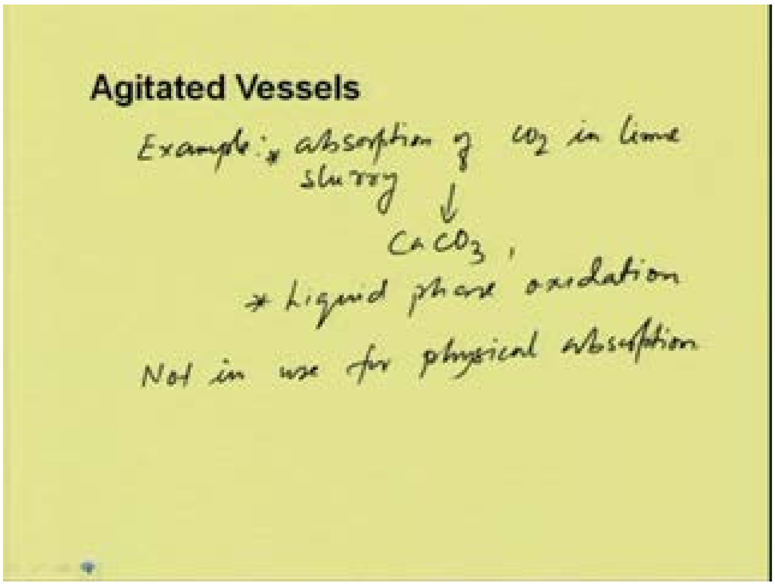

The agitated vessels are generally used for the gases which undergo chemical reactions with the liquid. And particularly for example for example, absorption of carbon dioxide in lime slurry which produces calcium carbonate; or, liquid phase oxidations. This is not generally used for the physical absorptions, for physi-sorptions, if there is back mixing or agitations in the systems, which will reduce the driving force for mass transfer. So, this is not generally used for physical absorption.

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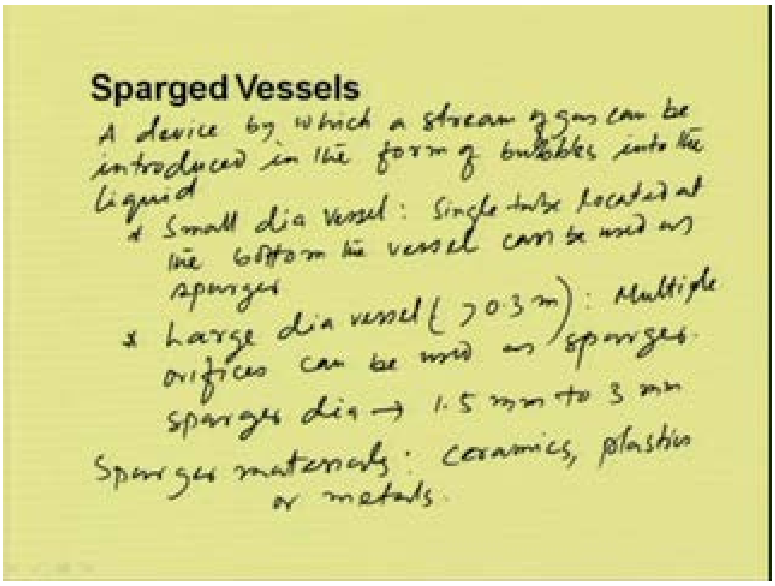

The next, we will discuss the sparged vessels. It is a device by which a stream of gas can be introduced in the form of bubble into the liquid. For small diameter vessels, a single tube located at the bottom of the vessel can be used as sparger. For large dia vessels, the sparger, say, large dia means, greater than 0.3 meter dia, multiple orifices can be used as sparger. In this case, for large diameter vessels, the sparger dia varies from 1.5 millimetre to 3 millimetre in size; and, the sparger materials generally used, we can use ceramics discs, plastics or metals. So, the purpose of the sparger is to intimate contact between the gas and liquid, or it may act simply as a agitation device.

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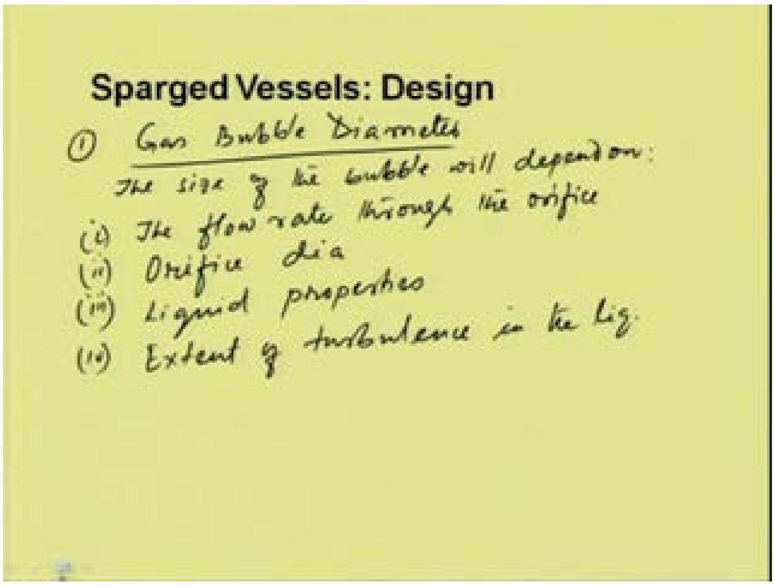

So, now, we will just see how to design the sparger. Through the sparger, the gas is generally bubbled. So, bubble size will change as it flows from bottom to top of the column. So, one is bubble diameter. The size of the bubble will depend on the flow rate through the orifice; second is the orifice dia, liquid properties and the extent of turbulence in the liquid. So, these are the major factors on which the size of the bubble will depend.

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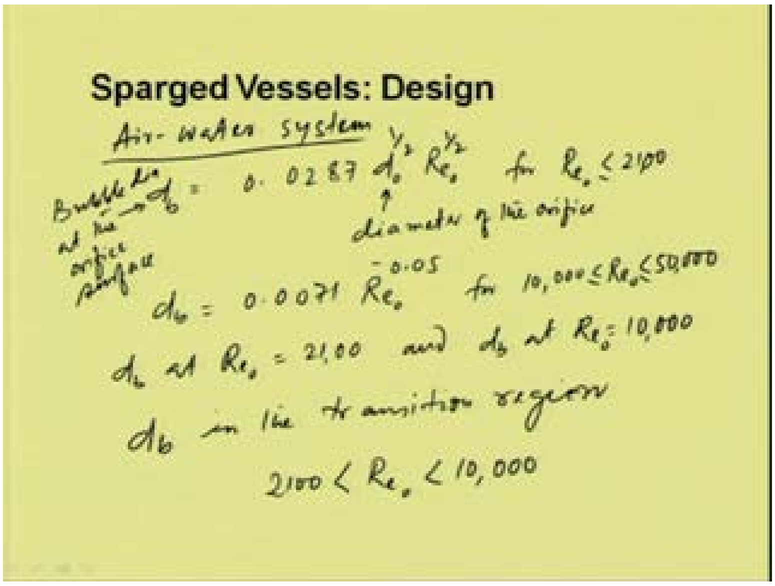

For air water system, we can use the size of the bubble which are leaving. Air water system, the correlations we can use, d b is equal to, d b is the bubble diameter at the orifice surface, which will be 0.0287 d 0 to the power half, Reynolds number 0 to the power half, for Re 0 less than or equal to 2100. So, this d 0 is basically the diameter of the orifice and d b will be equal to 0.0071 Reynolds number to the power point minus 0.05 for Reynolds number greater than 10000 and less than 50000, so d b in meter and d o also, the diameter of the orifice also, in meter.

So, for transition region, that is, the Reynolds number in between 2100 to 10000, we can use, particularly for air water system, we can use the interpolations between these two equations. So, between the points d b at Reynolds number is equal to 2100 and from this equations d b at Re 0, 10000. So, from these equations, we can get Re 0 at 2100 and Re 0 at 10000 and if we interpolate among these two points, we will get the bubble dia in the transition region, that is, Re 0 less than 10000 and greater than 2100.

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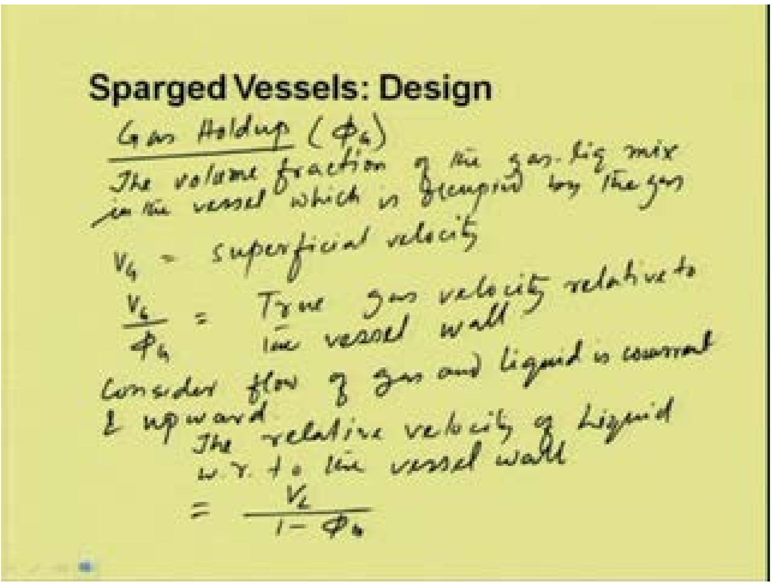

Now, the gas holdup we can calculate. The gas holdup is defined as the volume fraction, volume fraction of the gas liquid mixture in the vessel which is occupied by the gas. So, this is called as gas holdup and is defined as phi G and if we consider V G as the superficial velocity, then we can write, V G by phi G is the true gas velocity relative to the vessel wall. Now, if we consider flow of gas and liquid is cocurrent and upward, then the relative velocity of liquid, relative velocity of liquid can be calculated with respect to the vessel wall, can be calculated as V L divided by 1 minus phi G.

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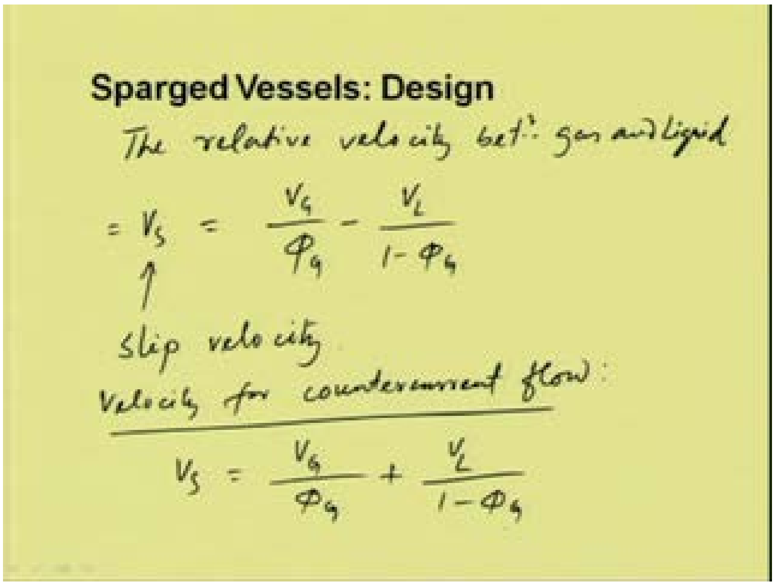

So, the relative velocity, velocity between gas and liquid is equal to V S, is equal to V G by phi G minus V L by 1 minus phi G. This is also known as the slip velocity, and from this equations also, we can calculate the velocity for counter current flow, flow where liquid is falling from the top and gas is flowing from the bottom. So, assigning the negative sign of V L, we can write for counter current flow, this relative velocity V S will be V G by phi G plus V L by 1 minus phi G.

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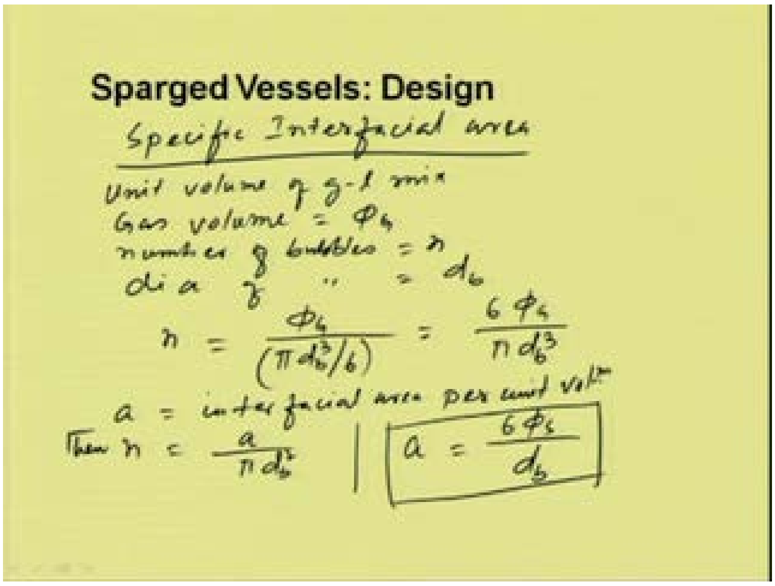

Now, we will calculate the specific interfacial area. Now, if we consider unit volume of gas liquid mixture, and contains gas volumes phi G and number of bubbles is n; diameter of the bubble is d b. And then we can write, n is equal to phi G divided by pi d b cube by 6, is equal to 6 phi G divided by pi d b cube. And if we consider a is the interfacial area per unit volume, volume, then n is equal to, we can write, a by pi d b square. So, from these two equations, if we equate, we can obtain a is equal to 6 phi S by d b. So, this is the equation to calculate the specific interfacial area, that is, interfacial area per unit volume.

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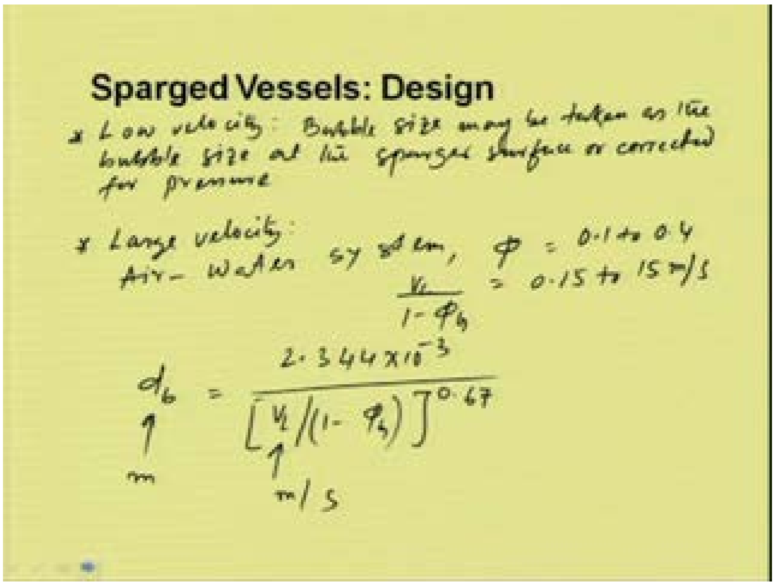

If the velocity is very low, the bubble size may be taken as that produced at the sparger surface; low velocity bubble size may be taken as, as the bubble size at the sparger surface or corrected for pressure if required. So, if the velocity is high, or large velocity, then the bubble size will change and vary as the turbulent conditions changes the bubble break up and coalescence of the bubbles occur. So, in case of air water system, and phi is in the range of 0.1 to 0.4; V L by 1 minus phi G is generally in the range of 0.15 to 15 meter per second. In this case, the bubble size may be approximated and d b can be calculated as 2.344 into 10 to the power of minus 3 divided by V L by 1 minus phi G to the power 0.67. And V L is in meter per second and d b is in meter. So, this way, we can calculate the size of the bubbles and then interfacial area.

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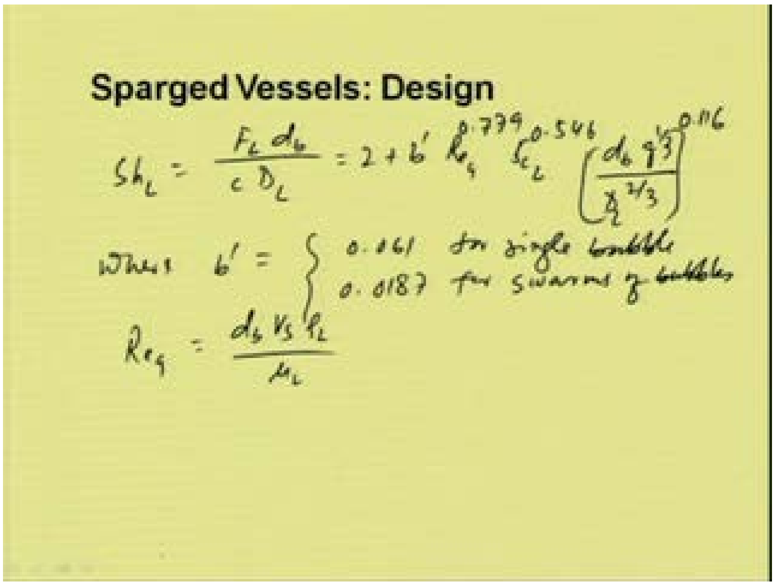

Now, how we can calculate the mass transfer coefficient? Particularly, gas bubble liquid system, the resistance are mainly in the liquid phase and the gas phase resistance are negligible. In that case, the Sherwood number may be correlated as Sh L equals to F L d b by c D L, which is equal to 2 plus b dash Re G to the power 0.779 Schmidt number to the power 0.546 into d b g to the power half, one-third, divided by D L to the power two third whole to the power 0.116, where b dash is equal to 0.061 for single bubble and 0.0187 for swarms of bubbles; and, Re G is equal to d b V S rho L by mu L.

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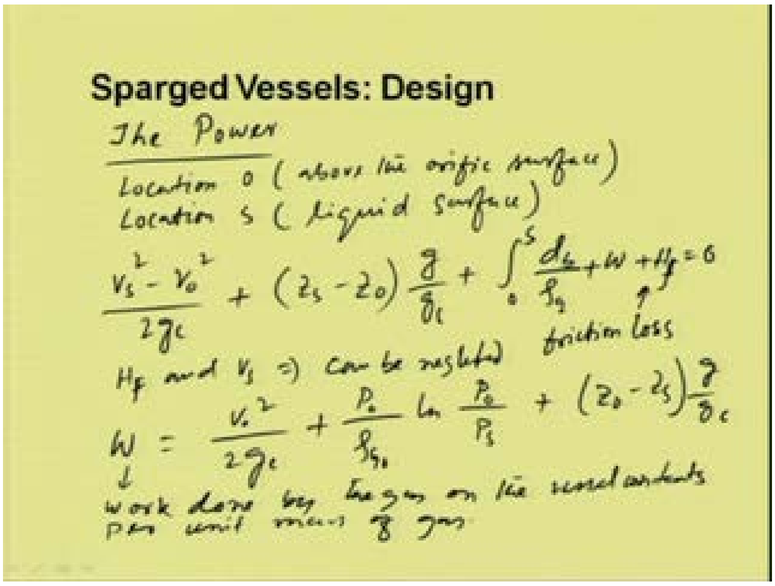

Now, we can calculate the power. We can apply the Bernoulli's equation between the two locations and we can calculate the power required, which is a mechanical energy balance equation. So, we can write the locations between location o, that is, above the orifice surface, and location s, that is, at the liquid surface. So, you can use the Bernoulli's equation. So, we can write V s square minus V o square by twice g c plus Z s minus Z o g by g c, plus integral 0 to s, d b by rho g plus W plus H f is equal to 0. H f is the friction loss. So, H f and V s can be neglected and the density of the gas can be calculated using ideal gas law. In that case, W will be V 0 square by twice g c plus P 0 rho g 0, l n P 0 by P s, plus Z 0 minus Z s g by g c and W is the work done by the gas on the vessel contents, per unit mass of gas.

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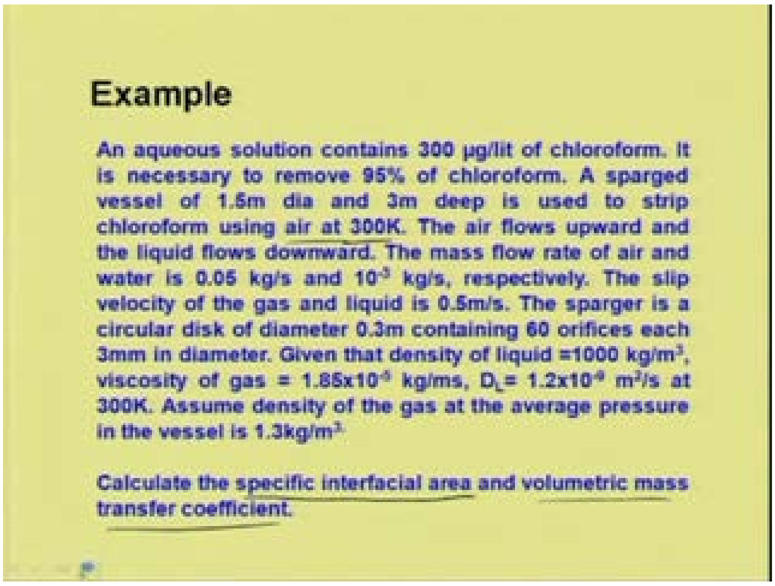

Now, let us consider a simple example. An aqueous solution contains 300 micro gram per litre of chloroform, and it is necessary to remove 95 percent of chloroform. A sparged vessel of 1.5 meter dia and 3 meter deep is used to strip chloroform using air at 300 Kelvin. The air flows upward and liquid flows downward. The mass flow rate of air and water is 0.05 kg per second and 10 to the power of minus 3 kg per second respectively. The slip velocity of the gas and liquid is 0.5 meter per second. The sparger is a circular disk of diameter 0.3 meter containing 60 orifices, each are 3 millimeter in diameter. Given that, density of liquid is 1000 kg per meter cube, viscosity of the gas is 1.85 into 10 to the power of minus 5 kg per meter second, diffusivity of the liquid is 1.2 into 10 to the power of minus 9 meter square per second at 300K. Assume, density of the gas at the average pressure in the vessel is 1.3 kg per meter cube. Calculate the specific interfacial area and volumetric mass transfer coefficient.

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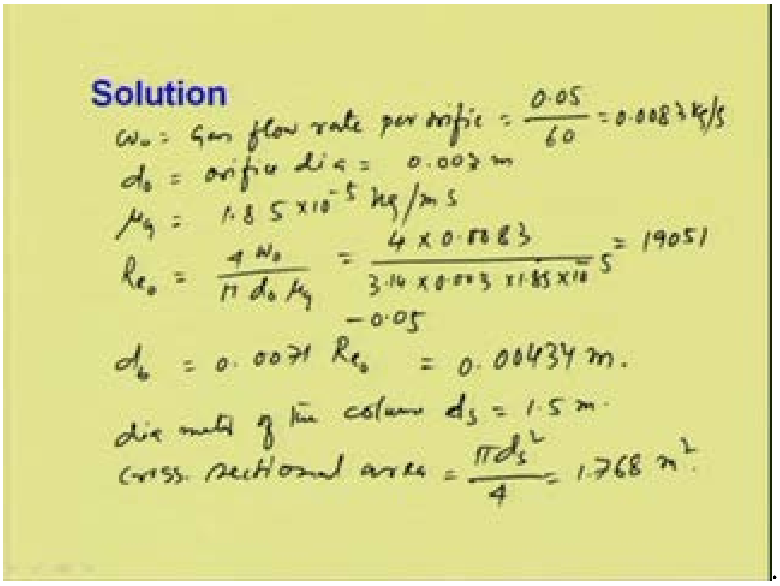

Now, it is given that, W 0 is the gas flow rate per orifice, is equal to 0.05 kg per second divided by 60 orifices, is equal to 0.0083 kg per second. And d 0 is given, which is orifice dia, which is 0.003 meter. Viscosity of the gas is given, 1.85 into 10 to the power minus 5 kg per meter second. So, we can calculate Re 0, Reynolds number, which is 4 W 0 by pi d 0 mu g, which is equal to 4 into 0.0083 divided by 3.14 into 0.003 into 1.85 into 10 to the power minus 5. So, this will give you 19051. So, this is the Reynolds number. So, we can calculate, d b is equal to 0.0071 Re 0 to the power minus 0.05. So, putting this Reynolds number, this will be 0.00434 meter. So, the bubble diameter is calculated and the diameter of the column which is given is, d s is equal to 1.5 meter, so vessel cross sectional area, pi d s square by 4, which is 1.768 meter square.

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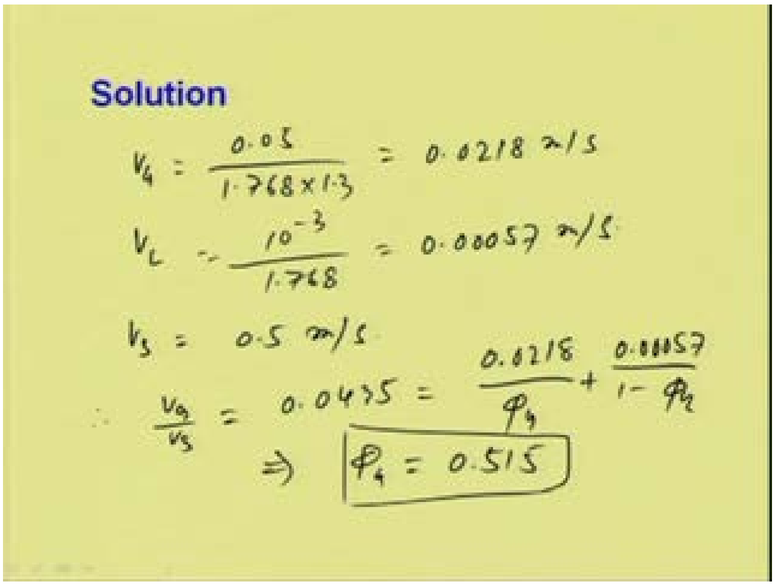

Now, if we calculate, V G will be 0.05 by 1.768 into the density, 1.3, which is equal to 0.0218 meter per second. And V L will be 10 to the power minus 3 by 1.768, which is equal to 0.00057 meter per second. V S is given, which is 0.5 meter per second. So, V G by V S is equal to 0.0435. So, this is equal to we can write, 0.0218 by phi G plus 0.00057 divided by 1 minus phi G. From this, we can calculate phi G is equal to 0.515.

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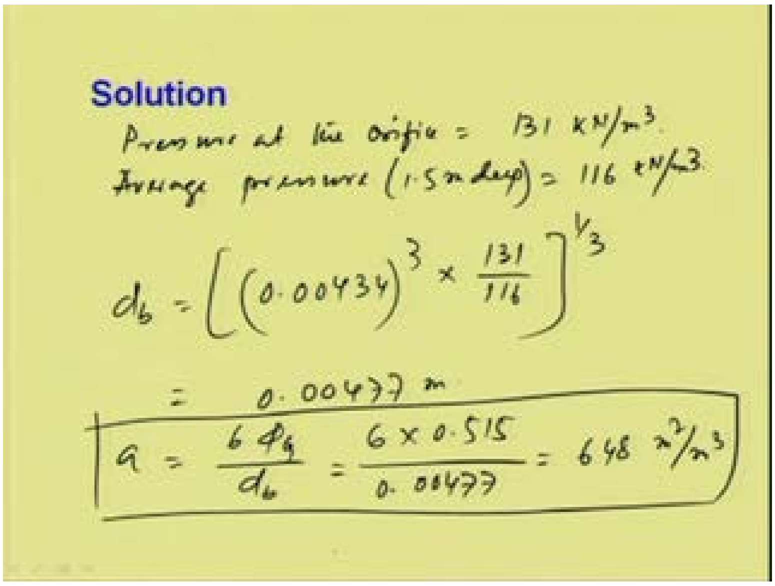

Now, pressure at the orifice will be around 131 kilo Newton per meter cube. So, average pressure, 1.5 meter deep, will be 116 kilo Newton per meter cube. So, we can calculate the bubble dia using the pressure corrections as 0.00434 cube into 131 by 116 to the power one-third. So, this will be around 0.00477 meter. So, a will be, the specific interfacial area will be 6 phi G divided by d b, which is equal to 6 into 0.515 divided by 0.00477, which is 648 meter square by meter cube. So, this is the specific interfacial area.

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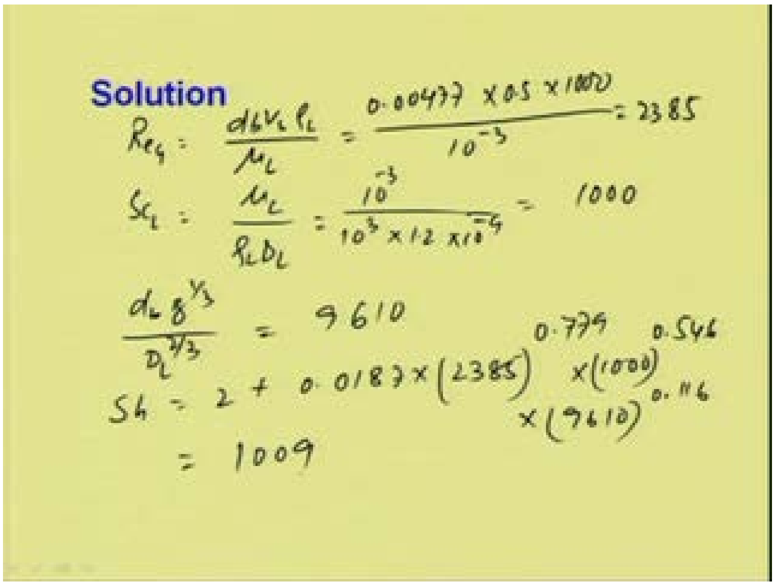

Now, we can calculate Re G, which is d b V S rho L by mu L, so using the data, 0.00477 into 0.5 into 1000 divided by 10 to the power minus 3, which will give you 2385. Similarly, we can calculate Schmidt number; mu L by rho L D L, which is 10 to the power minus 3 divided by 10 cube, 1.2 into 10 to the power minus 9 and this will give you 1000. We can calculate d b g to the power one-third by D L to the power two-third; so this will be around 9610. Now, if you substitute this data, Sherwood number will be 2 plus 0.0187 into 2385 to the power of 0.779 into 1000 to the power 0.546 into 9610 to the power of 0.116. So, this will be around 1009.

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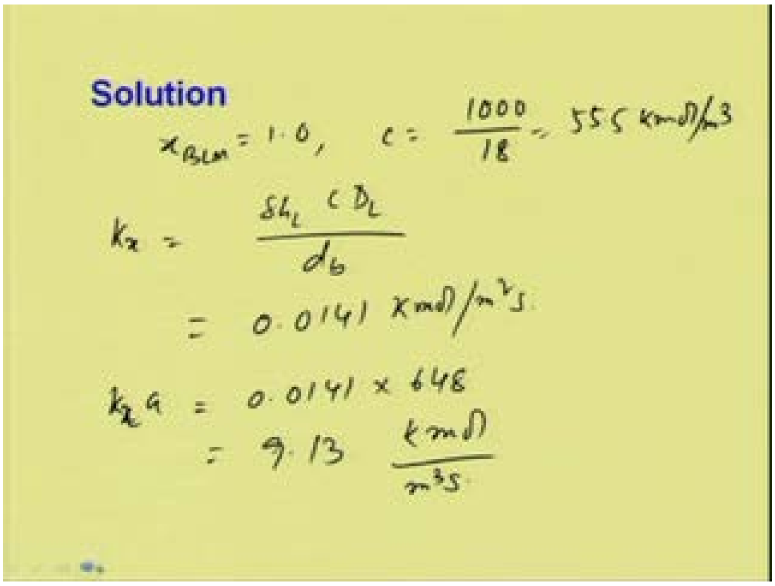

Now, for dilute solution x B L M will be 1.0 and c will be 1000 by 18, which is 55.5 k mole per meter cube. Now, K x we can calculate, Sherwood number c D L by d b. So, substituting the values, it will be 0.0141 k mol per meter square second. So, K x a will be, volumetric mass transfer coefficient will be 0.0141 into 648, which is equal to 9.13 k mol per meter cube second. So, in the next class, we will consider gas liquid equipments, that is particularly treat our design. And next few lectures, we will consider the mass transfer equipment in the liquid dispersed as well.

Thank you.