Mass Transfer Operations-I
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Lecture - 17
Introduction, classification, Sparged and agitated vessels design

Welcome to the 1st lecture of module 3 on Mass Transfer Operation, in this module we will discuss equipment for gas liquid operations. So, before going to the first lecture let us have small recap on our previous modules what we have discussed.

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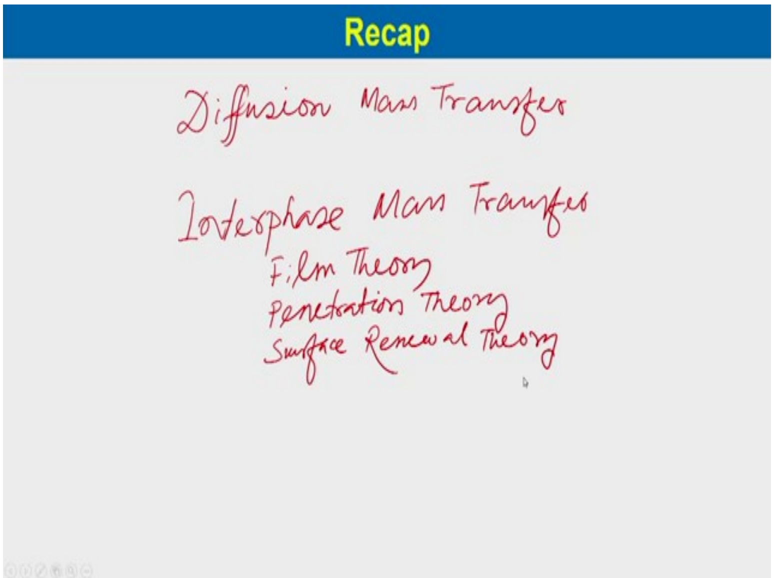

In the first module we have discussed mainly on diffusion mass transfer under which mainly we have learn the molecular diffusion and the convective diffusion and also the diffusion theories and then the measurements of the diffusion coefficient for the gas diffusion and then the liquid diffusion and then diffusion in solids.

So, we have learn them and then we have move to the 2nd module where we have discussed interface mass transfer. So, in interface mass transfer as we have discussed that know the in most of the cases the mass transfer happens from one phase to the other phase, either from the gas to liquid or liquid to gas or gas solid or solid liquid systems. And in this case we have considered different mass transfer theories one of them is film theory and then second one we have considered penetration theory and the third one we have considered surface renewal theory.

We have also considered different cases how to determine the mass transfer coefficients and what are the relations among them. So, in this module we will mostly concentrate on the mass transfer equipments which are used for the separation or mass transfer operations.

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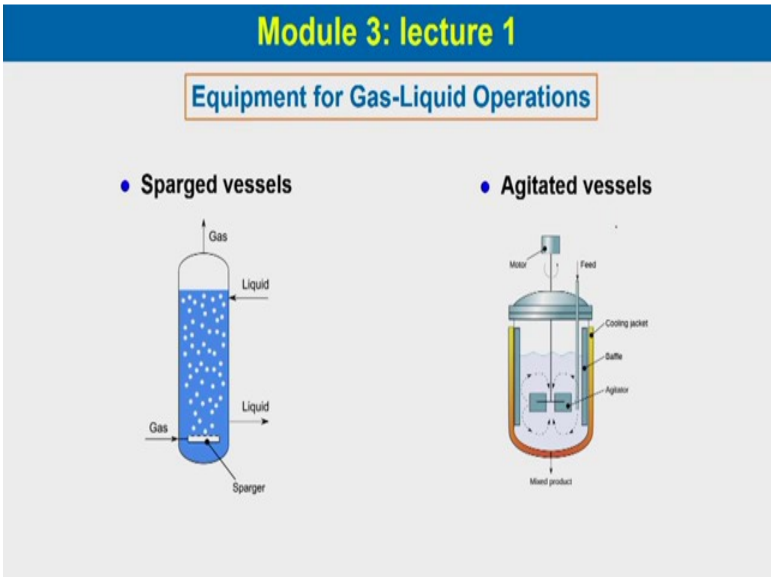

In lecture 1, we will show you different batch and the continuous mode of contact equipments which are used for this gas liquid systems, one of them is sparged vessels. So, you can see in this case the gas enters at the bottom and liquid enter at the top and there is an intimate contact enter inside the column so that the mass transfer happens from either from the gas phase to the liquid phase or from the liquid to the gas phase.

The next equipment which is mostly operated in terms of the batch process is agitated vessel, you can see there is a container or the vessel which is designed with baffle, agitator, cooling jacket and feed inlet then you have a motor to run the impeller and the mix the product and then you can get the product out after a certain period of time. So, this is no agitated vessel and then the past vessel.

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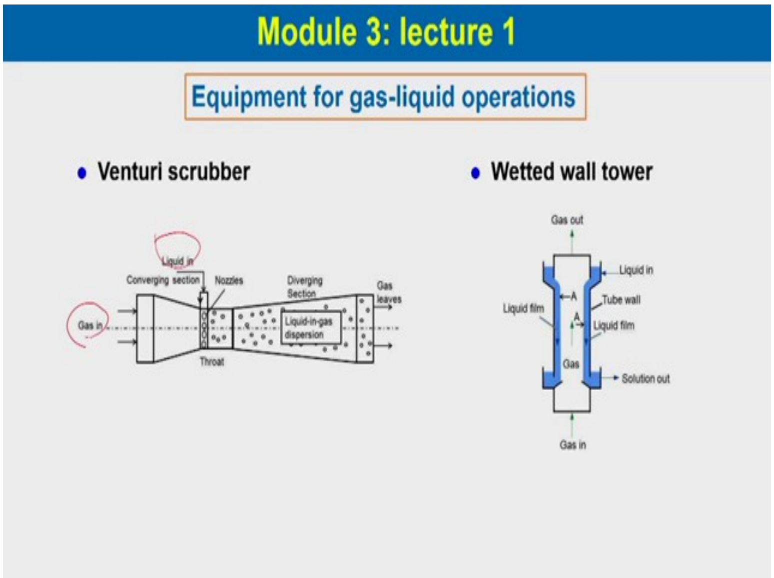

The other equipment is the venturi scrubber, you can see that the gas there is a gas inlet and there is a converging section and then the diverging section and the liquid entered at the converging section which is called as throat and then it no gas liquid intimate contacts happens in this after the nozzle in this diverging section and then there is a separation after that. So, venturi scrubber one of them, another is the wetted wall tower you can see there is a gas inlet at the bottom and there is a gas out and the liquid in at the top and liquid falls as a film inside the column hollow column. So, it falls as a film and then gas goes through the you know in middle as a centre core.

So, there is a transfer of mass either from the liquid to the gas or from the gas to the liquid phase. So, we can maintain over here no different flow rate of the gas and liquid and we can change the conditions from laminar to the turbulent.

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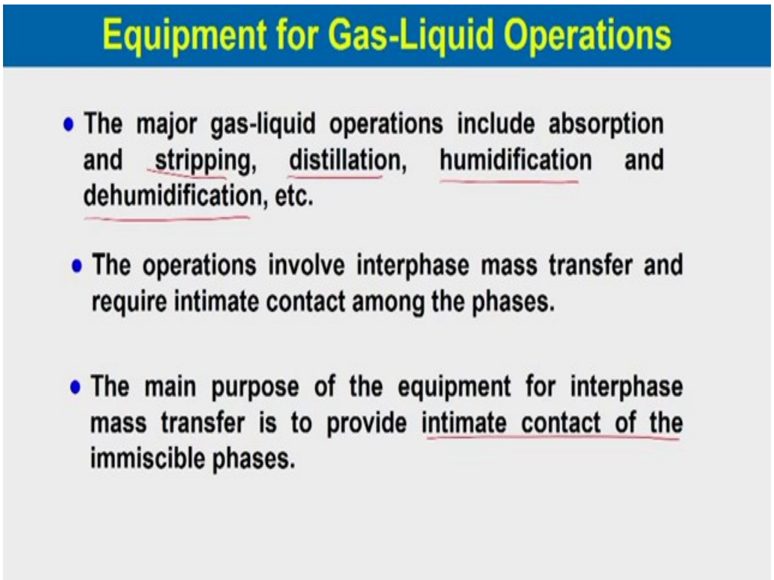

The major gas liquid operations include absorption, stripping and then distillation humidification and dehumidification.

So, we will discuss know absorption and stripping as well as distillation in this know mass transfer operation course in detail. So, in absorption or stripping we have already at the beginning we have discussed how the absorption occurs and how the stripping occurs and the distillation, the fundamentals of distillation how the separation happens based on what conditions we have discussed.

But the equipments which are used for absorption stripping and distillation humidification and dehumidification will almost similar in nature. And for industrial scale either we use tray column or the packed column; the operation which involve interphase mass transfer and require intimate contact of gas and liquid.

The main purpose of the equipment for interphase mass transfer is to provide intimate contact of the immiscible phases, because when we take gas and liquid they are heterogeneous phases and certain components preferentially transfer from one phase to the other. So, the mass transfer equipment has to provide the interfacial no area so, that the transfer can happen among the phases, among the immiscible phases.

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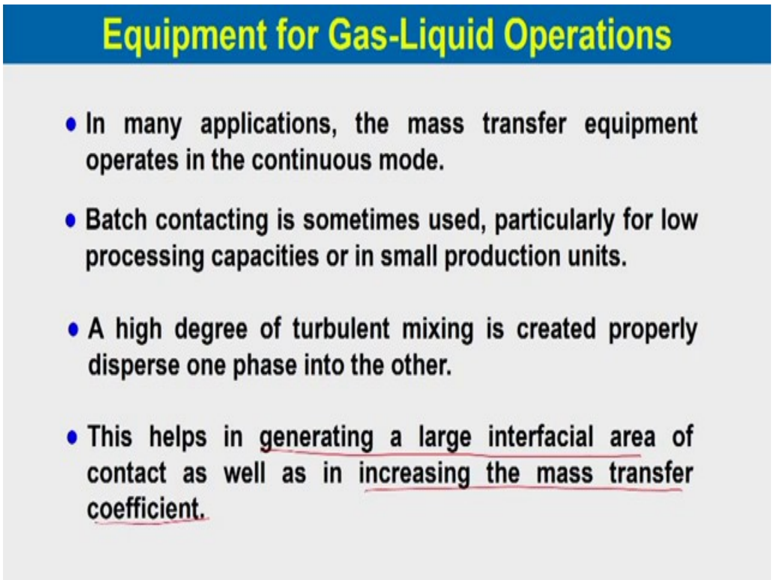

In many applications the mass transfer equipment operates in the continuous mode. Batch contacting is sometimes used particularly for low processing capacities or in small production unit, like we have shown you the agitated vessel those are used as a batch process it can be used as a laboratory use also can be used in the commercial scale. A high degree of turbulent mixing is created properly disperse one phase into the other.

So, in the batch process or in the continuous process we have to provide a sufficient mixing among the phases among the immiscible phases. So, that there is intimate contact between the phases for the mass transfer to happen and with the less penalty towards the energy consumption of this equipments, this helps in generating a large interfacial area of contact as well as increasing the mass transfer coefficient.

So, if we can create the turbulence inside the know inside the column and among the phases, it helps generating large interfacial area of the contact as well as increase the mass transfer coefficient which will improve the efficiency of the separation process.

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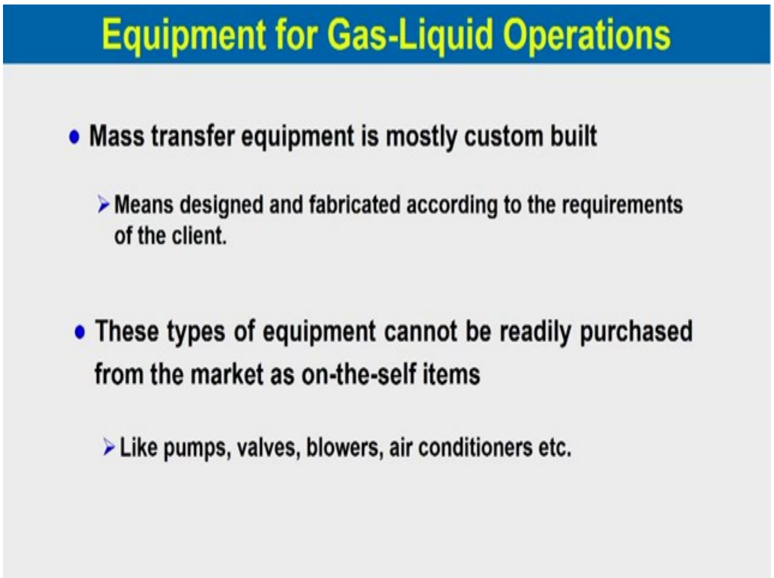

Mass transfer equipment is mostly custom built means it is designed and fabricated according to the requirement of the client. So, depending on our applications or depending on the no industrial requirement for a particular process, they will provide the product purity required for the separations and based on that it has to be designed and then has to be custom built for that requirement.

So, most of the mass transfer equipment is mostly custom built this type of equipment cannot be readily purchased from the market as on self items, like we purchase pumps, valves, blowers, air conditioners etcetera it has a specification feature well defined and already available on the self in the market. So, these are readily available, it is not in case of the gas liquid contact equipment they are not available on the self. So, they are mostly custom build.

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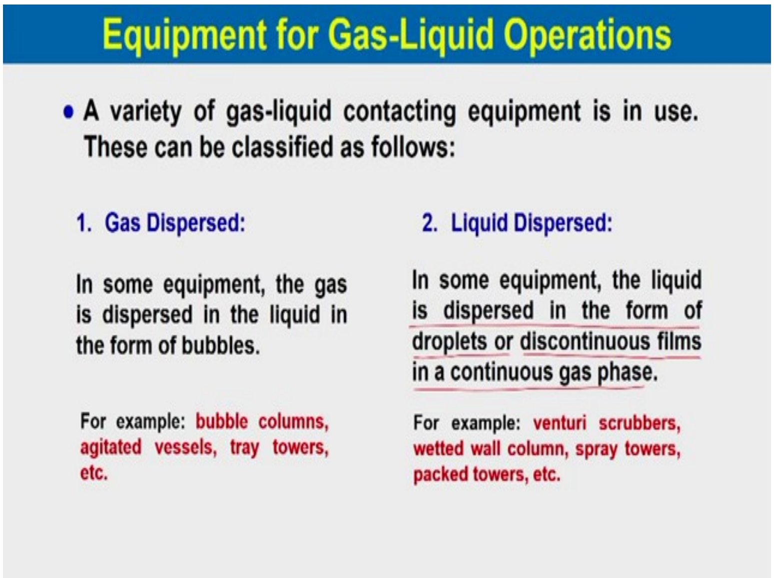

A variety of gas liquid contacting equipment is in use, this can be classified as follows. One is gas dispersed: in some equipment the gas is dispersed in the liquid in the form of bubbles like, bubble columns, agitated vessels, tray towers in this case liquid flows through the column, but gas is bubbled through the liquid. So, it is called the gas dispersed.

And another thing is that the liquid dispersed: in some equipment the liquid is dispersed in the form of droplets or in discontinuous film in a continuous gas phase. So, in one case your liquid phase is continuous gas is dispersed another is gas is continuous and liquid is dispersed, like venturi scrubber, wetted wall column, spray towers, packed towers in this cases the liquid is in the form of discontinuous films and then and the gas is in continuous films.

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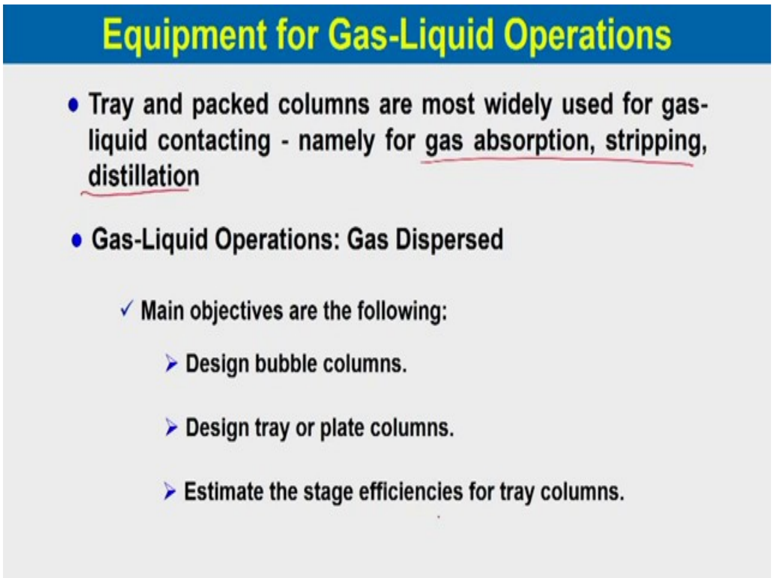

Tray and packed columns are most widely used for gas liquid contacting namely for gas absorption, stripping and distillation. So, for this three applications tray or plate columns and packed columns are widely used. Gas liquid operation: so, gas dispersed the main objective are the following: here the design of bubble column design of tray or plate columns and estimate the stage efficiency for tray columns.

So, if we take a bubble column or the tray column, main objective has to be designed the column how it will operate, what are the different specification and then we have to calculate the efficiency of each tray.

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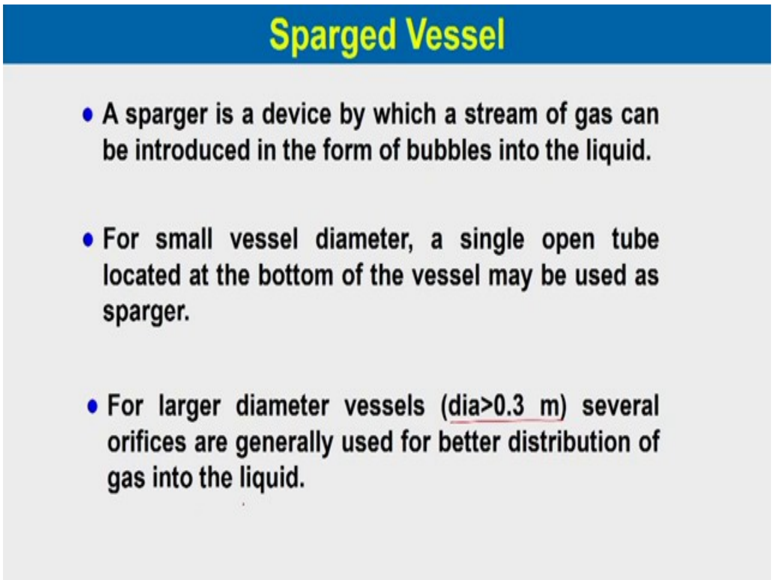

Now, will discuss on sparged vessel. A sparger is a device by which a stream of gas can be introduced in the form of bubble into the liquid. So, for small vessel diameter a single open tube located at the bottom of the vessel may be used as sparger. So, if the vessel diameter much bigger in that case we have to use multiple tubes, for larger diameter vessels say diameter greater than 0.3 meter, several orifice are generally used for better distribution of the gas into the liquid.

So, in most of the equipment you will see in refineries or about the distillation or an observer they are designer the diameter of the column are usually greater than 0.3 meter and there are several orifices are used for the better distribution of gas into the liquid.

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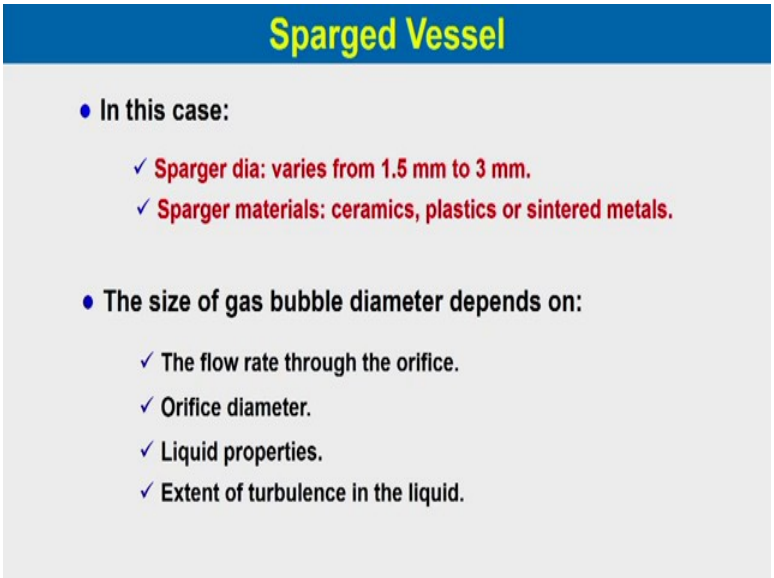

So, in this case sparger diameter which varies from 1.5 millimeter to 3 millimeter, sparger material generally we use ceramic, plastic or sintered metals and the size of the bubble diameter depends on the following factors. The flow rate through the orifice, depending on the flow rate the size of the bubble diameter will depend and then orifice dia, liquid properties whether it is no highly viscous or less viscous depending on this liquid properties and then extent of turbulence in the liquid what is the flow rate we are maintaining of the gas and liquid. So, extent of turbulence inside the liquid is also important for the size of the bubble.

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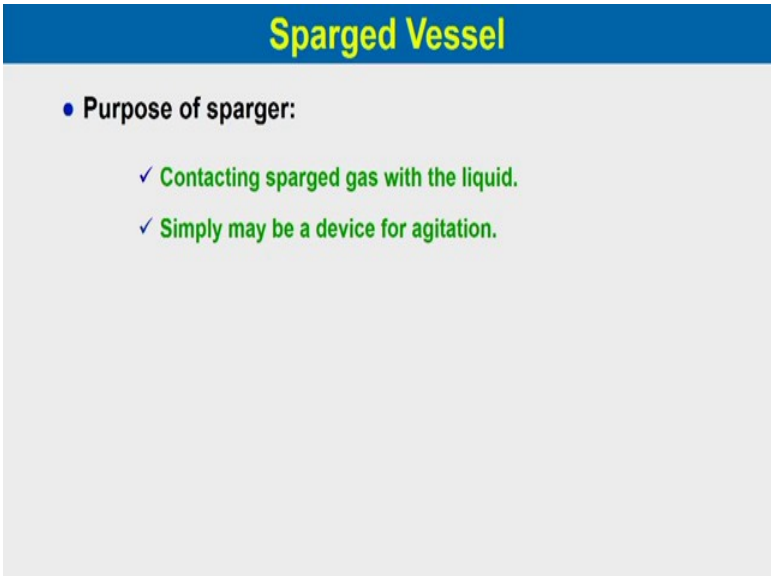

Purpose of the sparger it is no well known fact that we need to have a good contact between the gas and liquid phase. So, contacting sparged gas with the liquid that is the purpose of the sparger sparger and simply it may be used a device for agitation. So, agitations simply help or not only to increase the no surface area, but also improve the mass transfer rate and also the heat transfer rate. So, to do that these are the no major purpose for the use of sparger.

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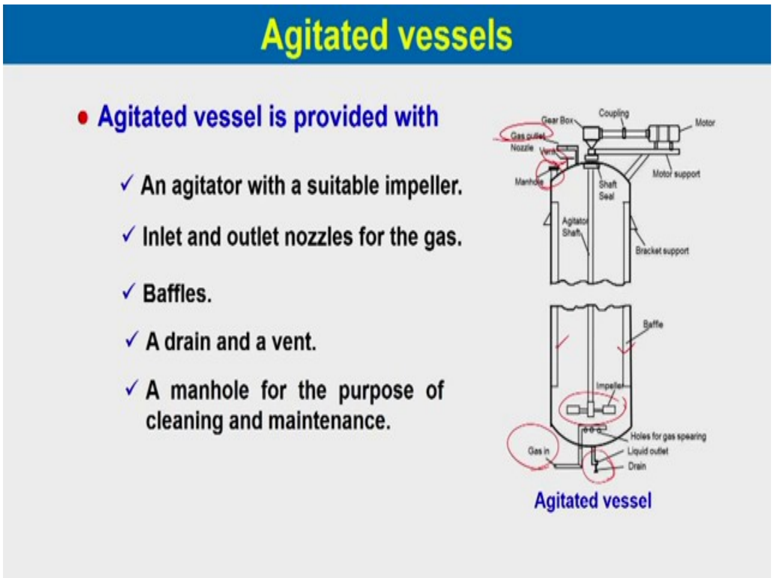

Now, we will discuss about the agitated vessels, agitated vessel is provided with no this configurations you can see it has an with a suitable impeller you can see over here the impeller is given. So, which will no give the rotational you know moment or mixing of the liquid phase and then inlet and outlet nozzles for the gas, you can see there is a no gas inlet over here and also there will be gas outlet which is given over here, gas outlet and then we have baffles. So, both sides you can see there is baffles and we will see later when we discuss the baffle and then impeller arrangement how the baffles help in the mixing process for the gas and liquid.

So, this baffles help us improve mixing between the gas and liquid. So, there are baffles, a drain and a vent. So, the liquid which will be outlet through the drain and then you have a vent over here for the purpose of safety. A manhole for the purpose of cleaning and maintenance you can see over here the manhole is provided for the no cleaning or maintenance of this equipments. So, generally this runs as no batch process once the run is over it has to be clean properly for the next batch to run.

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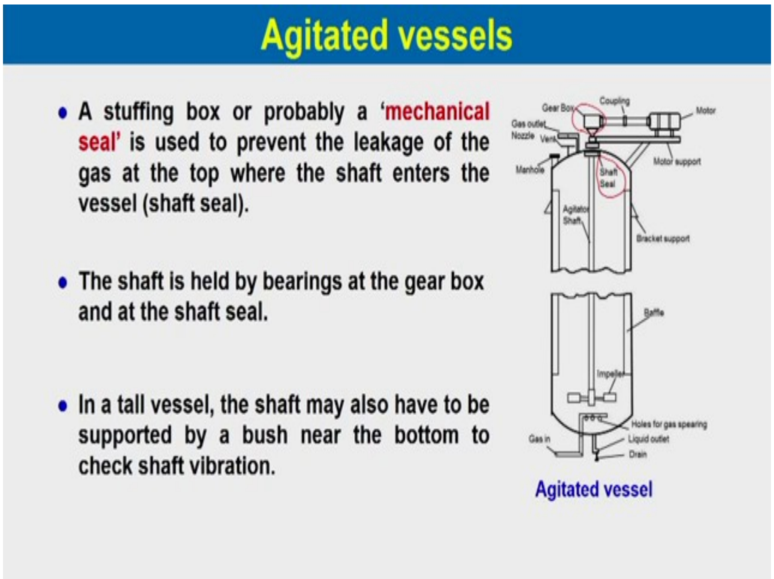

A stuffing box or probably a mechanical seal is used to prevent the leakage of the gas at the top where the shaft enters the vessel. So, you can see shaft seal is provided over here that is required in the stuffing box over here, the shaft is held by bearings at the gearbox and at the shaft seal. So, you can see the gearbox over here with a shaft seal. So, this is no required for the arrangement of the impeller. In a tall vessel the shaft may also have to be supported by a bush near the bottom of the check shaft vibration which is required.

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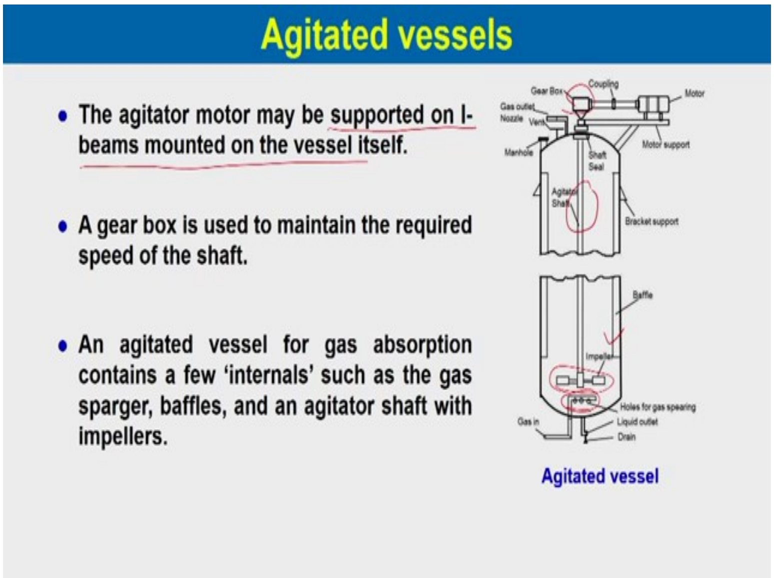

The agitator motor may be supported on ibeams mounted on the vessel itself. So, you can see it has to be no mounted somewhere or supported with ibeams mounted on the vessel itself. And then a gearbox is used to maintain the required space of the shaft over here which is already discussed, then an agitated vessel for gas absorption contains a few internals such as the gas sparger baffles and an agitator shaft with impeller.

So, this are internals called which is already discussed and you have a gas sparger over here and you have a agitator shaft; shaft, impeller and as well as baffles. So, these are no vessel internals.

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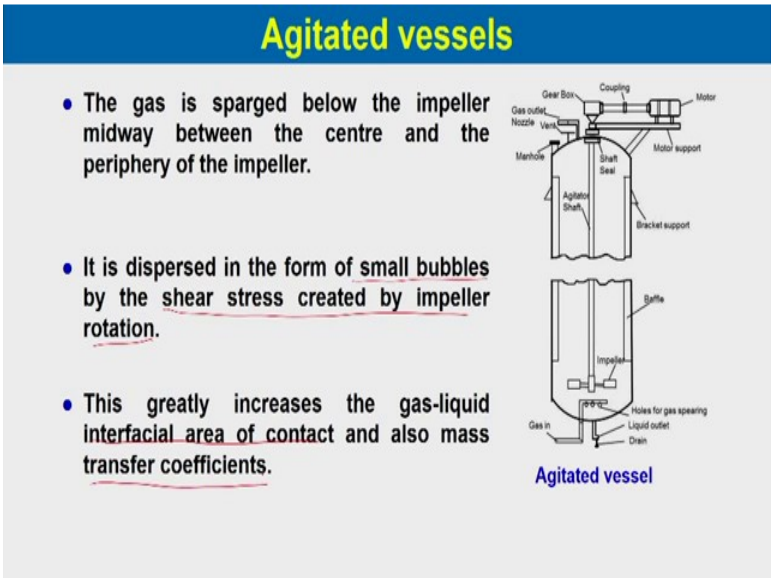

The gas is sparged below the impeller midway between the centre and the periphery of the impeller. So, the liquid which is coming over here which is kept inside the container and then gas is passed through it.

So, once gas is passed and impeller will take this gas and liquid and will mix both gas purging as well as the impeller will help in intimate contact between the gas and liquid. It is dispersed in the small form of small bubbles by the shear stress created by the impeller rotation. So, this greatly increases the gas liquid interfacial area of contact and also the mass transfer coefficient.

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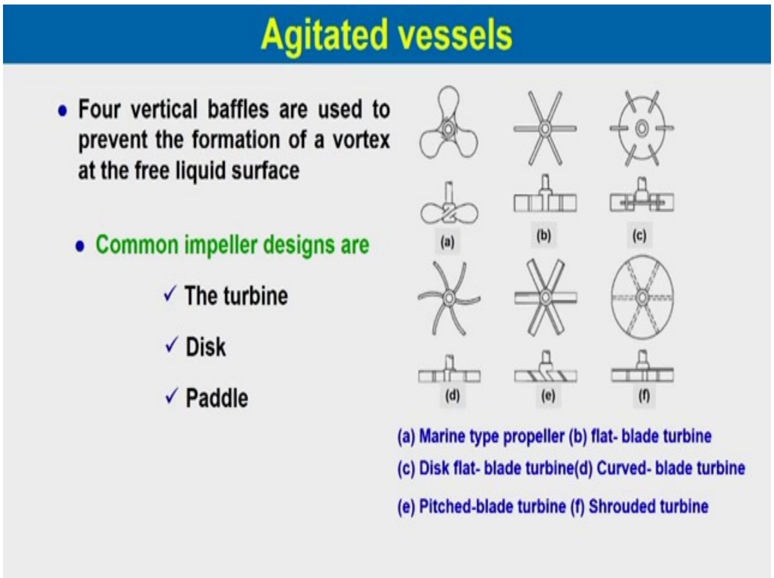

Now, in this case as we have said there are different types of impeller design, you can see four vertical baffles are used to prevent the formation of the vortex at the free liquid surface, you have seen the no baffles which are used now the you can see over here the common impeller design which are given over here. So, one is marine type propeller a, then flat blade turbine, disk flat blade turbine, curved blade turbine, pitched blade turbine and shrouded turbine.

So, different types of impeller design are there to improve the no agitation in the liquid phase and the where the gas is dispersed; turbine, the disk, paddle. So, these are the main thing in this case of no impeller design.

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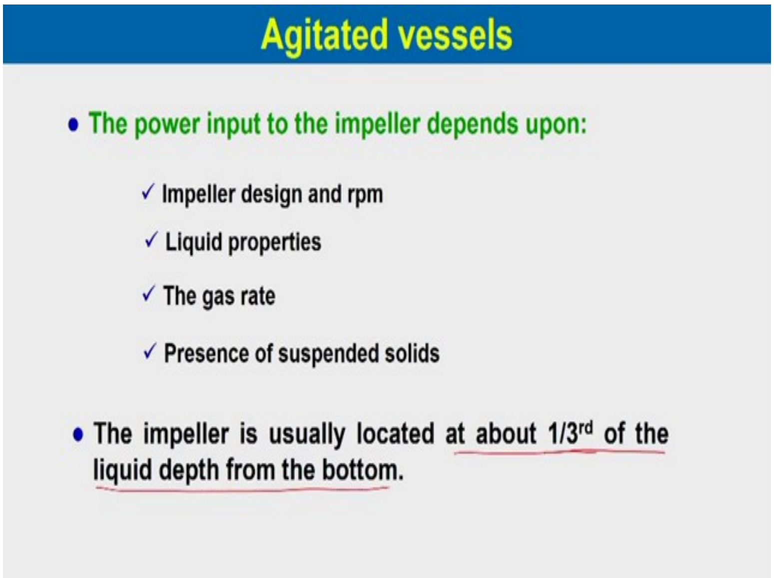

The power input to the impeller depends upon the following factors, one is impeller design and rpm; then liquid properties liquid mainly viscosity density of the liquids will depend on the no the power required for the impeller. Then the gas rate, presence of suspended solids the impeller is usually located at about one third of the liquid depth from the bottom. So, this is a typical design a one-third of the liquid depth from the bottom of the agitator.

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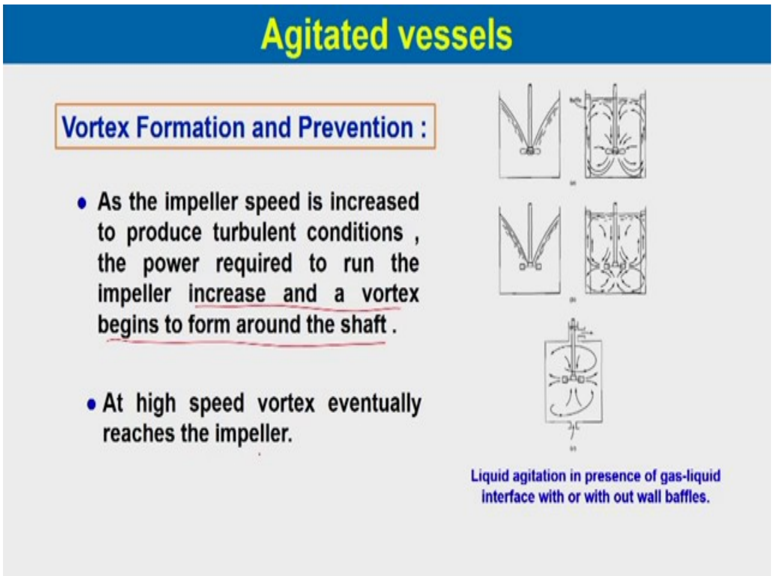

Vortex formation and prevention? So, you can see if you have only impeller there will be vortex formation and there will not be very good no agitation inside the liquid. So, as the impeller speed is increased to produce turbulence turbulent conditions the power required to run the impeller increase and a vortex begins to form around shaft, at high speed vortex eventually reaches the impeller.

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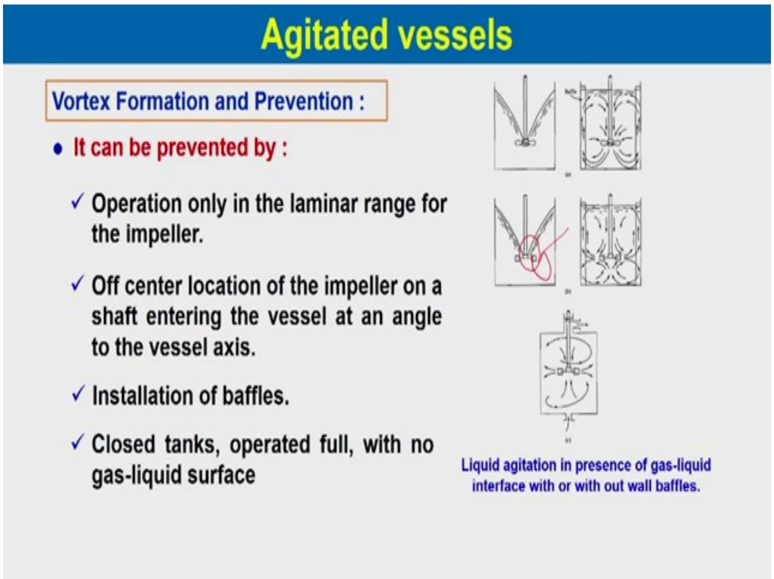

It can be prevented by different ways, one of them operation only in a laminar range for the impeller, but if you run the impeller in the laminar range then although it will not create the vortex, but the intimate no mixing between the gas and liquid will not enhance much. Off center location of the impeller on a shaft entering the vessel at an angle to the vessel axis.

So, if we can put some angle like this in a put impeller like this there made may be more no agitation compared to if we put it centrally and then the third option is you can use the baffles. So, and which is most commonly practiced using the baffles which helps breaking the vortex formation and give good mixing in the phases, closed tanks operated full with no gas liquid surface.

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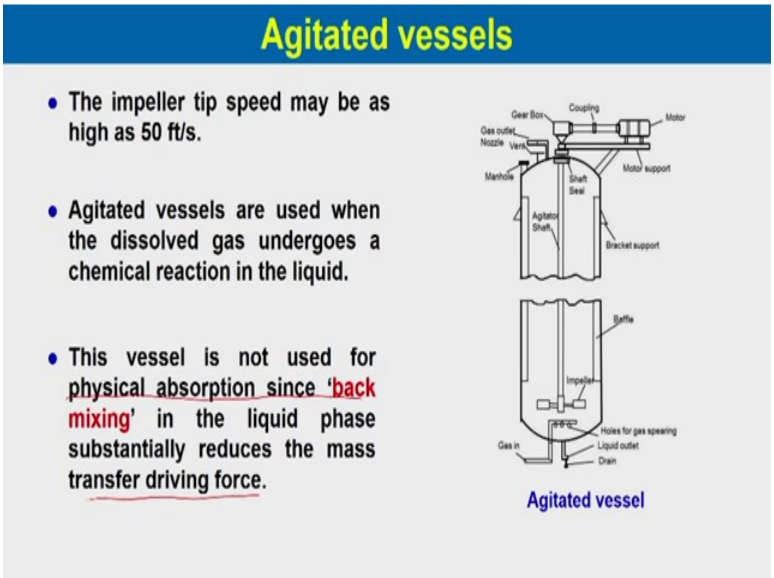

So, that also can be done; the impeller tip speed may be as high as 50 feet per second. So, impeller speed can be as high as 50 feet per second depending on your column internal design agitated vessels are used when the dissolved gas undergoes a chemical reactions in the liquid. So, if it undergo chemical reactions it helps in case of agitated vessels, the vessel is not used for physical absorption since back mixing in the liquid phase substantially reduces the mass transfer driving force. So, for physical absorption generally it is not used, when there is chemical reactions then generally this type of agitated vessel is used.

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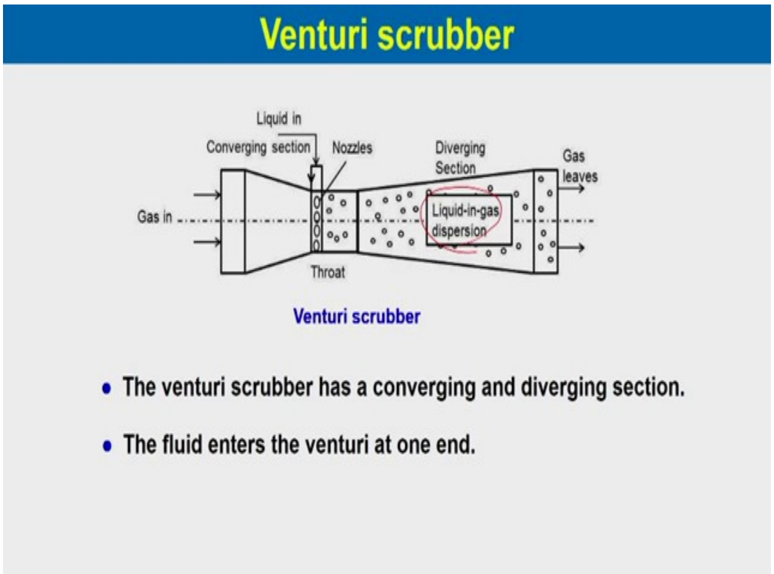

Now, another is venturi scrubber as we have no introduced at the beginning, the there is a gas inlet in the converging section and then there is a throat of the nozzle and where the liquid enters through the nozzles and then there is an intimate contact in the diverging section the gas liquid dispersion. Liquid in gas dispersion; the venturi scrubber has a converging and diverging section the fluids enters the venturi at one end.

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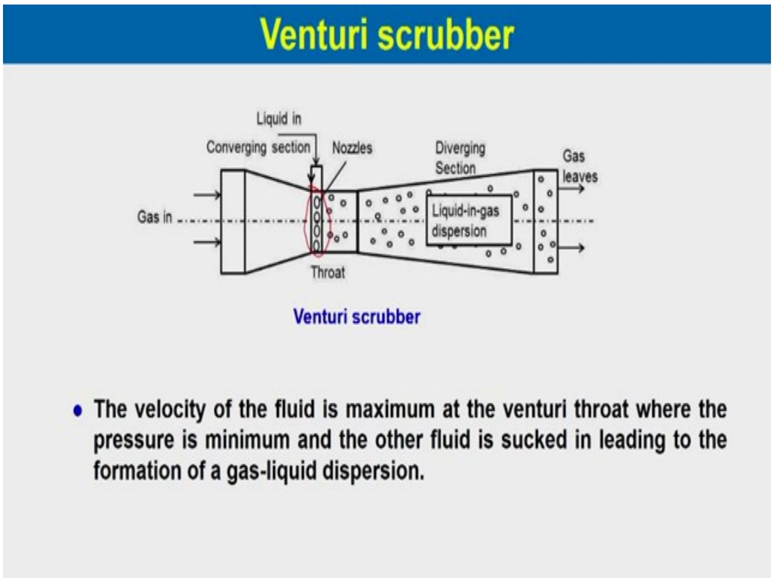

The velocity of the fluid is maximum at the venturi throat. So, where the pressure is minimum and the other fluid is sucked in leading to the formation of the gas liquid dispersion. So, basically since the velocity of the gas over here is very high there is a suction force which occurs in this section which suck the liquid and then the liquid is dispersed in the continuous flow of the gas. So, this is liquid dispersed.

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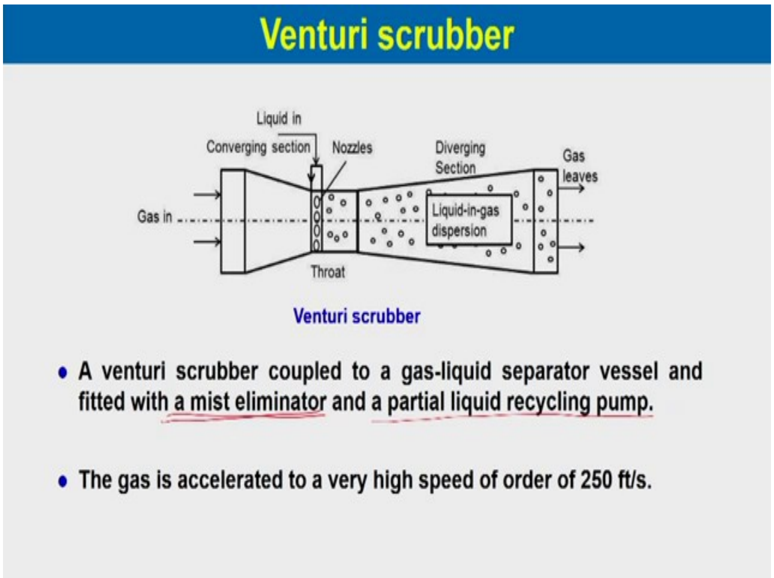

A venturi scrubber coupled to a gas liquid separator vessel and fitted with the mist eliminator and a partial liquid recycling pump. So, what happens no after the gas liquid intimate contact happens or mass transfer happened there will be a separator we need where, you need to separate the no the between the two phases. And also you need to have a mist eliminator after that and then a partial liquid which will be no come can be recycled back.

So, the recycling pump is also required; the gas is accelerated to a very high speed of the order of 250 feet per second. So, at a very high flow rate high speed it is accelerated.

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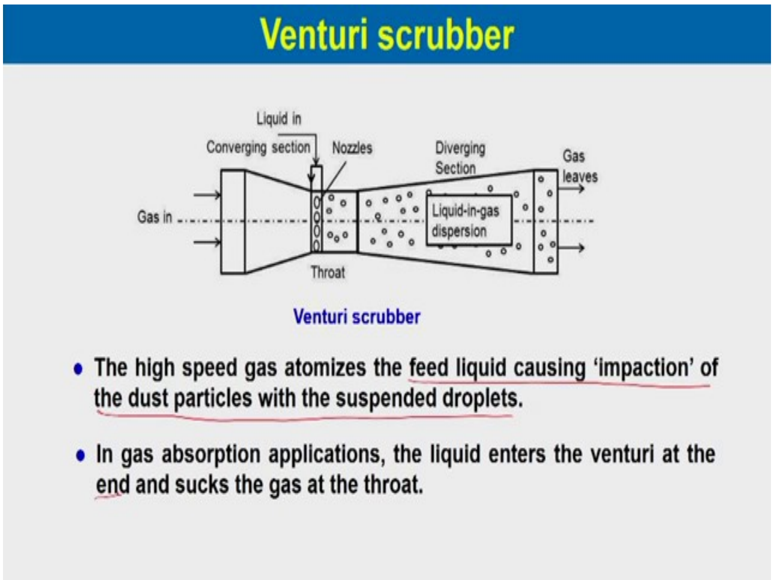

The high speed gas atomizes the feed liquid causing the impaction of the dust particles with the suspended droplets. So, if you have a dust particles, it will cause infections of the dust particles with the suspended droplets.

In gas absorption applications the liquid enters the venturi at the end and sucks the gas at the throat. So, it is a little bit different in case of the gas absorption application, where the liquid enters at the end and it sucks the gas at the throat.

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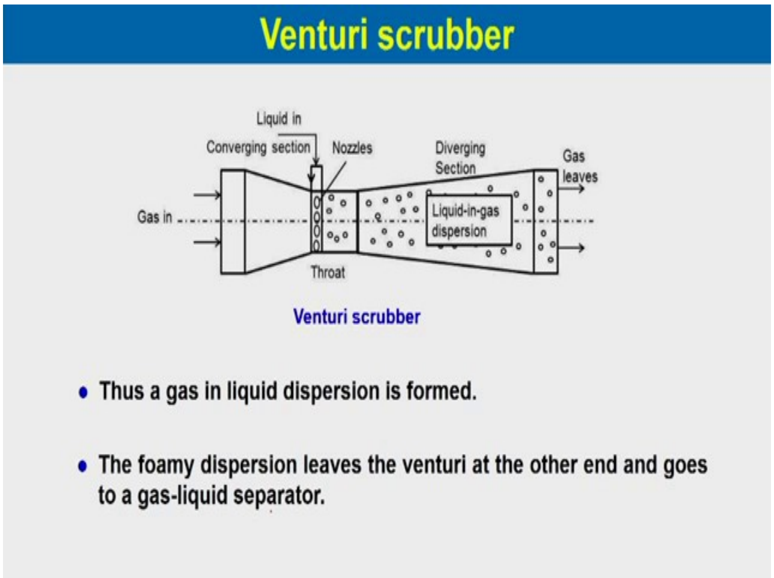

Thus a gas liquid dispersion is formed, the foamy dispersion leaves the venturi at the other end and goes to the gas liquid separator. Now we will introduce you another no tower or the column is the wetted wall column which is mostly use in the laboratory experiments or lab scale measurements for fundamental data generation.

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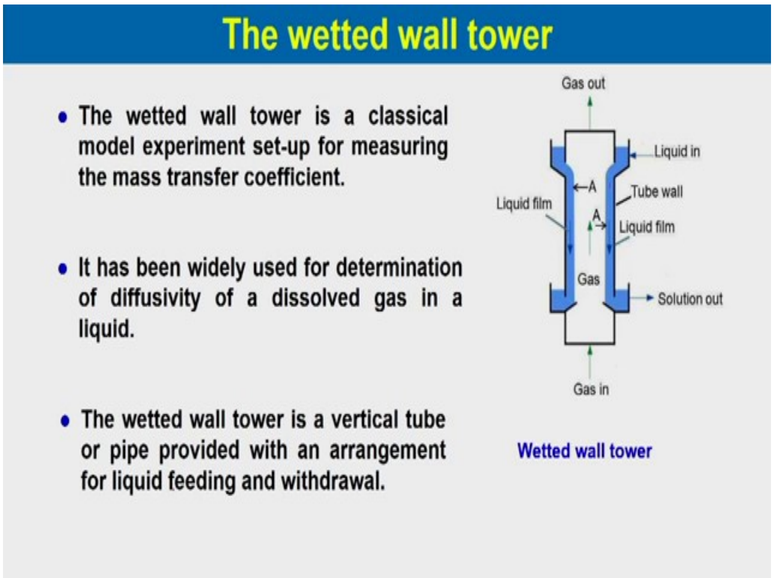

So, you can see the wetted wall tower, there is an inlet gas in at the centre core of the column and the liquid falls from the top through the surface of the column. So, this is the surface; the wetted wall tower is a classical model experiment setup for measuring mass transfer coefficient. And it has also been widely used for the determination of the diffusivity of the dissolved gas in a liquid it also used for the measurement of the kinetics of the reactions which happens when there is chemical reaction mass transfer with chemical reactions.

We can use this equipment to find out the mass transfer rate or the reaction rate, the wetted wall tower is a vertical tube or a pipe provided with an arrangement for liquid feeding and withdrawal. So, you can see over here is a countercurrent operations gas and liquid, but it can also be made concurrent in manner.

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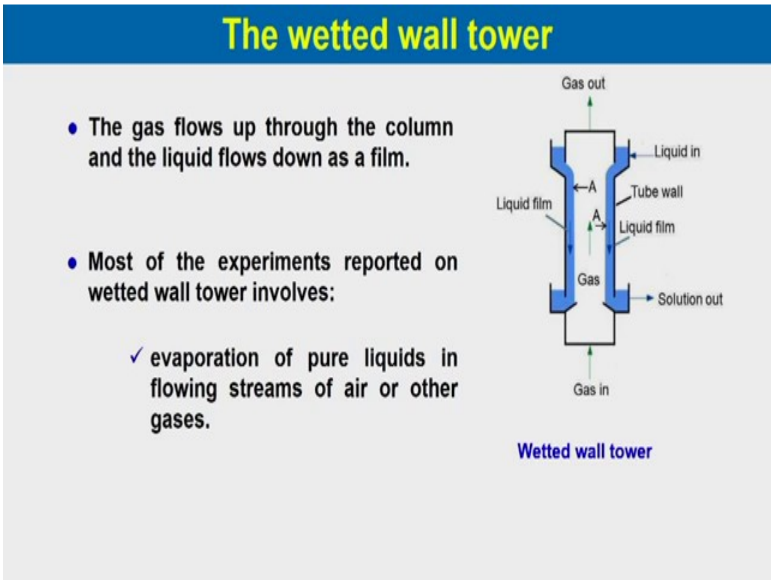

The gas flows up through the column and the liquid flows down as a film, most of the experiments reported on the wetted wall tower involves evaporation of the pure liquid in flowing streams of the air or other gases.

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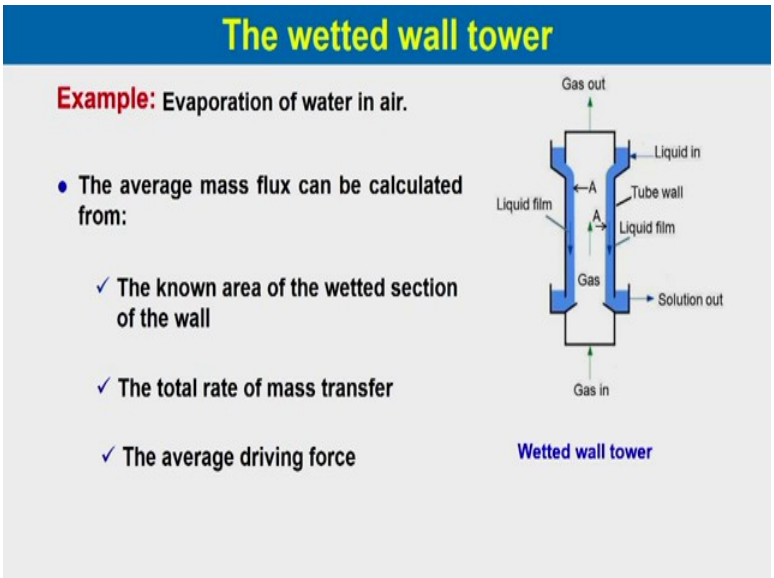

Like evaporation of water in air that is in case of humidification the average mass flux can be calculated from the known area of the wetted section of the column. So, so, as it is known thus the it is a film which is falling on the internal surface and this column can be made glass so, that you can see from the outside the no the film and you can control the flow rate and you can operate in the laminar as well as in the turbulent region.

As the film is known for a certain distance you know the area of the no surface, then it is easy to find out the average mass flux through this experiments the total rate of mass transfer the average driving force this can be calculated from this.

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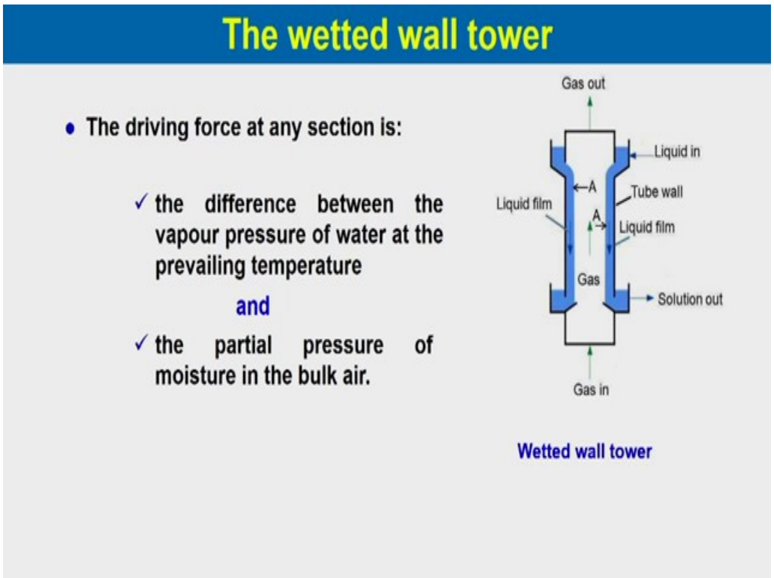

The driving force at any section is basically the difference between the vapour pressure of water at prevailing temperature and the partial pressure of moisture in the bulk air. So, the driving force can be calculated over here.

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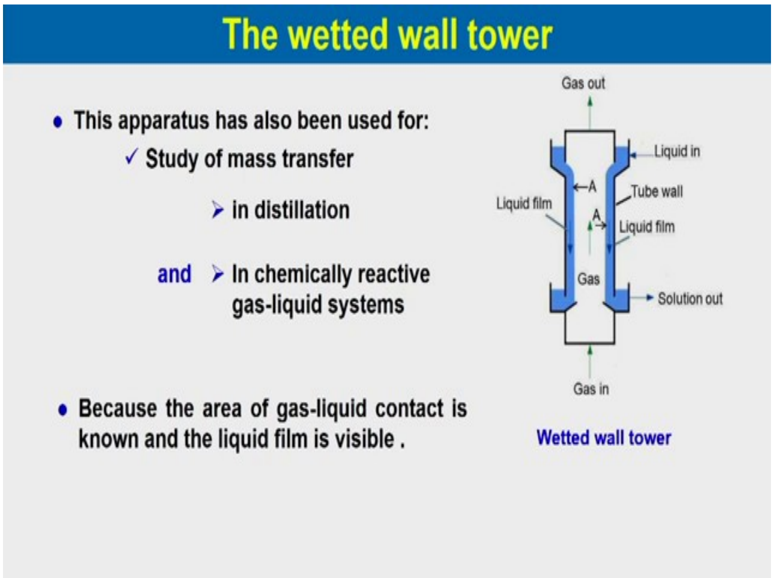

The apparatus has also been used for study of mass transfer in distillation and also in chemically reactive gas liquid systems. So, because the area of gas liquid contact is known and the liquid film is visible. So, you can see the liquid film and you can do the your study whether there is ripple formation, if you wanted to run in the no in the laminar region.

In our lab we have developed the similar wetted wall column absorber to study the kinetics of the gas absorption, but our design its little different which is the liquid is falling from the outside surface and there would be a glass shroud over it through which there will be no flow of the gas and that is co current arrangement and you can also see the film from outside, as well as you can see whether there is ripple formation or not. So, you can run at different flowrate of the gas as well as the liquid, but more as advantage in our setup is that we can control the gas liquid contact time by changing the length of the column.

So, since it is outer flow we can just change the column length, vary the column length. So, we can change the gas liquid contact time. So, which are helpful for study the mass transfer coefficient diffusion coefficient as well as the mass transfer rate and kinetics. This type of design already we have published in couple of our research work on carbon capture that is carbon dioxide separation from the flue gas carbon dioxide nitrogen mixture and we are having design which are published in the literature.

So, thank you for hearing this lecture and we will continue our discussion on gas liquid equipment in our next lecture.