Mass Transfer Operations I
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Lecture - 4
Equipment for Gas Liquid Operations
Packed Tower

Welcome to the fourth lecture of module three which is on gas liquid operations and particularly for equipments, we will discuss in this lecture. In the previous lecture, we have discussed the equipment in which the gas is dispersed into the liquid, and that equipment particularly we have designed the tray tower design.

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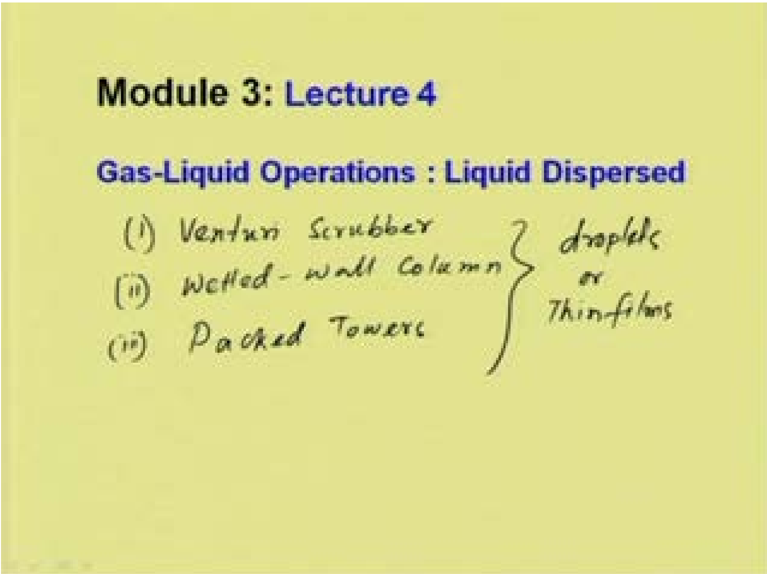

And today, we will discuss the liquid dispersed equipment, and out of these equipments the important equipments which are useful for gas liquid operations are the Venturi Scrubber, Wetted- wall column and Packed Towers. So, in these equipments, the liquid is dispersed in the form of droplets or thin films.

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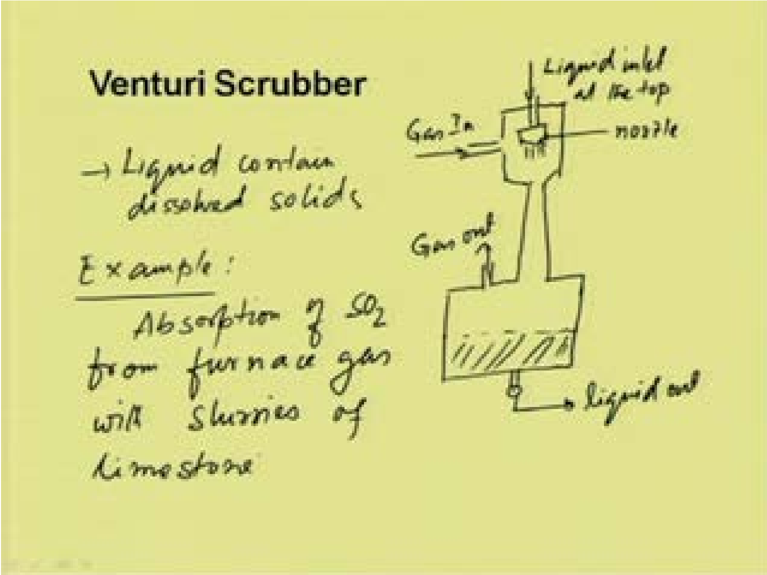

Let us consider Venturi Scrubber in which liquid is dispersed as a droplet. So, we have a reservoir; we have a liquid inlet at the top, and there is a nozzle through which liquid is dispersed; and gas in at the top and gas out at the bottom; and the liquid out also at the bottom. This is very simple equipment, and in which the liquid is dispersed in the gas as a form of droplet and gas is in the continuous mode; and this is very much helpful, when the liquid contains dissolve solids for example, absorption of SO2 from furnace gas with slurries of limestone.

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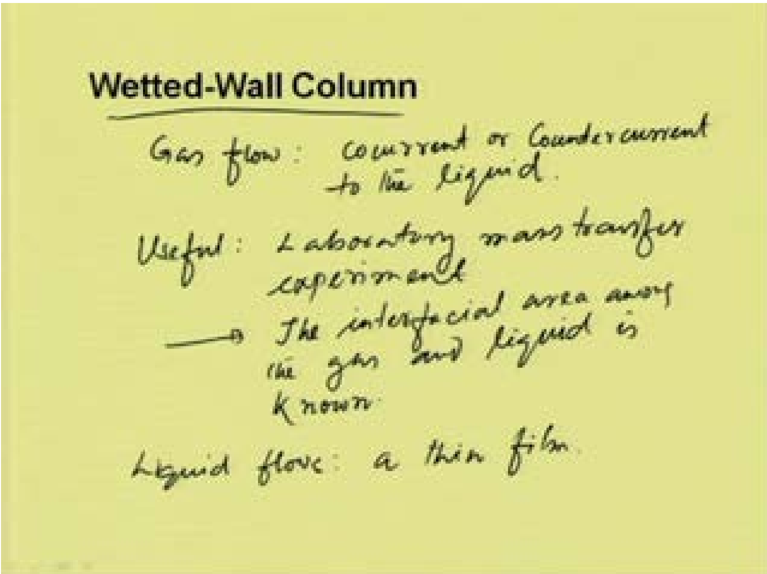

So, another equipment which is also very much useful for laboratory conductor is the Wetted-wall column. It is a vertical cylindrical tube in which the liquid is flowing as a film either outside of the tube or inside of the tube. And the gas flow may be co-current or counter current to the liquid. And this is very much useful for laboratory mass transfer experiments since in this case, the surface area or the interfacial area among the gas and liquid is known. And we can vary the gas liquid interfacial area depending on the design of the wetted-wall tower. So, this is the interfacial area, is also our control and this is this equipment is very much useful for laboratory mass transfer studies. So, here the liquid flows as a thin film.

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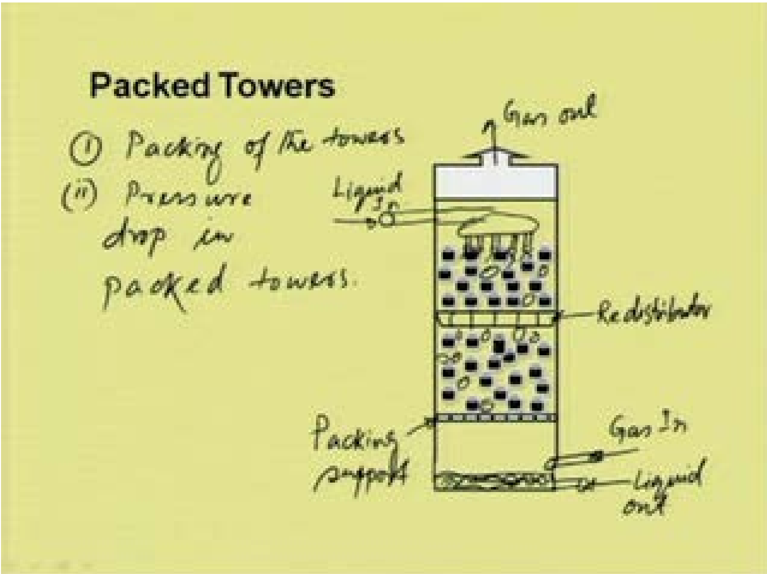

Now we will discuss very important equipment which is used industrially for the gas liquid operations is the packed towers. It has two things, we need to design for this packed towers. So, there is a liquid inlet at the top. So, we have a liquid distributor . So, liquid is distributed at the top on the packing surface, the packing materials are placed inside; and there is a redistributor in the middle for proper distribution, this is redistributor; and the gas out is at the top and there is a gas in at the bottom. So, liquid out at the bottom; and this is a packing support which we will take care of the weight of the packing. So, in this case for packed our design we need to know different type types of packing, and how they are packed in the towers? What should be their criteria? The packing of the towers and the second thing is the pressure drop in packed towers. So, these are the two important things we will discuss while designing the packed towers.

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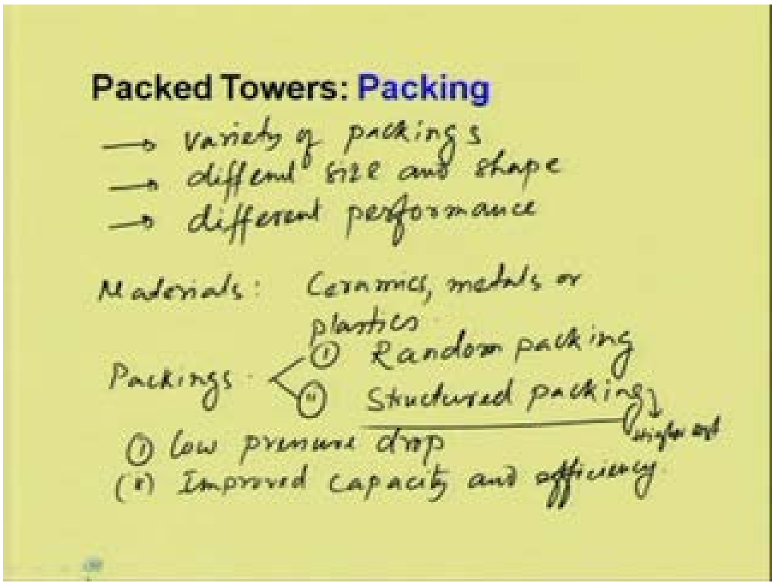

And the packing, there are variety of packing is used for the packed towers. They are of different size and shape also different performance. The material used for this packing, in general, ceramic metals or plastics. There are commonly two types of packing: one is random packing and second one is structure packing. So, in random packing it is the simplistic way of packing, just dump the packing materials through in the tower and let them settle freely on the packing support. And in case of structure packing, different variety of structured packing are available. And the advantage of structured packing is, first one is the low pressure drop and second is improved capacity and efficiency capacity. The disadvantage for this case, the structured packing is that the cost is relatively higher compared to the random packing. Generally this packing is prepared where we need specific arrangement in the packed towers.

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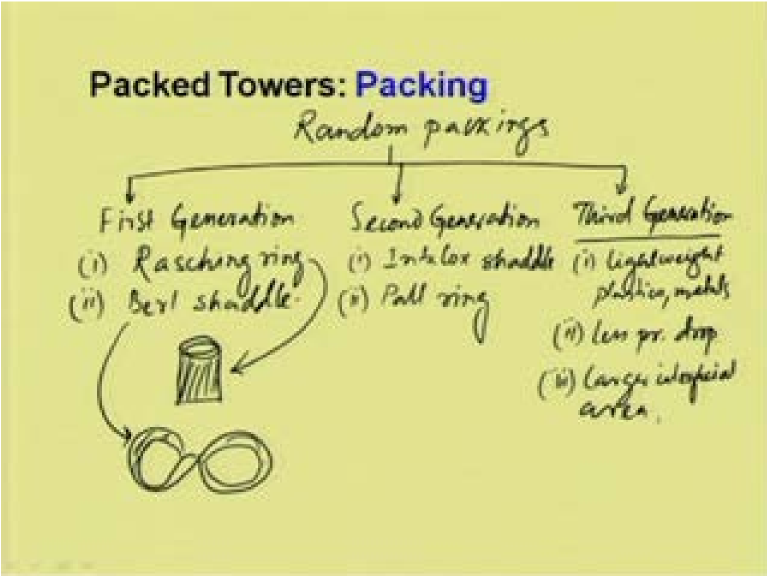

The random packing is also of different kinds. This may be classified into three categories one is first generation packing, then second generation packing and third generation. In the first generation the two most commonly used packing are the Rasching ring and Berl shaddle. Rasching ring are cylindrical in nature, this is the Rasching ring and another one is Berl shaddle, this is Berl shaddle. The second generation packing is the intelox shaddle and pall ring; and the third generation packing is generally light weight material like plastics and metals; and second one is the less pressure drop, compared to the other two generation packing and has the larger interfacial area, the most important thing for the packing is its surface area.

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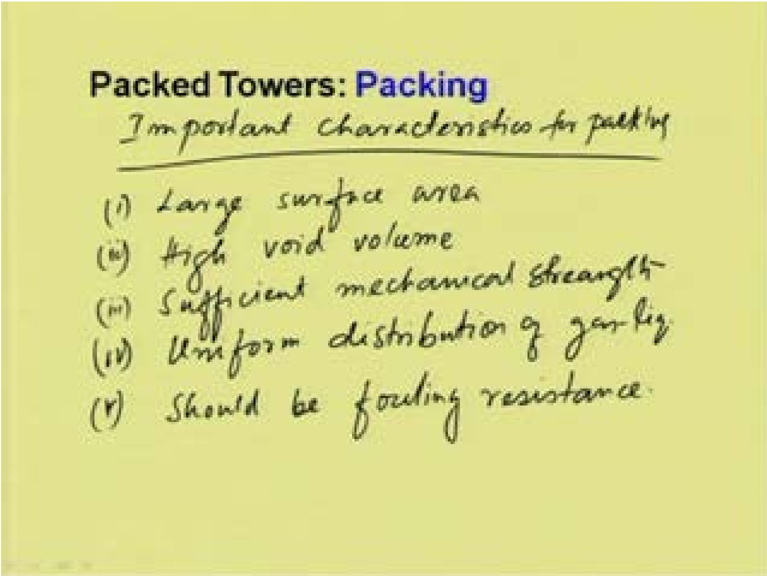

The important characteristics for packing are the following: one is large surface area which is desirable high wide volume so that the gas and liquid flows smoothly without any interference, sufficient mechanical strength, uniform distribution of gas and liquid and should be fouling resistance. These are the preferred characteristics of the packing. And another important tower characteristics is the liquid distribution. Proper distribution of the liquid at the top of the tower is necessary that is why we need to use proper distributor at different points.

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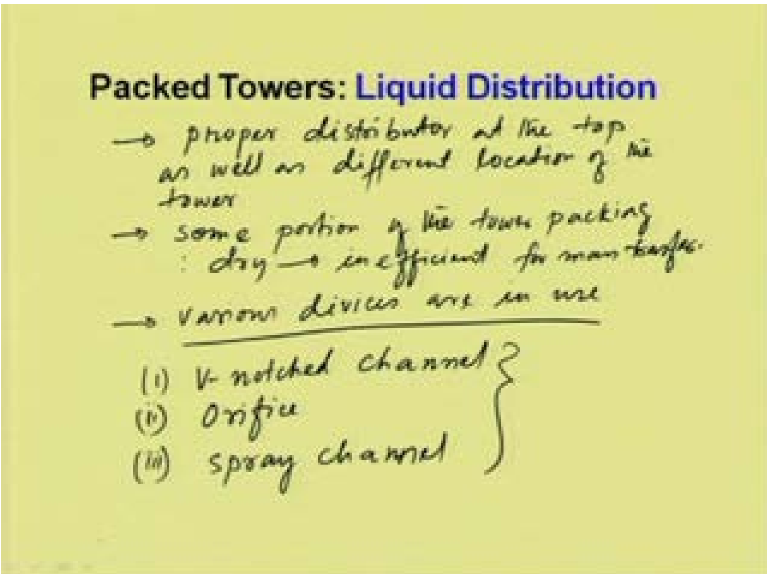

Distributor at the top as well as different location of the tower; and if the distributor at the top of the tower is not properly installed in that case some portion of the tower packing may remain dry. So, this dry packing is inefficient efficient for gas liquid or for mass transfer. Ideally the liquid should be distributed at infinite points at the top and for this there are various devices are in use: one is V-notched channel and second one is orifice and third one is spray channel. These are used at different locations for distribution and redistributions of the liquid in the packed towers. Another important thing is the liquid holdup; there must be some reasonable liquid holdup to the bed which will facilitate the mass transfer.

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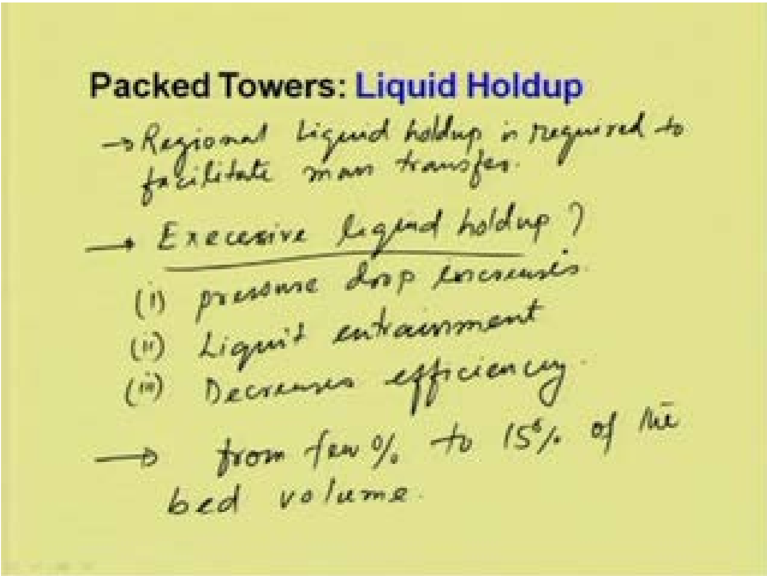

If there is excessive liquid holdup, what happens? The pressure drop increases; and there is a possibility of liquid entrainment; and third one is decreases efficiency. Generally the liquid holdup its permissible limit is around from few percent to 15 percent of the bed volume.

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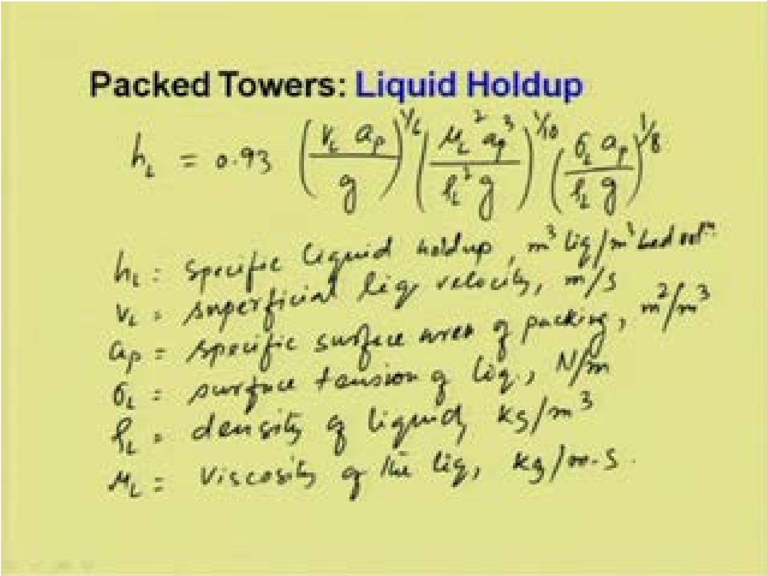

The liquid holdup can be calculated from the correlations h l is 0.93 v l a p divided by g to the power 1 6 mu l square a p cube divided by rho l square g to the power 1 10 sigma l a p by rho l g to the power 1 8. This h l is the specific liquid holdup in meter cube of liquid per meter cube of bed volume; v l is the superficial liquid velocity which is in meter per second; a p is the specific surface area of packing this is meter square per meter cube; sigma l is the surface tension of liquid Newton per meter; sigma rho l is the density of liquid kg per meter cube; and mu l is the viscosity of the liquid kg per meter second. Now we will discuss another important phenomena which occurs in the tower is the loading and flooding, when liquid flows through the tower down due to the gravity the gas flows from bottom to the top.

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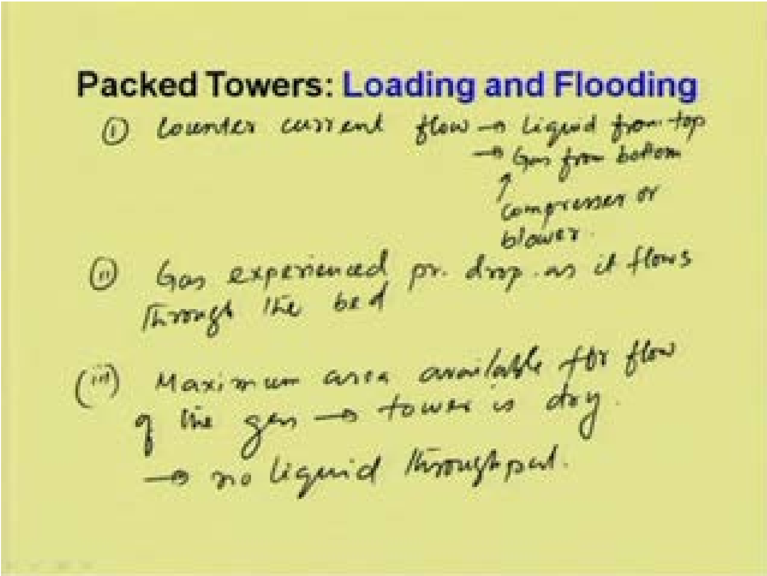

If we consider counter current flow in the packed towers; counter current flow liquid from top and gas from bottom liquid flows due to gravity and gas flows due to compression or the blower power, compressor or blower. Then when the gas flows and the liquid also flows from top to down; the gas experience pressure drop as it flows through the bed the maximum area available for flow of the gas when the tower is dry; that means, there is no liquid throughout.

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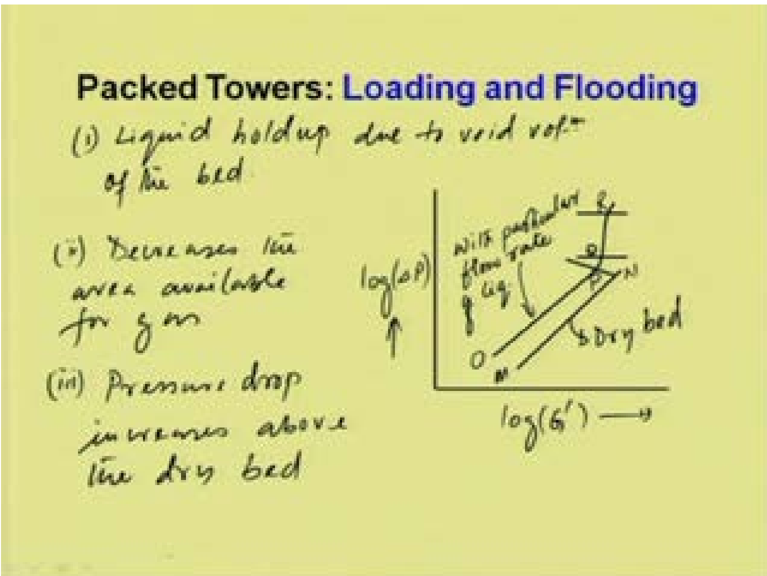

In this case we can see that if we plot log delta P versus log G dash; the pressure drop for dry bed increases linearly with the gas flow rate; in the log log plot we can see it is for dry bed, and when there is a liquid flow from the top of the tower, there is a liquid holdup due to the wide volume of the bed; then the area available for the gas flow reduces so the pressure drop increases above the dry bed. This is the pressure drop line for a particular flow rate of the liquid. So, the pressure as we can see the pressure drop for the bed increases linearly like in the dry bed and after that period there is a sudden increase of pressure drop; this is when say point this is m and n curve for dry bed and this is at a particular liquid flow rate o, p, q and r these are the points.

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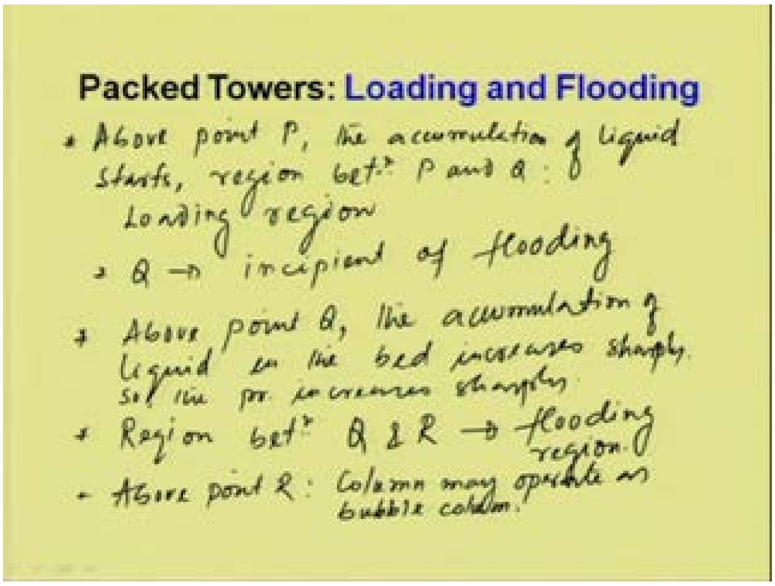

Above point p the accumulation of liquid starts. So, the region between P and Q is known as the loading region. And also the point Q is known as the incipient of flooding. So, the flooding starts at point Q where there is a surf increase of pressure drop. The above point Q, the accumulation of liquid in the bed increases sharply so the pressure drop increases. The region between Q and R is known as the flooding region. As we can see above point R the column is completely flooded and at that time column may operate as bubble column. Now we will discuss the pressure drop in the packed towers.

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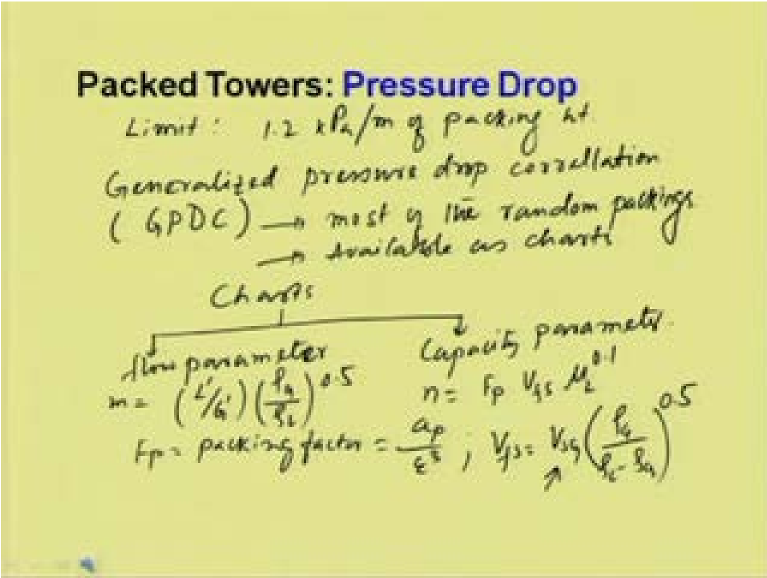

The pressure drop allowable limit for the packed towers should not be 1.2 kilopascal per meter of packing height. So, there are many correlations available to calculate the pressure drop in the packed towers and there is a generalized pressure drop correlations obtained in the literature known as generalized pressure drop correlation which is known as GPDC; and which is applicable for most of the random packing; and available as chart charts, this will available at most of the standard literature standard books; and this chart has two part: one is flow parameter and other one is capacity parameter. The flow parameter which is design given by m and defined by L dash by G dash into rho G by rho L to the power 0.5. And the capacity factor which is n is equal to Fp V f s mu l to the power 0.1. L and G these are the liquid and gas flow rates; rho G and rho L is the density of the gas and liquid; F p is the packing factor and which is a p by epsilon cube and a p is the packing interfacial area and epsilon is the porosity or the wide fraction. We can calculate V f s is equal to V s g, super facial gas velocity, into rho G by rho L minus rho G to the power 0.5.

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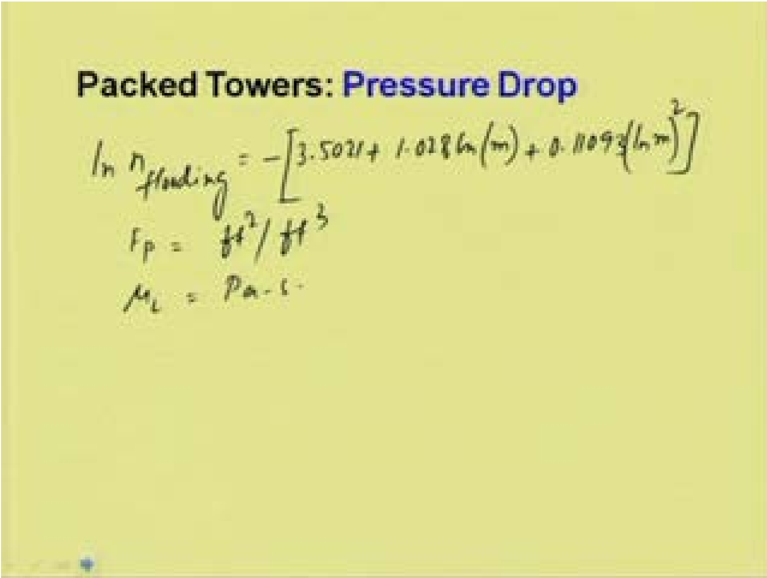

The capacity factor can be calculated at flooding conditions from the following correlations: ln n flooding is equal to minus 3.5021 plus 1.028 ln m plus 0.11093 ln m square. And the capacity factor which we have defined earlier in this case F p. So, packing factor F p is in feet square per feet cube and the viscosity of in liquid pascal second.

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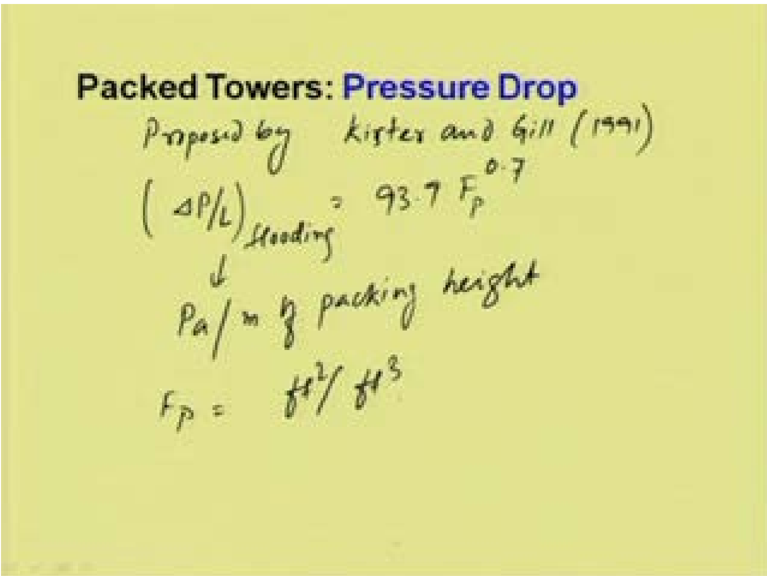

So, we can calculate the pressure drop for the packed towers and there is a correlation proposed by kister and Gill in 1991. That correlations can be used; delta P by L at flooding is equal to 93.9 F p to the power 0.7 and the unit of this is Pascal per meter of packing height. And F p is unit of, as we have said, F p is feet square per feet cube.

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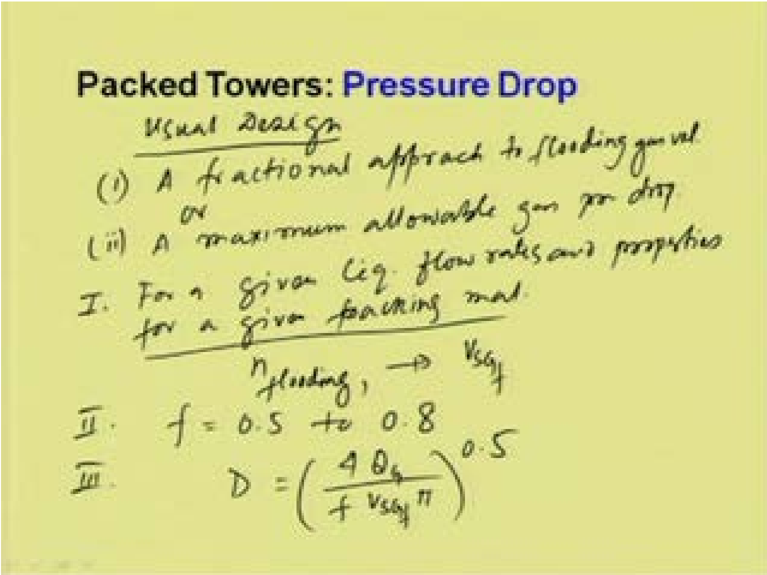

Now, usually the packed towers are designed based on any one of the two criteria: a fractional approach to flooding gas velocity or second approach a maximum allowable gas pressure drop. Now for a given liquid flow rate and properties for a given packing material we can calculate n flooding. And then we can use this one to calculate V s G and then in the second part we can assume the flooding say around between 0.5 to 0.8 packing flooding factor; and then we can calculate the diameter of the tower from this equation: d is equal to 4 Q G by f v s G f pi to the power 0.5.

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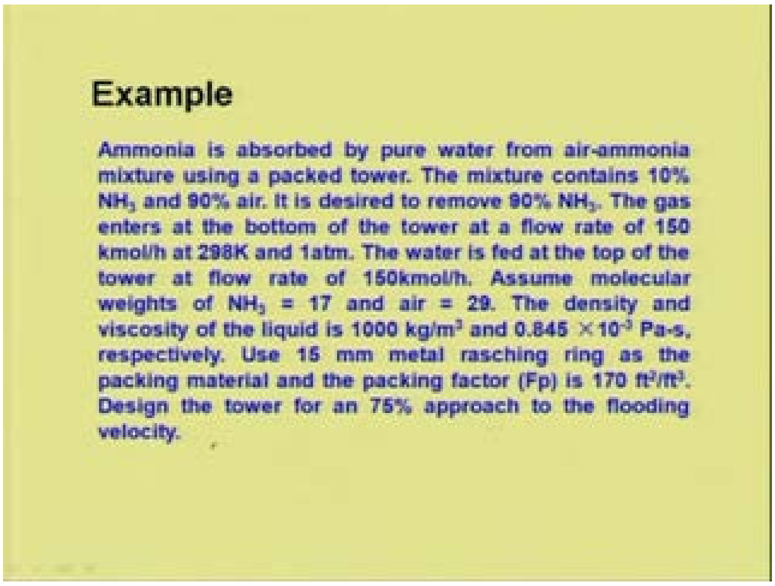

Now, let us consider the example we have considered for the plate column design. The same example if we consider in this case for packed tower design, only we have to mention the type of packing used and what is the packing factor for this case. Then we can see how to calculate the diameter of the column requires and the pressure drop. So, ammonia is absorbed by pure water from air ammonia mixture using packed towers. The mixture contains 10 percent ammonia and 90 percent air. It is desired to remove 90 percent ammonia. The gas enters at the bottom of the tower at a flow rate of 150 kilo mole per hour at 298 Kelvin and 1 atmosphere. The water is fed at the top of the tower at a flow rate of same as gas 150 kilo mole per hour and the molecular weight of ammonia is 17, air is 29. The density and the viscosity of the liquid is 1000 kg per meter cube and 0.845 into 10 to the power of minus 3 Pascal second. Use 15 millimeter metal Rasching ring as the packing materials and the packing factor f p is 170 feet square per feet cube. Design the tower for an 75 percent approach to the flooding velocity.

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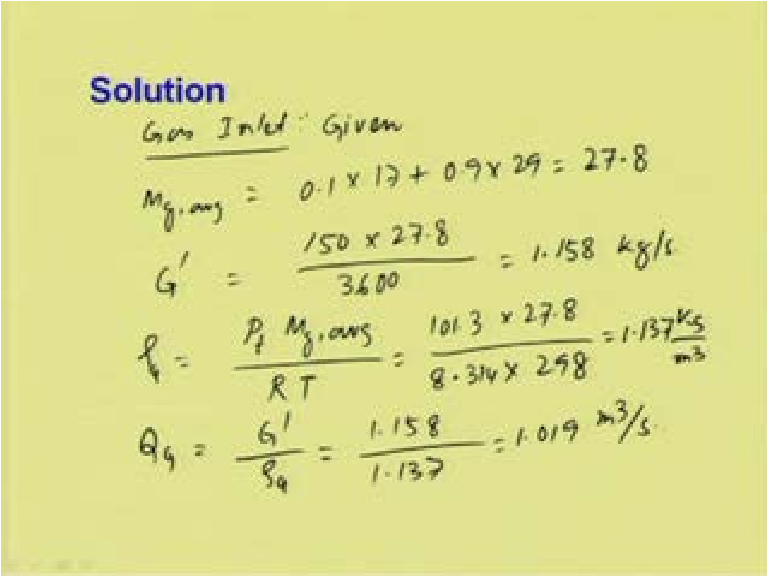

Now, for the gas inlet let us calculate the parameters which are given Mg average is 0.1 into 10 percent ammonia plus 90 percent air. So, this is 27.8. The gas flow rate we can calculate 150 kilo mole per hour into 27.8 divided by 3600 which is equal to 1.158 kg per second; rho G is Pt total pressure Mg average by RT which is equal to 101.3 into 27.8 divided by 8.314 into 298 Kelvin which is equal to 1.137 kg per meter cube. QG the volumetric flow rate of the gas is G dash by rho G which is equal to 1.158 divided by 1.137 which is equal to 1.019 meter cube per second.

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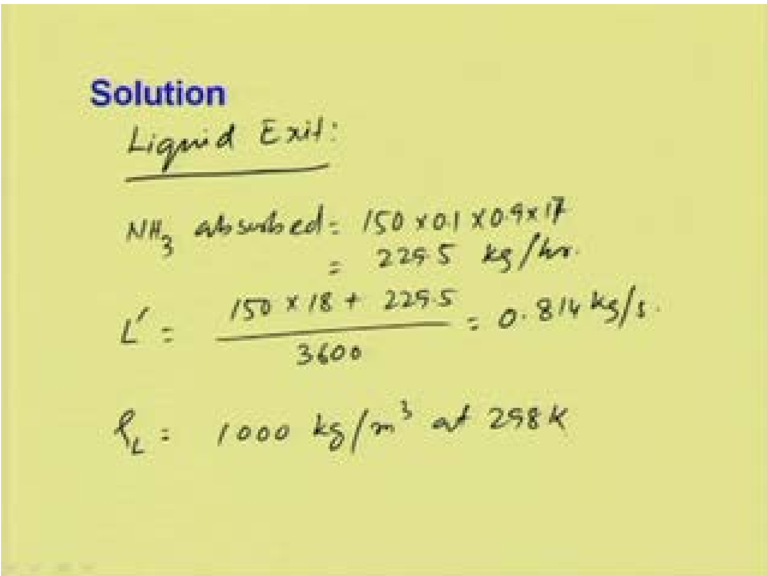

Now, for the liquid exit, we can calculate the parameters the ammonia absorbed is equal to 150, is the flow rate kilo mole per hour, into 0.1 into 0.9 into 17 which is equal to 229.5 kg per hour. L dash is 150 into 18 plus 229.5 by 3600 this is equal to 0.814 kg per second. And density of the liquid is given 1000 kg per meter cube at 298 Kelvin.

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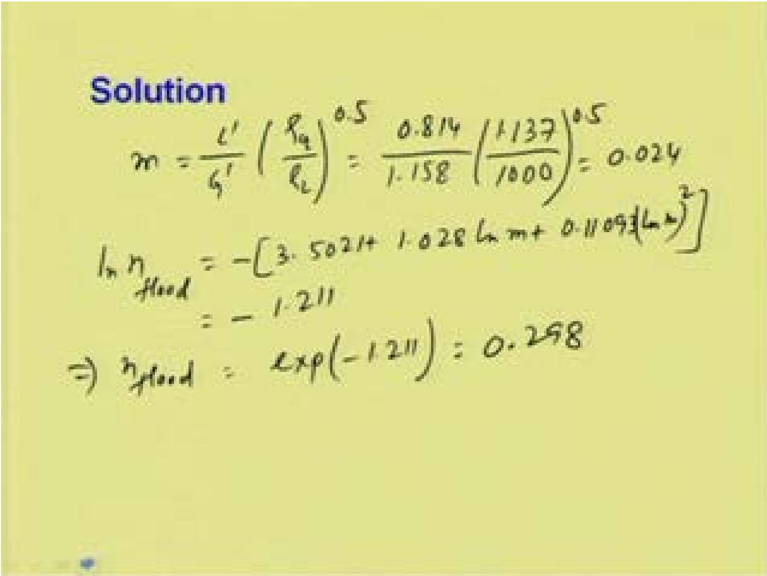

Now we can calculate the flow parameter m is equal to L dash by G dash rho G by rho L to the power 0.5 is equal to 0.814 divided by 1.158 into 1.137 divided by 1000 to the power 0.5 this is 0.024. Now l n flooding n flood we can calculate minus 3.5021 plus 1.028 l n m plus 0.1193 l n m square. So, if we put the value of m this will be minus 1.211. So, n flood from this will be exponential minus 1.211 which is equal to 0.298.

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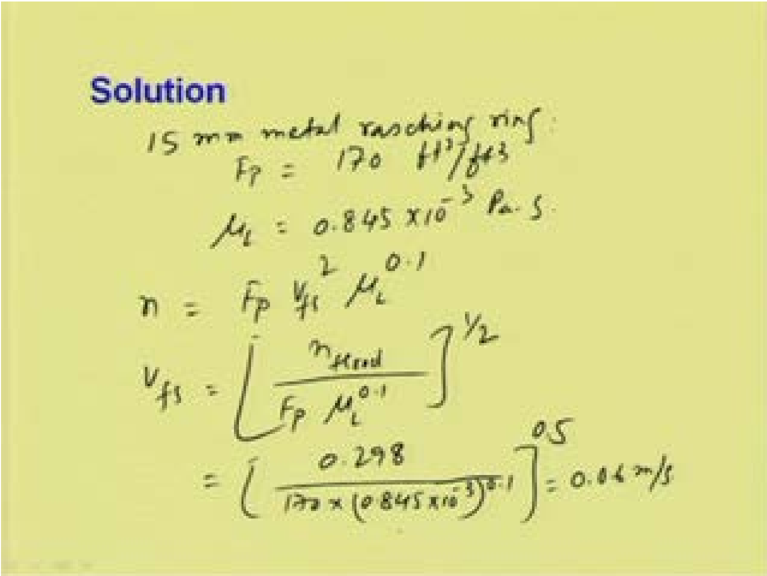

Now, for 15 millimetre metal Rasching ring F p is given which is 170 feet square per feet cube and mu L is 0.845 into 10 to the power minus 3 Pascal second. We know that n is equal to F p v f s square mu L to the power 0.1. So, v f s we can calculate n flood divided by F p mu L to the power 0.1 to the power half, this will be 0.298 divided by 170 into 0.845 into 10 to the power minus 3 to the power 0.1 whole to the power 0.5. So, this will be equal to 0.06 meter per second.

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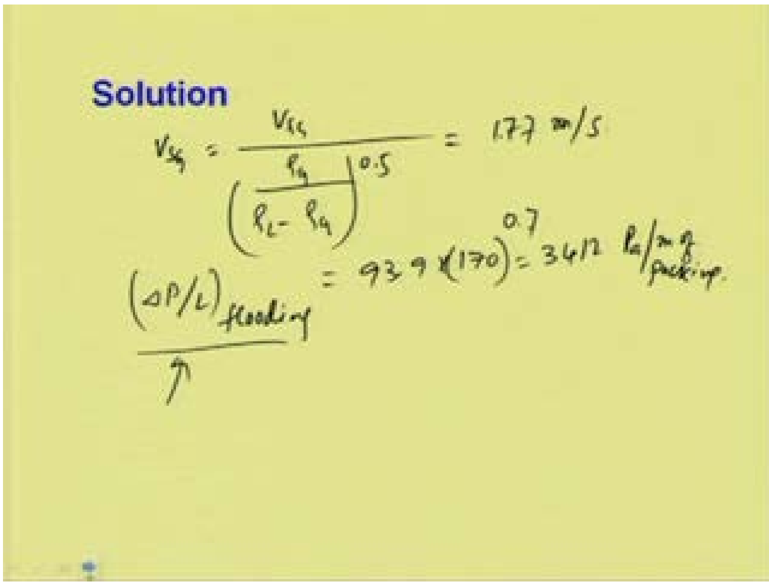

So now, we can calculate, V s G is equal to v f s divided by rho G by rho L minus rho G to the power 0.5 and substituting these values this is 1.77 meter per second. So, delta P by L flood, at flooding, the pressure drop we can calculate 93.9 into F p is 170 to the power 0.7 which is 3412 Pascal per meter of packing.

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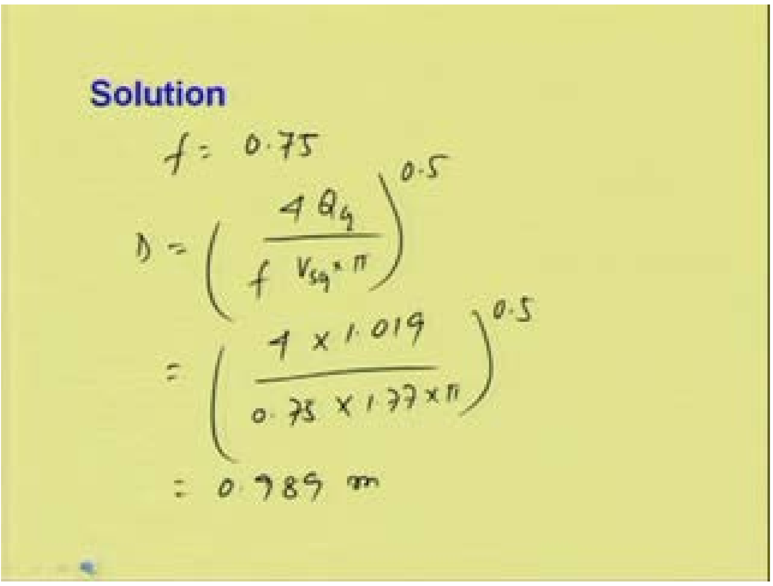

So, the flooding pressure drop we can calculate. Now we can calculate the diameter f is given 0.75; and D we can calculate 4 Q G by f v s G into pi to the power half. So, substituting 4 into 1.019 divided by 0.75 into 1.77 into pi to the power 0.5 which will be around 0.989 meter. This is the diameter of the column required for the particular operations. So, this is end of lecture four of module four and this is the last lecture. In the next lecture we will discuss the absorption of certain component into the liquids that is absorption module, module four.