# Lec 18: Mixing and agitation of fluids/slurries

Hello everybody. Welcome to this massive open online course on solid-fluid operations. So, in the previous two lectures we discussed about the solid mixing and also assessment of the solid mixing in the module of that solid-fluid mixing in a system. So, in this lecture we will try to understand the mixing and agitation of the fluids or slurries. So, in this lecture the mixing of fluids, mechanism, flow patterns, standard design of mixing vessel with agitators will be discussed. As we know that the mixing of fluids with other miscible or immiscible liquids, gas and with fine particles is important for separation of contaminants in liquid, separation of gas by solvents, separation of fine particles from slurry or muddy water or waste water treatment etc.

Not only that in presence of slurry that means catalyst particle with the liquid you will see that we are producing different hydrocarbons just by cracking heavy hydrocarbons to the lighter hydrocarbons. And there we are actually following the procedure of Fischer-Tropsch synthesis. There itself the gas, liquid and solid three-phase will be come in contact to give you that yield of different hydrocarbons. So there itself the process yield depends on that mixing of that slurry in that particular reactor, okay? So that is why this mixing of solids or slurry is very important.

So here we can say that we learnt about that what is mixing, what is blending, what is agitation like this and what is the difference among these three terms there. We were actually discussing in the previous lectures itself also. So blending miscible liquids to for the you can say that homogeneous even homogeneous solutions there it is very important. And also dispersing of gas in a liquid as a dispersed phase of bubbles that is also important in that case bubbles will be mixed or randomly distributed in the bed that based on that kinetic energy dissipation inside the bed and based on which you will see that liquid will be flowing randomly into the vessel see that it will be flowing at a certain pattern and that pattern depends on that kinetic energy and because of that energy transported that gas whatever will be dispersed in the dispersed phase of bubbles also will be distributed inside the bed and based this is that depends on that mixing of the liquids there. And also you will see that dispersing on immiscible liquid in another liquid to form and that emulsion or suspension of fine drops or particles oil in suppose dispersing in to pour its fine drop in water like this and also suspension of minute particles in the atmosphere as an aerosol and also you will see that for promoting heat and mass transfer between phases this mixing is very important and whenever you are going to disperse that liquid drops in a gaseous medium specially for that application of physical operation where the liquid drop will be absorbing some gaseous contaminants there in the drop.

So those type of operation actually depends on that dispersion phenomena of the Also you will see that fluidizing powder in a gaseous medium there itself that particulate materials will be dispersing inside the bed of the fluidized bed that is catalyst particle in presence of which you will see that there will be a conversion of hydrocarbon to different other chemicals there. So in that case that mixing of that solid particles as a catalyst will be that important. So you have to learn that why that mixing is very important and also where it can be applicable and how that mixing phenomena will be influencing on that yield of that reaction or physical operation there. Now already we have discussed the different mechanism of that mixing some will be you know the turbulent mixing, laminar mixing and molecular diffusion. So those mechanism are very effective you will see that in that case turbulent mixing you will if you are talking about that mixing is due to the turbulent flow which result in random fluctuation of that fluid velocity at any given point within the system and in that case fluid velocity at a given point changes in three directions x, y and z.

And in case of laminar mixing you will see that the mixing of two dissimilar liquids through laminar flow that is applied shear stresses the interface between them you will see that will be forming and because of which that distribution of that contaminants particles among this through this interfaces there will be transported and you will see that mixing happens because of that diffusion of that solid particles over that interfaces and also you will see that suitable for liquids which require moderate mixing there you will see that this type of laminar mixing phenomena will be required. And in case of molecular diffusion that mixing at molecular level in which molecules diffuse due to the thermal motion. So these are three different mechanisms based on which you can get that mixing and whenever you are talking about that mixing of that solids or slurries or liquids there will be certain equipment on which that or in which that this mixing will happen. Already we have discussed the different equipments for solid-solid mixing but here agitators will be called as a mixing equipment where that slurry that means liquid and solid will be mixed in a agitator or you can say that liquid-liquid mixing will be there or gas liquid mixing will be there. So that equipment is called agitators.

So agitators basically a container or it is called vessel with a mixing device, mixing device maybe impeller as shown in figure here in this slide is used to mix the liquids with other phases like gas, liquid and fine particles in a certain pattern. And at the bottom of this vessel is made round to eliminate sharp corners into which fluid currents would not penetrate there. And the fluids depth is controlled approximately equal to the diameter of the vessel. So this is the typical mixing vessel you will see there will be some accessories of this mixing vessel one will be mortar that certain speed of this mortar will give you that rotation of this impeller and this impeller rotation will give you the certain fashion of that fluid element or solid element or slurry element inside the vessel or inside this agitator. And there also you will see that to get that intense mixing or certain fashion of that movement of that fluid or slurry there will be certain baffle will be as a mechanical provision will be attached here to get a certain fashion of that flow.

And also some jacket here suppose if you want to do in a constant temperature or pressure that there will be certain jacket on which or based on which you can get that isothermal mixing. And there will be some deep lake through which that liquid or slurry will be inserted into the vessel and there will be a shaft on which that impeller will be mounted and then it will be rotating at a certain speed by a rope mortar. And also that there will be a drain valve through which that after mixing it will be drained out. And there will be certain liquid in surface that means up to certain level of that you know slurry or liquid will be maintained inside the vessel. So this is the typical the geometry of that agitators and in that case to you know give you that mixing of that slurry or liquid in that agitator there will be a certain mixing device it is called impellers.

So the impeller creates a flow pattern in systems causing the fluid to circulate through the vessel and return eventually to the impeller. The impeller which generates currents parallel with the axis of that impeller shaft it will be called as axial flow impellers. Whereas if it generates currents in a tangential or radial direction it will be called as radial flow impellers. And this impeller for the mixing is classified based on shape and piece into three types such as propeller, turbines and pedals. Here in this picture shown some three blade turbine, open straight blade turbine, blade disc turbine, even vertical curved blade turbine, even pieced blade turbines are there.

Here it is shown that A this is basically the three blade turbine mixer, B is basically open straight blade turbine, C is called blade disc turbine and D here it is basically the vertical curved blade turbine and here is the pieced blade turbine. So all these prohibitions will give you the certain fashion of that pattern in the system which will cause the fluid to circulate through the vessel. And also you will see that different types of flow pattern will be created in that agitators or vessels. The flow pattern in the agitated vessels depends on basically type of impeller, what type of impeller that you will use that we have discussed in the previous slide that there are different type of impellers are there. And also characteristics of the fluid whether it will be that highly viscous fluid or less viscous fluid or it is a slurry or then others.

Even size and proportions of tank baffles and impellers, so here also the geometry of this tanks also it is important to get that certain flow pattern. Also you will see that this flow pattern depends on the variations of velocity components either in the radial or axial directions. So this radial and axial directions of this fluid element with certain velocity that will actually give you that certain flow pattern. Basically two flow patterns are important, one is called vortex formation and another is called swelling formation. You will see that here in this picture that how vortex is formed here and how swelling is formed here.

And you will see that whenever vortex will be formed in that case the shaft is when it will be vertically aligned there and centrally located in the vessel you will see that there will be tangential flow that follows a circular path around the shaft and it will create a vortex in the liquid for specially flat bladed turbine. So you can get it piece bladed turbine or propeller. The vortex is developed when a lighter fluid like here or other gases or you can say that kerosene flows a circular path around the shaft then you will get that vortex. At higher impeller speeds the vortex may be so deep that it recesses the impeller. So this vortex formation basically depends on that orientation of this shaft.

If it is vertically mounted or inclined then you will see that the vortex formation will be different shape. So in that case that when it will be vertical and centrally located in the vessel the tangential flow follows a circular path around the shaft and there will be a formation of vortex. And as higher impeller speeds will reach there you will see the depth of that vortex will be more. Whereas swirling is another pattern this basically that perpetuates that stratification at the various levels without accomplishing longitudinal flow between levels. So the swirling pattern develops if a flow if a low viscous liquid is started in an unbaffled vessel by a centrally mounted impeller and the formation of that vortex and reduce the degree of vegetation and mixing.

So important point here swirling is basically a pattern which develops if a low viscous liquid is started in an unbaffled vessel by centrally mounted impeller. So in that case you will see that these two types of flow patterns like vortex formation and swirling. So if you have that more vortex or swirling formation their reduction of the mixing will be there. So as much as possible you can say that reduce that vortex or swirling then you can expect that more mixing inside the bed. So the formation of vortex and swirling reduce the degree of agitation and mixing.

Now how can it be reduced for getting that intense mixing inside the agitator? So you have to prevent that swirling and vortex. There are three ways to reduce that swirling and vortex. Way one is that if you use a small vessel and if you mount off the impeller to the center of the vessel whereas for large tank impeller can be mounted in the side of the vessel. So for small vessel if you mount that impeller to center of the vessel then you can have this that low swirling and vortex whereas for the large tank you can give the provision to mount it in the side of that vessel. And in case of way two you will see that some other way that means by installing baffles you will see that some vertical strips will be placed inside that agitators which impede rotational flow without interfering with the radial or longitudinal flow.

And the third way you can reduce this swirling or vortex by using diffuser ring with turbines there. So basically these three ways you can reduce the swirling and vortex. Then we come to the point another component of that mixing devices there it is called propellers. This propellers consist of number of blades generally three bladed design is most common for that liquids. Two or more propellers are used for deep tank for directing the liquid in the same direction.

Sometimes two propellers work in the opposite directions or push pull to create a zone of specially high turbulence between them. Also these propellers are used when strong vertical currents are desired like when heavy solid particles are to be kept in suspension then you have to use these you know propellers. And they are not usually used when the viscosity of the liquid is greater than about 50 poirs so that you have to remember. So propellers basically a mixing device or mixing mechanical provision based on which you can get that currents of that fluid inside the bed in a certain direction. Especially these propellers are used for strong vertical currents when it will be required when heavy solid particles are to be kept in a suspension.

There will be some advantage of these propellers that it will be used when high mixing capacity is required and it is effective for liquids which have maximum viscosity of 2.0 Pascal second or slurry up to 10 percent solids of fine mesh size. Effective gas liquid dispersion is possible at laboratory scale. Whereas the disadvantage is that these are not normally effective with liquids at high viscosity greater than 5 Pascal seconds such as glycerin, castor oil etc. Then another component of this increasing that mixing it is called turbines.

So this basically consists of a circular disc to which a number of short blades are attached. In this case, blades may be straight or curved and the diameter of the turbine ranges from 30 to 50 percent of the diameter of the vessel and turbines rotate at a lower speed than the propeller specially 50 to 200 rpm and flat bed turbines will see that produces radial flow and tangential flow. As the speed increases radial flow dominates and pieced blade turbine produces axial flow. So you will see that near the impeller zone rapid currents will be generated and high turbulence and intense shear will be observed. And shear produced by turbines can be further enhanced by some diffuser ring that may be stationary perforated ring which surrounds that turbine.

And diffuser ring this is used to increase the shear forces and liquid passes through the perforations which reduces that rotational swelling and vertexing that is why that diffuser ring can increase the shear forces. And pieced blade turbines with 45 degree down thrusting blades are used to provide strong axial flow for suspension of solids. And next that you have to know what is the basic or standard design of mixing vessel with agitators. So there will be standard design criteria to give you that optimum mixing inside that agitator. So here you will see that standard design of that mixing vessel with agitators includes the proportions as shown in the figure.

You will see there will be certain height of that mixing devices, there will be certain diameter of this agitator and you will see that there will be a baffle and there will be that impeller, there will be a draft and here you will see that every geometrical measurement will be depending on that diameter of that vessel. So if diameter of the vessel is dt if you are considering then dA that means this diameter of this impeller will be dt by 3, one third of dt. And from this base to that impeller axial position it will be length up to one third of that diameter of that vessel. And here this oval shape of this here it will be dt by 3 and also height will be is equal to diameter of this vessel. So this will be optimum so that you can get better mixing.

Whereas other dimensions also given in this picture that here this impeller or propeller blade length will be is equal to dA by 5 and also here up to this if you are using n number of or different number of blade there in different positions also you can get that this you can place where dimensions are given here. So in this way you can design that mixing vessel with agitators. So I think you can follow how that mixing vessel can be designed for this mixing of slurry or liquid. Now whenever you are doing mixing in that mixing vessel there will be flow phenomena inside that vessel. There should be some of velocity component of that impeller whenever it will be rotating inside that vessel.

So consider a flat bladed turbine impeller as shown in the picture. There are three components of that velocity of that impeller turbine impeller. So those are radial velocity component, longitudinal velocity component and tangential or rotational velocity component. Radial velocity components here you will see that acts in a direction perpendicular to the shaft of impeller and longitudinal velocity component acts in a direction parallel with the shaft. Whereas this tangential or rotational velocity components will be acting in a direction tangent to a circular path around the shaft.

So here in this diagram it is given that here you will see that UBT, UBT is called velocity of the blade tips and VL you will see that it is given tangential velocity of the liquid leaving the blade tips here it is given as like this and VL you will see that radial that will be is equal to actual radial velocity of the liquid leaving the blade tips and also total or actual total velocity of the liquid leaving that blade tips that will be represented by VL total okay VL total here. So this will be your VL total and this is your VL tangential component and this is your radial component okay. So here we are getting these three components of this velocity of the blade tips. So whenever we are considering these of course some relationship of this tangential components of this velocity with the blade tips velocity. So this tangential component will be is equal to some factor multiply with that velocity of the blade tips.

So that will be your constant value that is VLTN will be is equal to K into UBT so K is constant here okay

Here the Equations

$$V_{l,\tan tan} = ku_{bt} = k\pi D_a n [where u_{bt} = \pi D_a n]$$

and also here you will see that there will be some other constant factors here this that actual total velocity of the liquid leaving the blade tips that will be is equal to some factor of that velocity of the blade tips that will be regarded as alpha here. So this VL total will be is equal to alpha into UBT okay. So in this way we are getting that different velocity components inside the vessel whenever fluid will be rotating at a certain speed. Now assume that the tangential liquid velocity is some fraction of the blade tip velocity which can be expressed by this equation here 1 here VL tangent will be is equal to K into UBT or you can represent it as K into pi DAN where N is called that impeller rotational speed UBT will be is equal to then pi DAN. Similarly VL radial that is radial components of that liquid velocity so it will be is equal to UBT minus VL tan into tan theta as per geometry you can get it.

Here the Equation

$$V_{l,rad} = (u_{bt} - V_{l,\mathrm{tan}tan}) \tan tan\,\theta = (\pi D_a n - k\pi D_a n) \tan tan\,\theta = \pi D_a n(1 - k) \tan tan\,\theta$$

So here pi DAN minus K pi DAN into tan theta after substitution of this UBT and then VL tan we are getting common on that pi DAN into 1 minus K into tan theta. So this equation 2 will give you that radial component of that velocity and equation 1 will give you the tangential component of that velocity. Now based on this radial component and that tangential components you can expect what will be the volumetric flow rate of the liquid through the impeller which is swept out by that impeller. So if the volumetric flow rate of that liquid through the impeller can be quantified by Q so Q will be is equal to what VL radial into Ap

Here the Equation

$$q = V_{l,rad} A_p$$

where Ap is the area of the cylinder swept out by the tips of the impeller blades which is basically pi into D into W.

Here the Equation

$$A_p = \pi D_a W$$

What is W? W is given that impeller blades width there so this is area so this area will be used to swept out that fluid element.

So what will be the volumetric flow rate of that liquid through that impeller will be swept out that depends on that surface area this Ap. So Ap is the area of the cylinder swept out by the tips of the impeller blades. So which will be defined by this equation number 4. Here in this case Da is basically the impeller diameter and W is the width of the blades and then the volumetric flow rate of the liquid through the impeller then can be calculated just after substitution of those values here then after simplification it will be coming as Nq small n into Da cube where W can be taken as Da by 5 as earlier that standard design of that vessel that we have shown that what should be the dimension of that width. So ultimately that volumetric flow rate of liquid through the impeller it will be coming as Nq N Da to the power cube.

Here the Equation

$$q = [\pi D_a n(1 - k) \tan tan\,\theta\,]\pi D_a W = \pi^2 D_a^2 n(1 - k)W \tan tan\,\theta = \frac{1}{5}\pi^2 D_a^3 n(1 - k) \tan tan\,\theta\,[since W = D_a/$$

So in this way you can calculate what will be the volumetric flow rate of the liquid through the impeller will be. So it depends on radial component and tangential component of this velocity of the liquid. Therefore the volumetric flow rate of the liquid through the impeller can be written as that it will be proportional to the rotational speed of the impeller and also the diameter of the impeller. But here it will be diameter cube that means volumetric flow rate will be proportional to the diameter cube.

Here the Equation

$$q \propto nD_a^3$$

So the ratio of the two quantities is called flow number which can be expressed as this Nq that will be is equal to q by N Da cube so that you have to remember.
Here the Equation

$$N_Q \equiv \frac{q}{nD_a^3}$$

So these two equations, equation number 6 and 7 are very important and you have to remember it. So what is the volumetric flow rate which is swept out by that impeller? That is basically proportional to the rotational speed of the impeller as well as that you know diameter of the impeller cube. And then this mixing intensity actually will be characterized by this ratio of these two quantities which is called that flow number. This is very important. So flow number can be expressed as this ratio of this volumetric flow rate and then divided by N Da to the power cube.

So this equation number 7. Now in this case you have to remember that this Nq value will be constant for each type of impeller. Whatever impeller you will be using that this constant value of Nq to be maintained. For a standard flat blade turbine in a baffled vessel Nq may be taken as 1.3 that you have to remember. For marine propellers generally square piece propellers are being used in that case this Nq value always to be 0.

5. And for a four blade 45 degree turbine if you are using for that marine purpose then they are W by Da will be is equal to 1 by 6 and Nq will be is equal to 0.87. For a standard flat blade turbine in a baffled vessel that Nq should be is equal to 0.92 into Dt by Da. So if you change the Da or Dt then accordingly what will be the flow number to be there.

So the total flow can be calculated as then Qt will be is equal to what just after substitution of Nq value here then it will be coming as 0.92 Dt by Da into N into Da cube. So it is applicable only for Dt by Da will be is equal to 2 to 4. So these are some important points that you have to remember. Next whenever you are doing mixing in that mixing vessel you have to calculate what will the power consumption to drive that impeller in the turbine mixer.

At turbulent condition if you are considered for that mixing the power required to drive that impeller for the mixing can be calculated based on this equation 8.

Here the Equation

$$Power = Flowrate\ produced\ by\ impeller \times Kinetic\ energy\ per\ unit\ volume\ of\ fluid Or P = q \times E$$

Here power will be is equal to flow rate that is produced by impeller and also kinetic energy per unit volume of the fluid or you can denote it by like this here P will be is equal to Q into Ek. P is called power and Q is called flow rate produced by impeller and Ek is the kinetic energy per unit volume of fluid. So in this case then Q we have already calculated that Q is equal to Nq into N into Da cube and then kinetic energy is equal to half of rho VL square. Now VL is the total velocity of the liquid and then here Nq into N Da cube into half of rho here VL total this is basically that some fraction of that velocity at the blade tube.
Here the Equation

$$P = N_Q nD_a^3 \times \frac{1}{2}\rho V_{l,tot}^2 = N_Q nD_a^3 \times \frac{1}{2}\rho(\alpha u_{bt})^2 [\because V_{l,tot} = \alpha u_{bt}]$$

$$= \rho n^3 D_a^5 \left(\frac{\alpha^2 \pi^2}{2} N_Q\right) [\because u_{bt} = \pi n D_a]$$

So that is why you can write here alpha into UBT. So VL total is equal to alpha into BT that we have shown earlier. So in this case after simplification it is coming as what is that rho N cube Da to the power 5 into alpha square phi square by 2 into N cube where UBT to be written as phi N Da. So this is basically that after substitution of this Q and Ek value and Q already that you can calculate it from the flow number. And then this can be written in dimensionless form as P by rho N cube Da to the power 5 that will be equal to alpha square phi square by 2 into N cube. That means in the equation number 9 here this equation is basically written just it is in the dimensionless form by equation number 10 or this dimensionless component that is P by rho N cube Da to the power 5 this is dimensionless.

So here it will be denoted by NP it is called power number and this is basically then alpha square phi square by 2 into N cube. So this power number is basically a function of flow number N cube. NP is called the power number which is defined as then NP is equal to P by rho N cube Da to the power 5 like this here.

Here the Equation

$$\frac{P}{\rho n^3 D_a^5} = \frac{\alpha^2 \pi^2}{2} N_Q$$

So therefore power required to drive impeller in terms of as like this P will be is equal to NP rho N cube Da to the power 5. So this is power is equal to this is power number and flow number it will be coming as like this here this NP will be is equal to that means power number will be as a function of flow number.
Here the Equation

$$N_P = \frac{\alpha^2 \pi^2}{2} N_Q$$

So power total power as a function of power number. So total power consumption will be is equal to power number into rho N cube into Da to the power 5.

Here the Equation

$$N_P = \frac{P}{\rho n^3 D_a^5}$$

So for a standard 6 bladed turbine N cube will be is equal to 1.3 this N cube is equal to 1.3 and if alpha is taken as 0.

9 the power number NP will be is equal to 5.2. So this calculation that you have to understand. In this case also you have to remember some important notes that for low Reynolds number if you are operating that mixing in the vessel if there is a low Reynolds number the power number is inversely proportional to the Reynolds number and power number for both the baffled and unvabeled condition will be same that you have to remember. For higher Reynolds number if Reynolds number is greater than 10000 the power number will be independent of Reynolds number and viscosity will not be a factor. For a baffled tank for higher Reynolds number where Reynolds number is greater than 10000 mixing time factor is almost constant at a value of 5. Now the power number NP is analogous to a friction factor or a drag coefficient remember it is proportional to the ratio of the drag force acting on a unit area of the impeller and the inertial stress that is the flow of momentum associated to the bulk motion of the fluid.

Where this Reynolds number will be defined by this equation here N into DA square rho by mu

Here the Equation

$$= \frac{n D_a^2 \rho}{\mu}$$

and the friction factor which is related to that power number. So if there are more friction of course that power consumption will be more because they are that interfacial friction that means flow will give you the more friction between that wall of that vessel as well as baffles or other mechanical devices or impellers. So in that case this power number will be more and also there will be a some mixing time factor which will give you that intensity of the mixing based on that you know operational mode whether it is laminar flow or turbulent flow. So that mixing time factor is basically a function of that how long you are operating that mixing and also what will be the rotational speed also what is the geometry of that standard vessels. So this mixing time factor can be expressed by this equation from which you can easily calculate what will be the mixing time factor.

Let us do an example based on those theories here one problem as per GATE 2004 it is given like to keep the power input constant for a stirred vessel operating under fully developed turbulent flow conditions where constant power number will be there if the impeller diameter is decreased by 20 percent what the factor by which the impeller speed should be decreased. So basically in this case you have to calculate that factor of that rotational impeller speed there whatever it increased there. So here to keep the power input constant for a vessel operating under fully developed turbulent conditions. So first of all you consider that what will be the power number. So power number is defined as P by rho N cube by DA to the power 5 which will be constant.

So we can write P proportional to N cube DA to the power 5. So this will be here. So from this equation we can write initially what will be the impeller speed and what will be the diameter of that impeller and finally what will be the impeller speed and diameter of the impeller. So since this power number will be constant so we can have this value N 1 cube into DA 1 to the power 5 is equal to N 2 cube equal to DA to the power 5 from this equation. So given that here DA 2 is given the second case this diameter of the impeller is given that will be 1.

2 times of impeller diameter which is used earlier initially. So in this case if we do the ratio of this N 2 by N 1 then we are having here from this equation we are having DA 1 by DA to the power 5 by 3 where DA 1 by DA 2 is given in this equation. So ultimately 1 by 1.2 whole to the power 5 by 3.

So the impeller speed should be decreased 1.2 to the power 5 by 3. So this is the problem which we can solve like this. And then another problem here it is also given in 2006 GATE examination. Here it is said that the mixing of rubber and latex solution was studied in a un-baffled mixer in the laboratory. The mixer was equipped with a 6 blade turbine impeller.

A tyre company scales this process up using a baffle tank. Now the baffle tank has 3 times the diameter of the lab scale mixer. If uses the same type of impeller operated at the same speed then the relevant shape factors will also be same. So assuming that laminar conditions prevail both the cases what will be the power requirement in the industrial scale mixer. So basically that laboratory scale and industrial scale mixer is there. So in both the cases they told that the shape factors will be same and also same type of impeller to be used with the same speed.

And the baffle tank has 3 times the diameter of the lab scale mixer in industry. So in this case we can say that P proportional to N cube if diameter is same of that impeller so P proportional to N cube that means P1 by N1 cube that is equal to P2 by N2 cube. So P2 will be equal to P1 into N2 by N1 so P2 will be equal to P1 into 3 by 1 into speed is 3 times it is told that here 3 times baffle tank has 3 times of the diameter of the lab scale. And also we are having here then it will be then 3 times means here 27 times of P1. So power requirement in the industrial scale mixer will be 27 times that of the lab scale mixer.

So here company scales process of using baffle tank the baffle tank has 3 times the diameter of the lab scale mixer. actually 3 times of the rotation of the impeller. So that is why we are having this power requirement would be 20 times of this. Let us do another example here this is given in GATE 2008. Consider the scale up of a cylindrical vessel configured to have the standard geometry that is height is equal to diameter in order to maintain an equal rate of mixing under same power input per unit volume under turbulent conditions for a Newtonian fluid what would be the ratio of the agitator speed.

See here again that power number is P by rho N cube dA to the power 5 to be constant. So P proportional to N cube dA to the power 5 for the tank dA is given volume of the tank is V so V will be is equal to like this pi by 4 dA square into H that means V is proportional to dA to the power cube. So P by V will be is equal to proportional to N cube dA square. So according to the given condition the power input per unit volume will be constant.

So we can write here N cube dA square that will be is equal to constant. So we can write N1 cube dA 1 square that will be is equal to N2 cube dA2 square it will be N2 by N1 will be is equal to dA1 by dA2 whole to the power 2 by 3. So we are having this after substitution of those values here then it will be coming as N2 will be is equal to your 2.52. And then next problem is that it is given in 2019 gate examination. It is said that a disk turbine is used to steer a liquid in a baffle tank to design the agitator experiments are performed in a lab scale model with a turbine diameter of 0.

05 meter and a turbine impeller speed of 600 rpm. The liquid viscosity is 0.001 Pascal second while the liquid density is 1000 kg per meter cube. The actual applications has a turbine diameter of 0.5 meter and impeller speed of 600 rpm.

A liquid density is 0.1 Pascal second and a liquid density of 1000 kg per meter cube. If the power required in the lab scale model is P1 and the estimated power for the actual application is P2 then what is the ratio of P2 by P1. Here see two types of model we are having one is lab scale model and another is prototype model. In lab scale model it is given the diameter is 0.05 impeller speed is 600 rpm, liquid viscosity is 0.

001 Pascal second and liquid density is 1000 kg per meter cube. So Reynolds number will be like this 15 into 10 to the power 5 and prototype it is given diameter is 0.5 meter, impeller speed 600 rpm, liquid viscosity 0.1 Pascal second, liquid density is 1000 kg per meter cube and Reynolds number here again it will be that 15 into 10 to the power 5. So for Reynolds number if it is 10,000 then you can say that this power number will be constant as we have shown in the special note there that you have to remember. So in that case we are considering that here P1 by rho 1 N1 into dA 1 to the power 5 it will be is equal to P2 by rho 2 N2 cube into dA to the power 5.

So from this equation you can write this since this power number will be constant. Here in this case rho 1 and rho 2 are same and N1 and N2 are same. So finally you can say that P2 by P1 it will be is equal to dA2 by dA1 to the power 5 that will be is equal to then after substitution of dA2 and dA1 here we are getting 10 to the power 5. So P2 by P1 that means ratio of power number for prototype to that power number to the lab scale model it will be 10 to the power 5. Now since we are talking about that mixing time you will see that whenever the turbine will be rotating at a certain speed during that rotation of turbine for mixing at a turbulent condition it is said to be a complete mixing that means 99 percent completion of that mixing for that particular phases in the vessel.

And the fluid completes about 5 times circulation. So this is the basic concept. For such cases mixing time can be predicted by the following correlation for a standard 6 bladed turbine the correlation is given here it depends on that is diameter of the tube and diameter of the impeller. So mixing time that will be is equal to here 5 into V by Q that after substitution you will get this is the value and finally you can say that here after substitution of Q value you can get this or it can be written as NTT into dA by dt whole square into dt by ds that will be equal to constant that will be equal to 4.3.

Here the Equation(s)

$$t_T = \frac{5V}{q} = \frac{5\pi D_t^2 H}{4} \cdot \frac{1}{0.92 n D_a^3 \left(\frac{D_t}{D_a}\right)}$$

$$n t_T \left(\frac{D_a}{D_t}\right)^2 \left(\frac{D_t}{H}\right) = Constant \;=\; 4.3$$

So here in this graph it is shown that how that mixing time will be changing with respect to Reynolds number.

If you are increasing that turbulence then mixing time also will be decreasing. So according to that based on different geometry of that vessel you will get that different mixing time factor as a function of Reynolds number where this Reynolds number will be defined by this equation. Now let us do an example here also. Suppose a mixing vessel of 0.3 meter in diameter contains a 6 blade straight blade turbine 0.1 meter in diameter which will be set 1 impeller diameter above the vessel floor and rotating at a speed of 60 rpm.

In this case it is proposed to use this vessel for neutralizing a dilute aqueous solution of sodium hydroxide with a stoichiometrically equivalent quantity of concentrated nitric acid in that case the final depth of the liquid in the vessel is to be 0.3 meter. If all the acid is added in one time then how long will it take for complete neutralization density of the liquid is given and viscosity of the liquid is given. So in this case you have to find out what would be the TT value that means here how long it will take to complete mixing to get complete mixing. So here DT is given, DA is given, N is also given that means rotational speed is given Reynolds number then you can calculate it is coming 1 into 10 to the power 3 and since from the graph we are having the relationship NTT versus Reynolds number.

So here NTT you can calculate from this graph here if Reynolds number is 10 what is that 1 into 10 to the power 3 which will give you the corresponding value of NTT. So it will be coming as NTT at this Reynolds number as 100 from this figure. So from which you can calculate what will be the TT value.

So it is coming around 100 second. I think you understood this problem here. So based on this mixing time you can calculate how long it will be required to get the complete mixing of that solution in a vessel. In this case you have to calculate what will be the Reynolds number that means whether it is the laminar flow or turbulent flow that will give you based on the Reynolds number. Once you get this Reynolds number based on that Reynolds number you will be able to calculate what will be the mixing time factor and this mixing time factor can be obtained from this graph as shown in the slide. So I think you got this point. Now another important mechanism to get that mixing of this fluid element inside the vessel it is called draft tube.

This draft tube is a tube which is mounted around the impeller or mounted immediately above the turbine as shown in the picture here. So the direction and velocity of the flow to the suction of the impeller are to be controlled. This draft tubes are generally used and the device is useful when the high shear at the impeller itself is desired. As an example you can say for making certain type of emulsion with particles where solid particles tend to float at the surface of the liquid in the vessel are to be dispersed in the liquid. So for a given power input they reduce the rate of flow that is why this draft tube will be more effective to have that intense mixing of the fluid element where basically the certain type of emulsion with the particles are to be prepared.

So in this lecture then we learned here what is the standard design of that mixing vessel especially for the mixing of slurries, particles, liquid-liquid or immiscible liquids there and what are the basic components of that mixing vessel and how that mixing vessel components will give you the intense mixing based on that impeller speed also impeller geometry also that vessel geometry. The power number and flow number will be interrelated. This power can be calculated from this power number which is actually related to the flow number. How that power number is related or power how it is related to the geometry of the standard design of that vessel, very important. So you can easily design just by keeping that power number constant or using that special type of impeller based on the flow condition.

So I think you understood this concept of that fluid mixing in a vessel and also what is the standard design for that. So this module I think is enough and the next module we will try to discuss more about that solid-fluid operation. There on the next module we will start with that fluidization operation. In the next lecture then we will start with that basic understanding and application of the fluidization. Thank you.