

Chemical Engineering.
Professor K. Krishnaiah.
Department of Chemical Engineering.
Indian Institute of Technology, Madras.
Lecture-50.

Nonideal Flow and Residence Time Distribution (RTD) Basics Part 1.

Professor: Yesterday I gave you, I think a nice story like thing about residence time distributions, right. So what you have to remember is that the 1st basic thing, okay, that any equipment, when you are sending something inside and when it is coming out, definitely there will be different timings for different packet of molecules to come out. Okay, it need not be reactors, please remember that. It need not be, any equipment with flow, when something is not done, you can imagine because molecules are very very small, you cannot see them.

But you can imagine some molecules as packets of molecules and it will be continuous only, some packets will come early, some packets will come later but if it is ideal equipment, then you have a specified distribution. Right, so distribution means again I have to tell you, most of the people will switch off their brain, the moment we say distribution, right, I also asked you sometime back. Can you see what is the residence, I mean age distribution in the class approximately? 22 to...

Student: (())(1:29).

Professor: Okay, you mean the cameras, cameras also cannot be 65 years old, okay. Yah, so that is the one is distribution. So if I go into actual groups, then there may be many people between 22 to 23, 23 to 24, 24 to 25, 65 you will have only one point, okay. So when you join all of them, then you will have the distribution. And if it is ideal equipment, then you will have a specific distribution. Like we have seen about reactors that we have discussed. So far the flow reactor, there is a specific distribution, it goes to 0 to infinity but the distribution is exponential decay.

Okay, that is exponential, mathematically also we can prove that, later. That is exponential. And if I have ideal plugged flow reactor, we again have residence time distribution, theoretically speaking but the distribution equal to 0. So when I plot, everything will come at one point, that means all particles are exactly spending 10 seconds, so at the outlet when I plot 10 seconds, so all that will come together as 10 seconds. The entire batch of molecules which you are trying to imagine. So like that any batch, everybody will have exactly same 10

seconds. What we are focusing is only on certain batch when it is entering and how many of that is coming out.

Why? Because when the behaviour of that we know and we also assume that the behaviour of all other molecules continuously entering will be exactly the same, it should be same for a given flow rate, for given conditions, temperature and all. Right. And that is what is the meaning of residence time distributions, any equipment, and without knowing yourself, you have also assumed some distribution for distillation columns, heat exchangers and your absorption columns, any equipment or heat exchange, what is that, extraction columns or rotary kilns, rotary kilns, okay.

So all these things, definitely, rotary kiln can also be used as a dryer, not as a reactor I am talking. So that means, very, material with moisture will enter at one point, hot air will be sent opposite to that, so by the time it comes out, then it should be having whatever prescribed moisture what you have. Maybe 1 percent moisture, 0.1 percent moisture, like that. Right, so because you are familiar with distribution, I will ask a question, what is with the distribution we have assumed the distillation? Okay, to start with heat exchangers? Heat exchangers will come earlier than distillation and also heat exchangers, all of you are experts.

Correct no, that is one subject everyone will like, no, Anupriya says no. Temperature, I am talking about the molecules, particles, entering particles can go. You see you have designed many heat exchangers but still we do not know what is that we have assumed there. Zero distribution, that means what?

Student: (0)(4:45).

Professor: Why do say 0, I am not saying you are right or wrong, I am just asking.

Student: Constant velocity. Same residence time.

Professor: Did you assume same residence time in heat exchangers?

Student: We assumed constant velocity.

Professor: You assumed flat velocity profile. Right, so when the pipe is there like this and our fluid is going inside, coming out, then you send the cold fluid, maybe countercurrent, cocurrent, so in both the pipes, what you are assumed without you knowing is that it is plugged slow, given residence time distribution. Okay, then only you can now see that at any

cross-section, the heat going from, okay, hot fluid to cold fluid, you can exactly write. Otherwise now you imagine, there are also some problems with if you have laminar flow heat exchangers, pipe flow, your reaction design is totally different.

You cannot use the same heat transfer coefficients if you have laminar flow in the pipe. Did you use or you never designed with laminar flow? Different equations, why? It is mainly because of the distribution, which you do not know at that time. Okay, now very good, that is nice, okay. So without knowing yourself you are done that already, you are assuming that plugged flow for heat exchangers because normally we use small pipes, high velocities for better heat transfer, so that is the reason why we have assumed a plugged flow, which is nothing but RTD equal to 0, okay.

Distillation columns, absorption columns, Swami?

Student: (0)(6:29)

Professor: No, I am asking what is the distribution inside the equipment?

Student: Constant molar volume.

Professor: Constant molar volume is not distribution. Constant molar volume assumption is that one molecule will go this way, another mole will go the other way, that is all. So that there is no imbalance in the transfer. You see, see, really, you do not appreciate, I have to appreciate myself, because, yah, I am bringing out all those things which you know, I am only trying to bring out the ignorance from the people. It is not that I am saying I am, great wisdom I have come I also have my own equivalence but has a region I know where you can be ignorant, that is why I am trying to bring that out, okay.

One definition of group is dark, removal of darkness, darkness is equivalent to ignorance, okay. You have assumed that also, particularly for absorption. Now you have 1st of all 2 phases, right, if you talk about absorption, which is easy to understand. Right, gas will go from the bottom, liquid will come from the top and then components of the gas will go to the liquid. At any cross-section, what is the velocity profile you have assumed, when you are writing the 2 film theory equations? You have written no 2 film theory equations? Where is Ramakrishna? Ramakrishna, you have also never thought about this?

This is what someone was telling me when I went to Gunthoor to give a lecture. Sir, it seems that we have heard that you connect Reynolds number with plugged flow, we never knew Sir

how did you do that. I said how did do that, that is the minimum think what we should know, correct no. Because I think laminar flow can never be plugged flow, so laminar flow is associated with Reynolds number. So plugged flow also must be associated with Reynolds number. Any flow is associated with Reynolds number, did not only plugged flow, yah. Right, I think even Lyonsfield did not write the, that same thing what you have told in the class in his book because why should Lyonsfield right, because Lyonsfield thought that it is basic, obvious.

So he did not write. So but I do not think you know many obvious things are not obvious, many common sense is not common, so that is why I thought you know I have to bring that out. You see without knowing yourself again in this absorption, when you are writing the balance, you assumed plugged flow. It is not perfect mixing. Okay, now I can extend, I can extend many many things now, okay. Like extraction, okay, you can conduct extraction, extraction operation in a packet bed, right, so that means like fluid and from the top or, either, normal simple exchanger, sorry say simple extraction column where drops or send from the bottom to the top if they are lighter or otherwise is there heavy, from the top to the bottom.

One fundamental question you have to answer always is which phase you take as a dispersal phase. You have 2 phases no in extraction, both are liquids and one should be lighter and another should be heavier. So which one you choose as dispersed, both cannot be continuous. I both cannot be continuous?

Student: (())(10:09).

Professor: I am only talking you know chemical engineering.

Student: (())(10:14).

Professor: Yah, contact will be once stream like this, another stream like this. So you will have only contact at that interface, which is not much. So that is why you break one fellow into pieces and pieces and pieces, generate large amount of surface area and allow that want to flow. Anyway, that question you can answer later, I will keep on going in asking that question, which one will be dispersal phase. So you have that, when you have these 2, again you always take that, the bubbles are moving at a constant velocity, in fact you have small bubbles, bubbles, large bubbles will leave faster, small bubbles believe slower because velocity is square root of DBA , yah D , okay.

So that is what you have all that equation, but even that we assume that, at any cross-section you have again flat velocity profile, okay. That is about the column, now you may take, you know there are mixed settlers are also used as exchangers. What you do is, you take the stir tanks, stir tanks as heat exchangers, you come across that or only columns you design? Both the phase are taken into in one vessel and then stirred. When you are stirring, one phase should break up, right, okay. So you have to allow like that, that kind of stirring where only one phase will break up, that generates lot of drops, right and then after some time maybe depending on the process time, you have to calibrate how much time as that.

And after you feel that if it is already extraction is over, I am talking about batch system, then allow it to set in. So one of the components, either in the continuous phase, this continuous is not with respect to flow but with respect to not breaking dispersal phase. So one component may go from continuous phase to dispersal phase or maybe from dispersal phase to continuous phase, settle out. After settling, separate it out, sent for a distillation column and then take out because the component which has gone to that other phase, both should have some kind of difference in the boiling points, then you go to distillation columns and then separate it out.

Now when you talk about these tank extractors, what kind of residence time distribution you assume for batch 1st of all. Batch, what is the residence time distribution? 0, now I can also use this for continuous. Continuously I will send 2 phases, I will arrange my stirring such that one will break but both will come out again, both will come out. Now I have 2 phases, right, yah, so again, what kind of contacting pattern or what kind of residence time distribution your resume for this kind of tanks in series? And you do not put generally one, you will put one tank, another tank, another tank.

Because we know that, I already told you, you know I already told the answer, you assume here is perfect mixing. Perfect mixing means the distribution of the droplets. Now you have to work about 2 phases, right. Both phases will be in perfect mixing, that continuous phase as well as the droplets. So when you look at the droplets, some droplets may come early, some droplets may come late and the droplet which is commonly, if there is a solute which has to be transferred to that continuous phase, the amount transferred will be very very less because it has not stayed much time in the system, in the stirring, so then the other drop which has stayed more time, the solute would have would have transferred almost everything.

So that all that will go to the next tank, next tank, next tank. So that means without knowing yourself you have assumed all this, okay. But only for reactors we discuss this, because reactions may be more serious and you know if you have some kind of mixing and all that or residence time distribution is not 0 to infinity, someone like axial dispersion and all that, so then temperature effects may be different, right. You are not, whereas in mixed flow you will get only one temperature, good control over temperature. For plugged flow, you do not have good control of temperature, so that is a reason why I think probably RTD has been used here, okay.

Most of the time and no mass transfer teacher, the teacher who is teaching mass transfer we will never explain what is the distribution you have in this column. And even absorption column, I asked you, I told you flat velocity profile, this flat velocity profile again, 2 phases, have liquid phase as well as gas phase. Right, so is it logical to assume for both the phases has plugged flow? Yes, because liquid is just coming out all the way and gas is going up, right, gas is going up in the form of bubbles if I have only tank, otherwise I also have falling films, correct no.

So I will just spread my liquid as a film and then gas will be just moving, so beautifully liquid will fall as in plugged flow and gas also goes as plugged flow, then at any cross-section you have the flat velocity profile and you can write the equations, okay, so that is what. Now we have to extend the same concept here in residence time distribution for the reactors, 2 reactors we know, ideal distribution we have already discussed. Now we are going to discuss about nonideal flow. Actually this residence time distribution subtitle is nonideal flow. That is one, right, good.

So basically what we have to remember is that every equipment will have its own residence time distribution for the particles entering and then coming out, that is number 1. How do I find out this? I want to find out the residence time distribution of, if possible each and every molecule, that is not possible, so at least each and every particle, particle means it is only imagination, right. Okay, how do I do that? In fact the best thing is if you are able to identify each and every molecule and if you are able to really find out what is the time spent by each and every molecule, you map the entire molecules, then you know how each and every molecule is behaving inside the, I mean how much time it spends inside the reactor and what it has done, right.

I mean it will not give you what is it, to the black box arrangement, at least on the outside you will try to find out what it would have done inside the reactor. Like exactly, I told you know, sugar test when they do, they will only take sample, blood sample and then try to find out what could have been the reason why this kind of sugar content is coming in the blood, okay. So it is just doing back and then trying to find out, here also same thing. So that ideal situation is less, so because it is not, give it possible for as you know, in one mole how many molecules are there?

Student: () (17:23).

Professor: Yah, so I know most of us will not have any feeling for 23, 10 to the power 23. Even if someone says it is kind to the power 210, still we do not have any feeling because beyond you know 100 you do not have any feeling are maybe 1000 or maybe rich people, maybe lakh or 1 crore. Suddenly if you ask me, one crore any zeros means I cannot answer. At least 1 lakh, how many, 5, yah, so then of course the 2, 7, that means my reference is 1 lakh, then I add 2. So another 10 crores means another one, so like that it goes. So that is why the zeros are very difficult, beyond a certain point we do not have any feeling for the zeros, okay, remember zeros are very important, good.

So that is why we will not have any feeling for this 10 to the power of 3, 6.03, 6.03 into 10 to the power of 23 molecules in just one. How many moles you will be sending into the reactor? How do you get that information, impossible. So that is why at least you know the Tracer tests where you can send some kind of Tracer along with the normal fluid, Tracer is nothing but something which can be identified, that is all. In the blood also they will give you suddenly more sugar, okay, so then, that batch of sugar how it comes, how it is absorbed by the flow of the blood inside the body, so then only we will try to interpret.

In fact it is very very surprising, it is not the engineers 1st who found the residence time distribution. Name is given by chemical engineers, but the 1st person who had used to this technique was a doctor. You have to appreciate, you know there is no limit for the human brain, if human brain wants to think. That is what, thinking is very important, we never think, the only writings examinations, that is all, we never think. Surprising no, that too I think in 1700 or 1800, have that exact reference, he is the person. And you also know that who was the 1st person to write the material and energy balances? Can you guess? Gopi?

Gopi, I thought Encyclopaedia Britannica. () (19:48), okay, any idea?

Student: ()(19:53).

Professor: No, he is again doctor, medical doctor from Britain to I think Thailand or Indonesia, he was travelling... Who?

Student: ()(20:07).

Professor: Langer?

Student: ()(20:08).

Professor: I do not remember the name but I have that, I have written somewhere. But you know that doctor, he wanted to find out how much energy is lost by humans when he was travelling from England which is a freezer and Indonesia which is a burner. Correct no? Because I think here the temperatures are very very high because it is almost near the equator and there I think, of course here is not come from Siberia, at least only England but still it is cold. So I think they were not able to do already stand of heat when they are travelling by boats. I think it had happened, it has happened again in 1700 or 1800.

So he wanted to systematically, people say that he made some mistakes but it does not matter, the concept, the concept itself you know to find out material energy balance, that means he will give water 2 litres and then how much will come out through sweat because maybe wait he may be taking or through, you know other urination and all that. So total amount he has to balance, that is mass balance. And energy, energy I do not know how he managed but I think you know energy, depending on his activity, how actively he is moving. If you do not have energy, you will just sit down no, you cannot do anything.

That is what most of you do, this generation does not have energy, okay, they have only mass. And they are not able to convert this mass into energy, $E = mc^2$, they are not able to do it. So that is if you are able to convert some of it, it will be excellent. Okay, so that is why I think it is excellent no, wonderful, these things to hear wonderful, I appreciate all this, I enjoy also telling others this because I always appreciate the human brain. I mean I do not have that kind of mind but at least appreciate, you know the other great minds.

So something you would always they will try to find out and Einstein brain I say, I think you know, physically if you look at it, all the brains are same but what has really happened, how he could imagine this theory of relativity when no one could imagine. Even now we cannot imagine, even now we do not know, we just read and we know only than $E = mc^2$

Square without feeling again. I told you know, anything we should have feeling, then only you will be good, right, otherwise I think without feeling it is waste. So that is what we will do, but you know how imagination that, even now I have asked many people why you should assume that the velocity of light is constant in the universe?

How he got the 1st of all that idea? Correct no, I think many people trying to now prove that was wrong, right, he was not wrong. I think again recently also one experiment, the experiment was wrong, not Einstein was wrong. So that kind of brain how he got and another great brain is our Harris. How he is able to think so many steps in you know before writing the final step, he writes that, I think, he also had excellent brains, Ramanujan. You know mathematician, how come I think he gives the problem and gives the solution, in between I think people are spending last 50 years, 6 years, 70 years to find out what are the steps in between, really.

How come I know, Ramanujan it seems when people asked how are you able to do it, in Cambridge University when he went, Cambridge no?

Student: (())(23:27).

Professor: There were sufficient notebooks even at that time. Yes, slate is convenient at that time because he was not confident whether you know he was right or wrong, that is why he is right and then...

Student: He derives on the slate and writes on the paper.

Professor: Yah, but I think you know it is not paper shortage, definitely, so...

Student: His calculation methodology was different.

Professor: Yah, see, the neural network inside is totally different, our neural network is totally different, right, because that is the reason why he is able to simply write and then when someone ask I think I told, Cambridge only event no, do not remember, yah. Yah, that University, he was, he was invited by that Hardy and then when he asked him, ha simply told I do not know how I am writing but goddess of Namakan, Namakan is a place no? Goddess, which goddess is that, Durga or something, he says that she is giving me all these solutions. That is the greatness of that man you know, he never thought that my brain is great, so I am imagining all that, you all are stupid people, so that kind of thing in ever had.

He was just attaching that because God had given me that thing, that kind of brain, I do not know whether he is aware of his brain. Right, so that is why I am able to write all these equations, final solutions. So I mean when compared to all that, what are we doing here? Correct no, Abdul, what we really doing here? Nothing no? Nothing. I think you know the same assignment which I have been given also no one is doing it. And all those problems I think if you look carefully in different books, most of the services are available somewhere or other, even searching we are not doing and we joined as research scholars, search and research no.

Okay, 1st you have to search, afterwards only researched. We are not even doing that research, I am in 1st search, so that is the reason why these brains you have to really appreciate, okay, this RTD also, that doctor doing it is really fantastic and afterwards I think Langer use it, it seems, not RTD directly, some boundary conditions and Dan Quartz used it so beautifully and popularised. Like Lyonsfield popularised reaction engineering, before that also there were few books, you know Wallace book was there and the other 3 books what you have, Auger Watson. Auger Watson, 3 books, 3rd book was, 3rd book is Dan adding, so those 2 books, but I think not much appreciation was there, yah Smith book was there before before Lyonsfield.

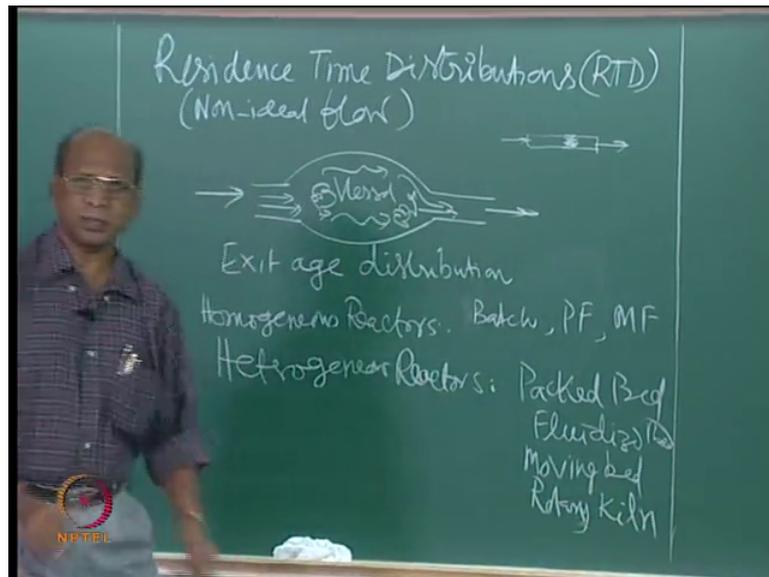
But Lyonsfield popularised it because that is the greatness of presentation, okay, so that is why, so I think they have done anyway. So now going back to residence time distributions, somehow we have to try to find out if it is possible each and every molecule, it is not possible, so at least packet of molecules. That is why we do this Tracer test, right. So these few lines I think you have to take, otherwise I am sure, you know you just forget, right, very happily you will forget. So that is why you, we do not have an ideal reactor because we do not know whether to the ideal not, we have to find out whether it is ideal or not.

Like you have A going to R, what is a lot of reaction, we do not. So unless we do experiments and try to find out, yes it is first-order, because I am getting from the data only first-order, then you can say it is first-order or elementary reaction, okay. Similarly even here, residence time distributions, you know all equipments will have residence time distribution but I do not know what kind of residence time distribution there. So if I have plugged flow, if I want to have plugged flow, then I define my residence time distribution in this way. If I have perfect mixed flow, then I will define my residence time distribution in this way.

What is the importance of defining this residence time distribution? To calculate conversions. If I know that in plugged flow, each and every molecules spending exactly same time per

packet of molecules spending exactly same time, the conversion in that is uniform. And all molecules will have exactly same conversion, so when I average at the outlet, I will have exactly same conversion. On the other if I have you mixed flow, there are some packets which are coming earlier and which are coming late. But the overall conversion is, the average of all the packets which I see at the outlet, that is what is the concept, right.

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So that is why the name is given perfect mixing but the actual thing that is happening is the residence time distribution. Again name is given plugged flow but what is actually happening is that each and every molecule coming exactly at the same time. So that is how disconnected, so that is why all, you know, Lyonsfield writes something like this, this will differentiate between ideal PFR, ideal PFR means always you write like this no, okay, mixed flow means we write the other way. So to distinguish there, he says that simply, kind of reactor there, any weather, so then something is entering, constant flow, something is coming out, constant flow.

And let us imagine that there is no reaction 1st in the, we are only worried right now about the flow, okay, either plugged flow or mixed flow, then we will extend that to one or 2 reactors, okay. So then this is the kind of vessel we have, so some may move like this, some may move like this, some may move like this, complicated flows. So, some may move like this and then finally everything has to come out, okay, everything is to come out. And if it is ideal plugged flow, I know how will they come, right. Right about we are not talking about them, in general. This is a kind of thing, so now just please take this.

In any vessel, I am not telling about reactor at all. In any vessel, different molecules or packet of molecules spend a different times under steady-state condition. We are talking about only steady-state conditions, under steady-state, flow conditions. How these particles are coming out of the vessel is an important parameter to be considered for the design, okay, to be considered for the design, yah, okay. Then you can continue, next para you can write, let us assume that each fluid particle, let us assume that each fluid particle is equipped with a timer that is activated when it enters the vessel and stops when it exits.

The vessel has only one exit and one entry, that is your subject, okay. So then each particle at the exit has a time t associated with it, which measures, which measures the time, which measure the time it spent in the reactor, spent in the reactor. This quantity is defined as the residence time of that particle, the distribution of the times is called residence time distribution. Since we are measuring this distribution at the exit, it is called what, exit age distribution, exit age distribution, okay, and you know, normally, it is E_t is, okay, symbol wise.

Exit age dissolution, no, sorry, I think it is, exit age distribution and the function representing this distribution, equation, the function representing this equation is called exit age distribution function, you have equation for that, for any vessel you have equation. It is called exit age dissolution function, E_t , E_t is a function, okay, good. So this is the one, I think you know other definitions will come, you know cumulative and all that will come later but this is the one. But here I have to just come I think have to go for the definition and all that now but I have to tell you here, each vessel may have more than one phase.

It is not that you have only single phase, flow is only single phase, it can be 2 phases and we have 3 phases, most of the time for reactors. So that is why for each phase is associate, it says is associated with an exit age distribution function, you come I think you can write that, usually in chemical engineering equipment more than one is involved. Right, and each phase have its own residence time distribution and its function, E_t , okay. Few examples are given here, I think that we will discuss quickly and then we can go to the definitions, then roll you a lot forget.

That means if I, without telling that if I go to only definitions and all that, you always think that you are talking about single phase. No, we are talking about general, any one. If I have 2, 3 phases in slurry reactors, each phase I have to now find out, how it is moving, what results distribution there. If I say that one phase in mixed flow reactor as not mixed flow reactor,

slurry reactor has 0 distribution, what do you imagine them, how it is flowing? It is flowing in plugged flow condition, okay. So if I say that okay another phase in the slurry reactor is with 0 to infinity distribution but exponential distribution.

So then you have to say that it is perfectly, perfectly mixed distribution, okay, perfectly mixed flow. That is why each phase is associated with that. The simplest one what you take is of course, homogenous, homogenous reactors. Okay, PF, no, batch, PF and MF, mixed flow reactors. Right. So what is the distribution here, by definition, because you have already done that, so this batch is not valid at all for us because we are not allowing the particles to move out, so that is why there is no distribution because of the particles which entered, which I am pouring, take out at a particular time, so that they will have exactly same time, so that is why distribution equal to 0.

PF, by definition again here and also PF single phase, homogenous reactors and here also I have only single phase, here also I have single phase PF, and that means specifically in homogenous reactors, PF, ideal plugged flow will have one and flat velocity profile. You are also, one and exponential decay, 0 to infinity. Right, so that is how, what we define. But the moment I go to homogenous reactors nonideal reactors, homogenous nonideal, right, so this is okay because if it is not nonideal, then again definitely reaction rate will not be that good because at any instant of time, throughout the reactor I should have same rate and if I do not provide that kind of mixing, somewhere low concentration, someone high concentration, you will have different rates, different places, it is not easy to solve that problem, that is why we design a pattern mixes and then try to solve the problem.

But here I do not have that in my control, it depends on the flow, right. And by mistake all the time many students also think that, I think one of my students, Krishna sent a mail saying that it seems even to some place for some interview for something, he asked same question, whether laminar flow is plugged flow. Not selection, what is that, lab exam. So then he wrote Sir entire, all the people in the lab were telling only laminar flow is beautiful plugged flow. Okay, so mission has not gone throughout the country (())(36:37). Okay, yah.

So that is why, he just sent me 2 days back that male. Because some of us formed a group to propagate this kind of concept outside, okay. Yah, even Jesus Christ used to call people, disciples just to go and then propagate entire good things across. I mean every religious, that big man will always have people like these, okay, just to go and to tell that this is my guru is telling, so this is true, follow, follow, follow, so like that. So that is why here if I have plugged

flow, sorry if I have laminar flow, definitely the distribution is different. Ideal plugged flow exhibition equal to 0, what kind of distribution you get for laminar flow?

By mistake you assume that laminar flow is the plugged flow, right but in laminar flow all the molecules are coming at thing that you the same time, definitely not. So that is why any also no, because fluid dynamics is very clear for laminar flow, one particle will come with the sitting on the top of tip of that profile, at the centrepoint, so that will come the fastest, that means that will spend the minimum time. So we know that this T bar by 2, from then onwards, average no. Yah, for maximum, yah, yah, T bar by 2 only spent but I think that comes a maximum velocity, okay. Tell us that is the time it spends, I am talking about in terms of times.

And what is the other extreme? The 1st particle what you see is at time T equal to T bar by 2, that means 10 minutes if you put, 5 minutes later you can see that, before that it will outcome, if it is ideal laminar flow, afterwards till what time it comes? Till infinity, why infinity? You have to give the reason. .

Student: (())(38:27).

Professor: So particles, why do they go?

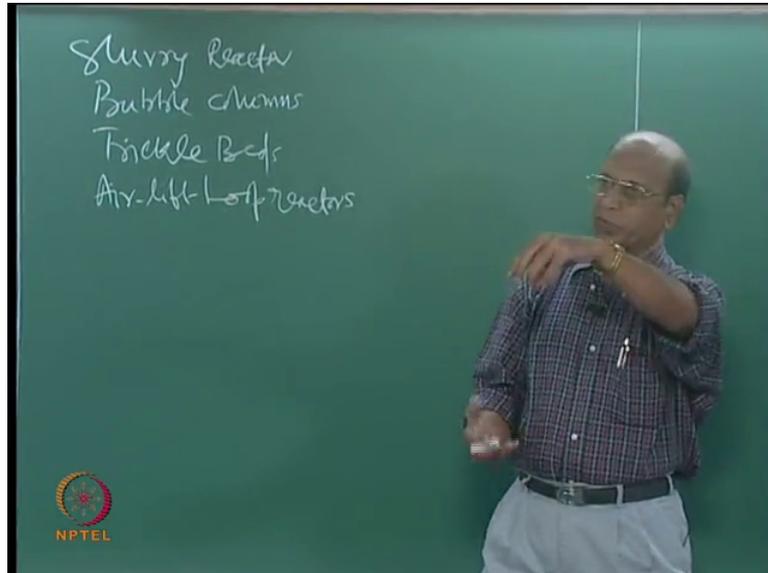
Student: (())(38:31).

Professor: Near the wall velocity equal to 0. And a lot equal to 0, it cannot move, so it takes infinite time. Okay, few particles, right, yah. So that is why changes now from T bar by 2, at T bar by 2, yah, T bar by 2 to infinity. But this is not the same distribution that has mixed flow where that is 0 to infinity but the function is different, that is exponential decay, this is some other function which you will derive at some time, okay. So that is why, so mixed flow of course, we know ideal, I think, okay, good. So the moment I go for, we from mixed flow, plugged flow, ideal plugged slow, then I have nonideal flow like, even laminar flow is a nonideal flow with respect to plugged flow.

Correct no, ideal flow is 0, 0 distribution but I have distribution, so that cannot be plugged flow. Right, and also as I told you, axial mixing, so particles will be going like this, like this, right, like that Tirupati queue I told you, people going and pushing backward, forward, there is a dispersion job inside that queue. So those people will be moving backward forward backward forward like that. So that is very bad for conversion because a molecule already

converted will come and join with other molecule which is this fresh, fresh means in that zone, okay. So that is why that will reduce the concentration, that will reduce the conversion, that is why, that is nonideal.

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Good, so like this. Now heterogeneous reactions, heterogeneous reactors, yah, reactors we have, the easiest one packet bed, we have fluidised bed and we have moving bed, we have rotary kiln and how many other reactors you know? Yah, still further, bubble column, that is gas liquid system. Very good, yah.

Student: Trickle bed reactor.

Professor: Trickle bed, very good. Yah.

Student: Air lift loop reactors.

Professor: Yah, you can, you have many, airlift... What is this loop?

Student: That is the name of the reactor.

Professor: Air loop reactors, yah, that is true, it is there, yah. Still? Savita?

Student: Biot towers.

Professor: Biot towers means what you have inside?

Student: Cells and...

Professor: Cells and then how the flow is going, is there gas flowing inside that?

Student: Gas from top to bottom and liquid...

Professor: Yah, that is bubble column. Okay, that is bubble column but you have solid particles, I think microorganisms can be treated as particles sometimes. So then if you are considering them as 3 phases, then you have particles in the form of microorganisms, then you have gas and then you have liquid. So that also will be equivalent to slurry reactors.

Student: (())(41:57).

Professor: Yah, pulse should come, reactors am asking. Yah?

Student: Residence time... Breeder reactor.

Professor: Which reactor?

Student: Breeder reactor.

Professor: Those are nuclear. You know the bad thing with nuclear is there is mass generated and all that, we cannot do anything. Okay, those reactors are not considered, nuclear reactors are separate, okay. So that is, okay, these are the things. Now how many phases are here? 2. How many phases are here?

Student: 2.

Professor: 2, and I think we also have three-phase fluidised bed, okay. And here moving bed?

Student: 2.

Professor: okay and rotary kiln?

Student: 2.

Professor: And slurry?

Student: 3.

Professor: 3, yah, and bubble columns?

Student: 2.

Professor: Trickle?

Student: 2.

Professor: Trickle 3. Yah, packing and then putting the liquid and then sending gas but in the cocurrent direction. Yah, again, how many of these things are cocurrent, how many of these things are countercurrent? Packet beds?

Student: Counter.

Professor: Does not matter because in packet bed, solids are fine, whether send from bottom or top, no problem. You should have people like that no, absolutely no problem, you do not have to worry. Fluidised bed?

Student: No. Not possible. Cocurrent. (43:20).

Professor: Yah, actually there is no current. Because that is you know the solid solid mixed flow condition and only you can say plugged flow for the gas but again big question mark, which is right, which is wrong, you have to wait till next semester to find out what is the actual flow in fluidised bed. It is very complicated reactor, very complicated. So the moment you go bigger and bigger, more complications will come into picture. So, okay, so then again moving bed, simplest one, okay, allow the packing to move automatically goes to moving bed, okay, this packing which is stationary, put a hole and then try to remove some solids and also feed correspondingly from the top.

So here it can be again, cocurrent, countercurrent. Rotary kiln can be cocurrent, countercurrent, slurry reactor because whenever you have mixing, you cannot say switch current, cocurrent or countercurrent because distance does not matter no, space will dissolve there. Correct, because there is no variation in space, yah. So then bubble columns.

Student: Co... (44:26).

Professor: You can operate both, you can also send liquid from the top and then bubble through and you can also send both from the bottom but I think the reverse is not possible, okay. So then I think lift the entire liquid, that is lift, okay, yah, your lift reactor you were telling. So then again take the liquid and again, that is what is loop, that liquid will come out right, that is what is the meaning of that loop. Then trickle bed reactors, trickle bed reactors, gas and liquid can be, no, trickle bed is always cocurrent, always cocurrent, okay. Gas is sent from the top and liquid is also sent from the top.

That is what is the definition of trickle bed, if you want to operate, you can operate like three-phase countercurrent, packet bed, like absorption also. There is from the top, to the packet bed, solids are there already packing, then you can also send gas from the bottom, that can be operated. But definition of trickle bed reactor is what coming from the top. Okay, again, excellent design things are available for trickle bed reactor because inside if you go there are many many many things are happening in trickle bed. In fact all these things I think fluidised bed and trickle bed are very difficult to decide, okay.

But what I am trying to tell you is that now for each phase you have to find out whether it is an ideal plugged flow or ideal mixed flow. That means 0 distribution or 0 to infinite exponential decay distribution, right. So that is why tomorrow I will spend some time, we take some, 2, 3 columns and then I will ask you how the flow is taking place and what kind of assumption we can make. Whether 0 to 0 distribution or 0 to infinite distribution, okay.