Chemical Reaction Engineering II
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Lecture - 30
Distribution of residence time

Friends, starting from this lecture for the rest of the course, we will be looking at the non ideal reactors, how to characterize non ideality in reactors.

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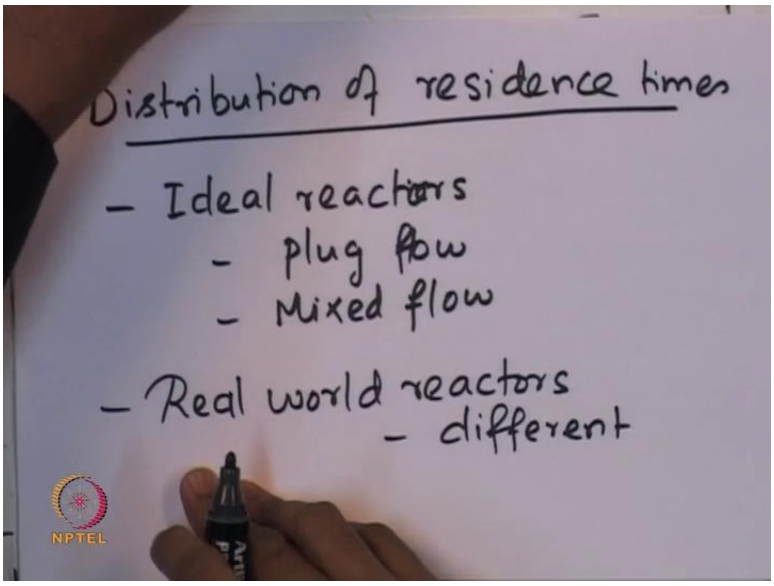

Distribution of residence times

- Ideal reactors
  - plug flow
  - Mixed flow
- Real world reactors
  - different

So, in this for this, we will be particularly looking at the distribution of residence time for chemical reactors. Particularly we are looking at the distribution of residence time. Now, it turns out, that the ideal reactors, that is the all the reactors that we have looked at so far they are all ideal reactors. That is the plug flow and the mixed flow reactors. These are all ideal reactors and it turns out that the real world reactors; they really do not behave like the plug flow or the mixed flow reactors.

So, the real world reactors are slightly different. Real world reactors; they behave differently. And it is actually important to diagnose and understand when they deviate from ideal behavior. So, we have seen how to write performance equations for ideal reactors, like plug flow reactors or under mixed conditions. And we have also know, how to write performance equation for CSTR which is not necessarily an ideal situation. We will see what is meant by ideal situation and how where does CSTR fall into that category.

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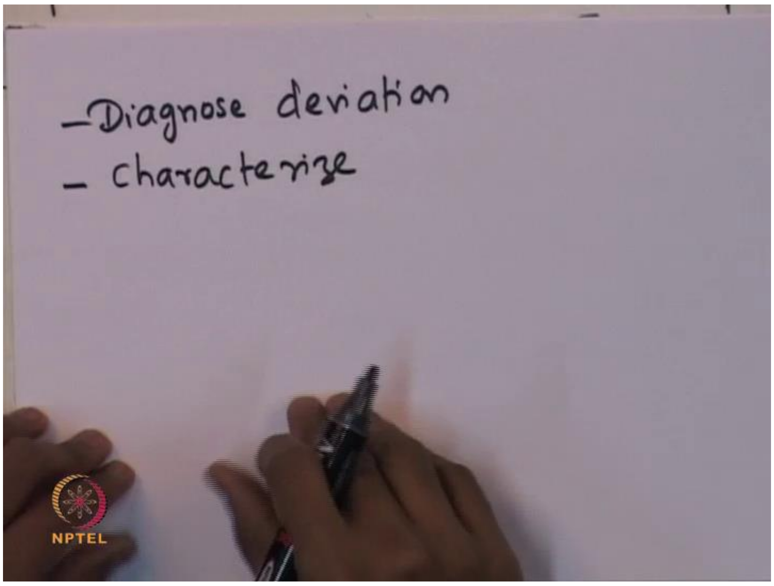
–Diagnose deviation
– characterize

So, it is important to diagnose the deviation from the ideal behavior. So, suppose if there is a reactor, if I assume that is it is a plug flow reactor. And I write a performance equation and I find out what is the a concentration profile of the reactant let say and the effluent, that is after when the stream leaves the reactor. Now the real world reactor perhaps may not attain that kind of a conversion. And so the way and that sought of indicates, that the reactor does not behave like a plug flow reactor.

So, now the question is; how do I diagnose such kind of a deviation? Now suppose, if I have diagnose that such kind of a deviation and how do I characterize, such a reactor which does not behave like the ideal reactor, such as the plug flow and the mixed flow reactors.

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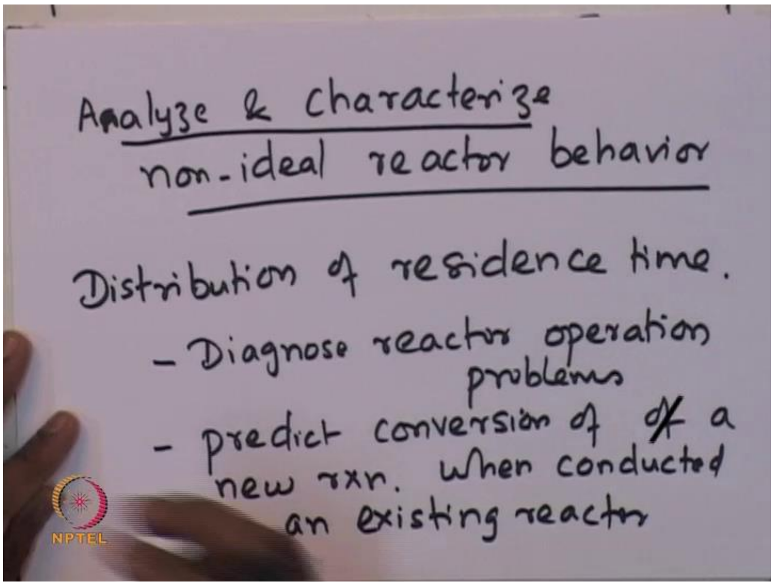

Analyze & Characterize non-ideal reactor behavior

Distribution of residence time.

- Diagnose reactor operation problems
- predict conversion of ~~of~~ a new rxn. when conducted an existing reactor

So, the objective of the rest of the syllabus of the course, is basically it will look at analyze and characterize non ideal reactor behavior. So, that is going to be the objective for the rest of the course. So, now the key piece of information; that is actually used in order to analyze and characterize non ideal reactor behavior is; the distribution of residence time. Residence time distribution of a reactor quantifies the time spent by various fluid particles in the reactor and is a characteristic of mixing that occurs in the reactor.

So, in the rest of this lecture, we are going to look at several examples of non ideal behavior that has been observed excrementally or observed in real systems. And also look at some of the definitions, of what is a residence time and what are the different ways to capture the residence time distribution etcetera. So, that is going to be the objective of this particular lecture.

So, the distribution of the residence time is actually used to diagnose the reactor operation problems. It is also used to predict conversion of a new reaction, when conducted in an existing reactor. So, these 2 are important aspects. If suppose, if there is a reactor that is already being characterized, now if you want to conduct a new reaction in that reactor, is it possible to predict the behavior of that particular reaction in that reactor?

So, that is an important question. And in addition to that, suppose if there is an experiment that is being conducted in a small scale and then we want to scale it up to a next level to increase the productivity of that particular product which is desired, then it is important to actually characterize the non ideal behavior and it helps in scaling up the reactors.

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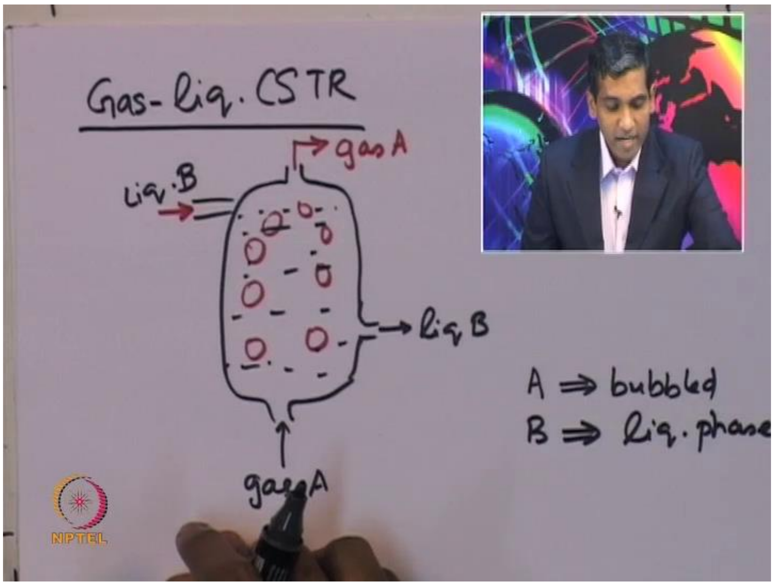

So, let us look at a specific case of gas liquid CSTR. Suppose, I take a tank and let us say that the gas A is being bubbled through the liquid. So, let us say that the liquid is filled; let say that tank is filled with liquid. And bubble A is actually bubbled through this liquid inside and then it leaves the reactor from the top, so that is gas A which is actually entering from the bottom and it is being bubbled inside and then it leaves from the top of the reactor.

Now, suppose there is another, there is a liquid B which is now flowing through this reactor. It is now flowing through this reactor and the gas is simultaneously bubbled through this liquid, so the liquid leaves from the exit stream for the liquid. So, now so A species A is actually being bubbled and species B is actually the liquid phase which is going through the reactor.

So, now, one can actually realize that, there are 3 processes which are actually occurring here. So, remember this is a gas liquid reactor. So, the reaction is actually occurring between the species A which is in the gas phase.

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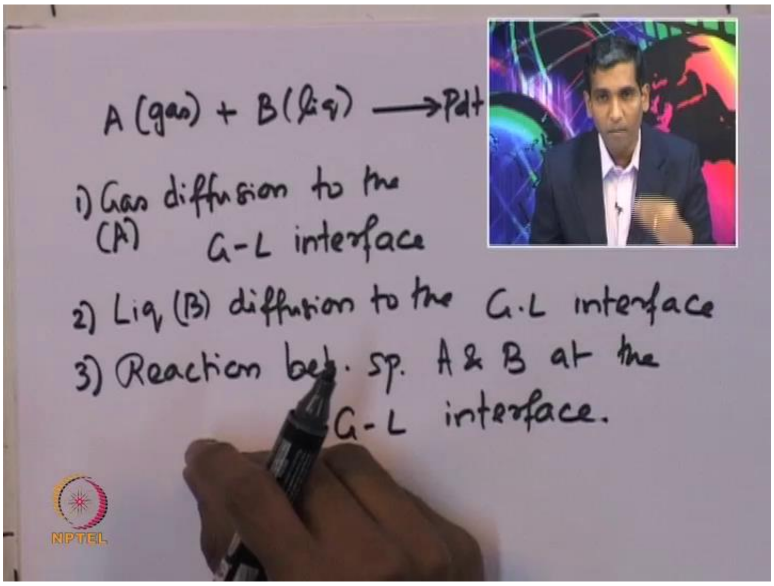

$A(\text{gas}) + B(\text{liq}) \longrightarrow \text{Pdt}$

1) Gas (A) diffusion to the G-L interface

2) Liq (B) diffusion to the G-L interface

3) Reaction bet. sp. A & B at the G-L interface.

The reaction is between species A in the gas phase and species B in the liquid phase and that is leads to formation of certain products. So, now, if this reaction has to happen, the species A which is present in the gas phase has to diffuse and come to the interface between the liquid and the gas stream. So, the first process is the gas diffusion to the gas liquid interface.

Now, suppose I assume that the gas is immiscible in the liquid, then the reaction has to occur at the gas liquid interface. So, there is an interface between the gas stream, which is present inside the bubbles and their fluid stream which is actually present around the bubbles. And so therefore the gas species has to diffuse from the bulk inside the bubble to the gas liquid interface, in order for it to get in contact with the liquid, if it with which it has to react. And similarly, so this is basically diffusion of species A.

Similarly, the species B has to actually undergo diffusion, there should has to be a diffusion of species B to the gas liquid interface. So, only after these 2 processes are have occurred, the reaction between these 2 species can occur. So, therefore, the third step is the reaction between species A and species B at the gas liquid interface. It has been assumed that the reaction occurs at the interface. However, reaction need not be confined to the interface, as per the cases that were covered in lecture 26.

So, these are the 3 processes which are actually occurring, in order for the reaction to actually occur. Now, suppose we can assume that the liquid which is actually flowing from the top of the tank. So, as if you look at the tank again, so the liquid which is actually flowing from the top of the tank through the tank and leaves the bottom of the liquid. So, this is, this can be assumed as a continuous liquid phase.

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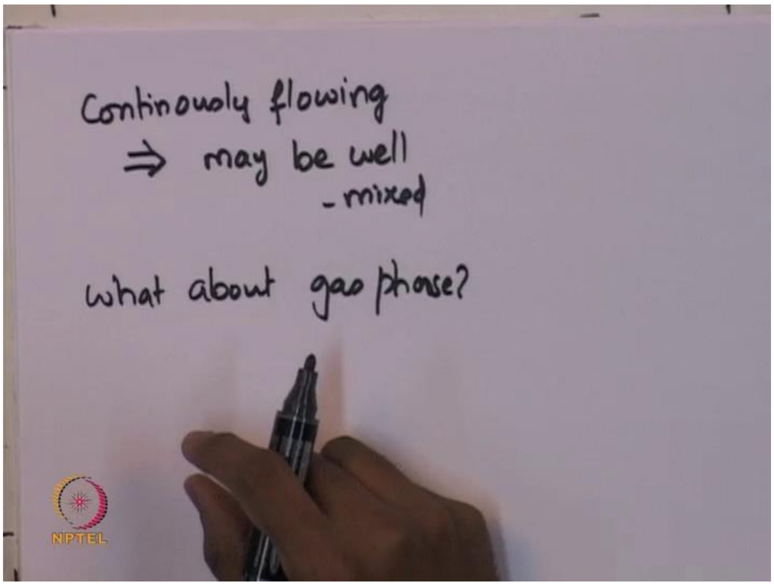

Continously flowing
⇒ may be well
-mixed

what about gas phase?

So, we can assume that the liquid is actually a continuous phase. So, the liquid is actually continuously flowing. And in fact, if perhaps it can also be assumed that, it is well mixed. It can be assumed that, it may be well… That is the concentration of the species in the liquid phase, is almost uniform inside the reactor. Now, that is not really true, but maybe we can assume for the time being, that it is well mixed, in order to actually appreciate what is happening inside the gas liquid CSTR and particularly in order in order to appreciate the nature of the non ideal behavior.

Although in reality, even the liquid phase will not necessarily be well mixed. But, if it is a continuous phase and it may be assume to be well mixed for the time being. So, the question is what about gas phase? In fact, comparing gas phase, the liquid phase can actually easily be assumed as a well mixed phase. Now, what about gas phase? Before we understand what happens in the gas phase, let us try to actually understand, how the, what are the different properties that actually control the reaction rate. In fact, it is that which gives an insight as to what is the nature of the fluid flow in the gas phase.

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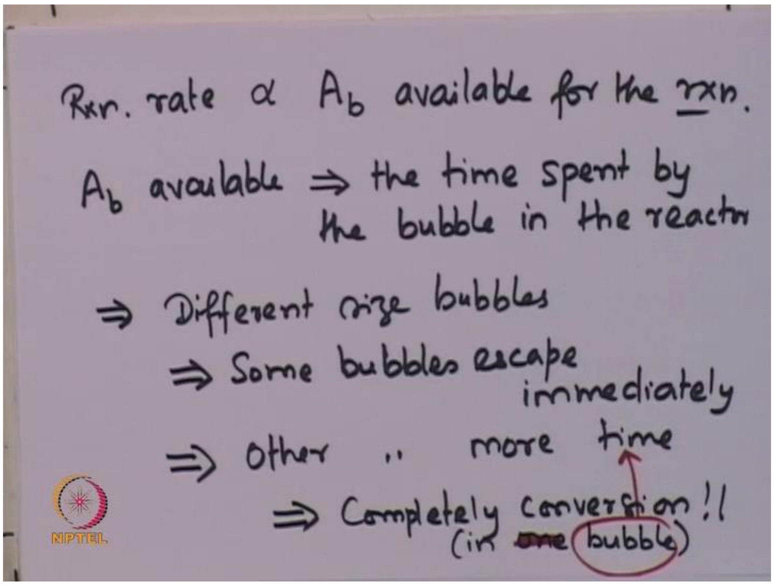

Rxn. rate α A_b available for the rxn.

A_b available ⇒ the time spent by the bubble in the reactor

⇒ Different size bubbles

⇒ Some bubbles escape immediately

⇒ other ,, more time

⇒ Completely conversion !!
(in ~~one~~ bubble)

So, the reaction rate is actually proportional to the surface area. Suppose A b is the surface area of a particular bubble. So, remember that, the gas which is actually flowing from the bottom to and leaves the top of the reactor, is actually bubbled inside. So, it forms bubbles and then the bubbles raise inside the liquid stream. And then while traces the reaction occurs in the gas liquid interface and then the bubble leave the reactor. So, the reaction rate is actually proportional to the surface area of the bubble, which is available for reaction. It is the surface area of the bubble which is actually available for the reaction to occur.

Now, the surface area of the bubble which is available for the reaction, what does it depend upon. It actually depends upon the amount of time that the bubble actually spends inside the reactor. So, therefore, the surface area of the bubble available … So, remember it is not the surface area, just the surface area of the bubble, it is the surface area of the bubble which is available for the reaction to occur, when the bubble is actually raising from the bottom to the top of the reactor. And that depends upon the time spent.

So, that is that depends upon the amount of time that the bubble actually spends inside the reactor. So, there are the gas bubbles when it is actually generated, when it is parged into the liquid, they are generally not of same size. So, different gas bubbles are going to be of different sizes. So, therefore, so different size bubbles, 1 can expect different size bubbles to be created and these different sizes are actually simultaneously they are raising up. And because that is the bubbles are of different sizes, different bubbles are going to raise at different velocities.

So, therefore, clearly some bubbles may actually escape immediately. So, some bubbles actually they will escape which means; as soon as they are created, they will quickly go to the top of the liquid stream and then they will leave the reactor. And so, the amount of time that these bubbles would have spent which have left immediately, will be extremely small.

Now, others might spend more time. Other bubbles may spend more time inside the reactor. And as a result of this, the amount of species which is present in the gas phase, can actually get completely consumed, because the bubble is now spending sufficient time inside the reactor, for all of the reactant to actually diffuse from the gas phase and reach the gas liquid interface and actually contact the liquid phase species in the liquid phase and the reaction to occur.

So, therefore, some of these bubbles complete gets completely converted. So, the gas species present in some of these bubbles gets completely converted. So, there can be complete conversion or complete consumption of all the species in each of these bubbles. So, when I say complete conversion, it means that in 1 bubble, which actually spends more time inside the reactor or in the bubble which actually spends more time inside the sufficiently time inside the reactor. So, that is what is meant by complete conversion in that particular bubble.

So, now, as a result of this observation, that different bubbles spend different amount of time inside the reactor and that some bubbles actually leave immediately and some bubbles actually spend more time in order for all the reactants present inside that bubble, to have undergone reaction or to get consumed.

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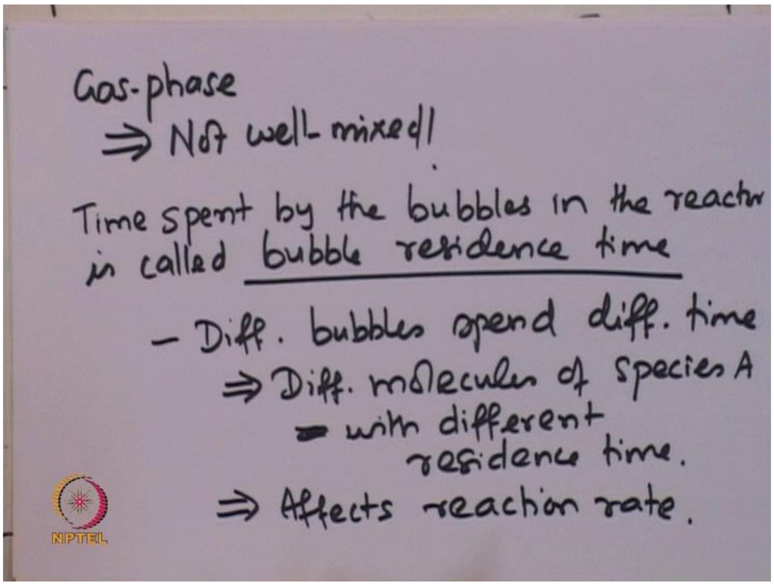

Gas-phase
⇒ Not well-mixed!

Time spent by the bubbles in the reactor is called bubble residence time

– Diff. bubbles spend diff. time
⇒ Diff. molecules of species A
– with different residence time.
⇒ Affects reaction rate.

The gas phase cannot be assumed as well mixed, cannot be considered as well mixed. So, therefore, it is important to consider the amount of time spent by the bubble inside the reactor, while designing these kinds of gas liquid CSTR's. So, just to define time spent by the bubbles in the reactor is called bubble residence time. That is the amount of time spent by bubble inside the reactor. Now as observed earlier, different bubbles spend different time inside the reactor. And therefore, different molecules of species A will have with different residence time.

So, different molecules of species A, although all of them would have actually come in to the reactor at the same time, because of this feature that different bubbles spend different amount of time inside the reactor, different molecules of species here would also have different residence time. So, clearly this is going to affect the reaction rate. It is important to note that RTD effects the conversion, but does not affect the intrinsic reaction kinetics. Why is that, because the reaction rate is a function of the available surface area and the available surface area depends upon the amount of time that is actually spent by the bubbles inside the reactor.

So, therefore, if different molecules of species A, they have different residence time, that is going to clearly affect the in a extent of the reaction, it is going to affect the reaction rate. And therefore, it is important to consider this aspect of different bubbles having different residence time into the model analysis.

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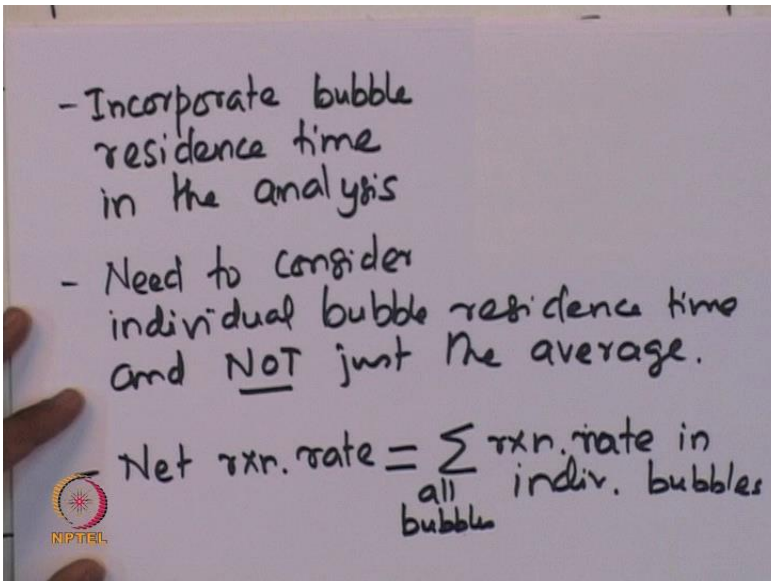

- Incorporate bubble residence time in the analysis
- Need to consider individual bubble residence time and NOT just the average.
- Net rxn. rate = $\sum_{\text{all bubbles}}$ rxn. rate in indiv. bubbles

So, therefore, it is important to incorporate the bubble residence time in the analysis of such reactor. And moreover it is actually important, its need to consider, it is important that 1 considers the individual bubble residence time and not just the average. So, it is not sufficient to consider only the average residence time of the bubbles, it is important to consider the residence time of each and every bubble, which is actually created because the bubble is being a sparched into the liquid.

So, and as a result the net reaction rate, as a result the net reaction rate is simply going to be sum of the reaction rate in individual bubbles and summed over all bubbles. So, if there are 100 bubbles inside the reactor, then 1 needs to actually find out what is the reaction rate in each of these 100 bubbles and sum them all and that gives you the net reaction rate inside the reactor. Net reaction rate here refers to the observed total reaction rate and not the intrinsic reaction rate.

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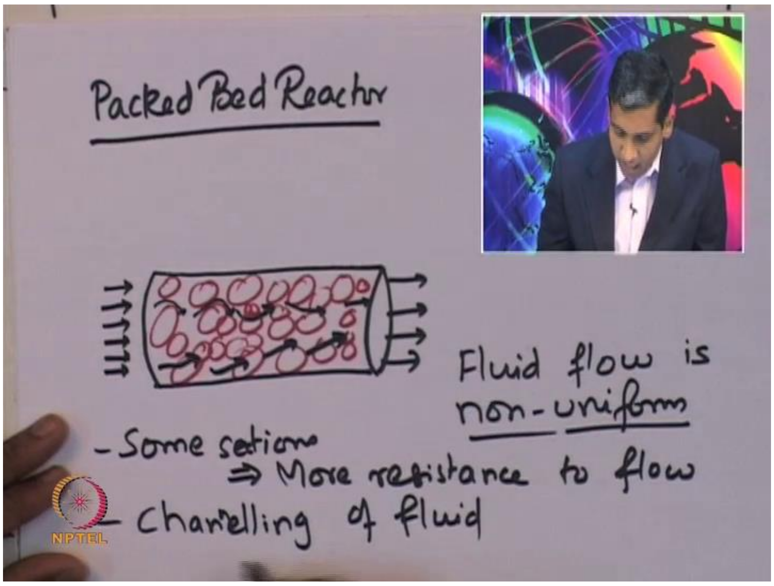

Packed Bed Reactor

Fluid flow is non-uniform

- Some sections ⇒ More resistance to flow
- Channelling of fluid

So, now, let us look at another example of a packed bed reactor. So, a packed bed reactor is nothing, but a tube and the tube is packed with catalyst particles. So, let us say that, these are the catalyst particles which are actually present inside the reactor. So, these are the catalyst particles which are packed inside. And suppose, if a fluid stream is actually flowing into the reactor, let us say that it has a flat profile. That means, the velocity with which the fluid is actually flowing and the concentration with which the fluid is actually entering the stream, is actually uniform across a given cross section.

So, suppose if it flows uniformly inside, then because of the packing, the resistance to flow is not going to be uniform at every location in a given cross section. So, therefore, 1 can observe that the fluid stream is now going to bend and then it is going to move through the crevices of the reactor and then they are going to leave from the other side. So, clearly 1 can observed that the fluid behavior is now at going to be uniform. So, clearly the fluid flow is going to be a non uniform and why would that be the case?

So, some sections can actually offer more resistance. So, some section will offer more resistance to flow. And as a result the channeling of fluids will occur. So, as can be as depicted here some in some sections of the reactor with the fluid will actually quickly go from the inlet to the exit of the reactor and leave the reactor while in the other sections they spend a lot more time. So, clearly the amount of time that is spent by every by a molecule by different molecules of the species that is entering the reactor, is going to be different

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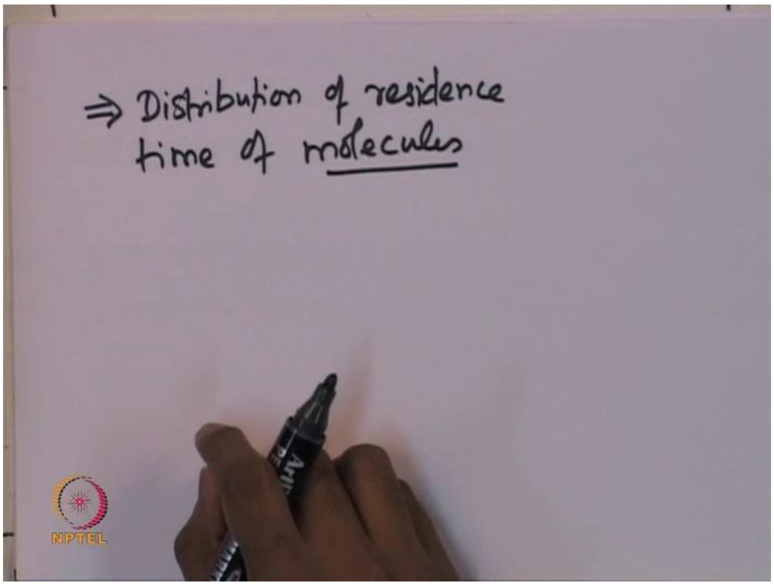

⇒ Distribution of residence time of molecules

Which means that, there is going to be a distribution of residence time; that is clearly going to be distribution of residence time of the molecules, which are actually entering the reactor and is participating in the reaction. So, let us take another example of CSTR, a well mixed CSTR.

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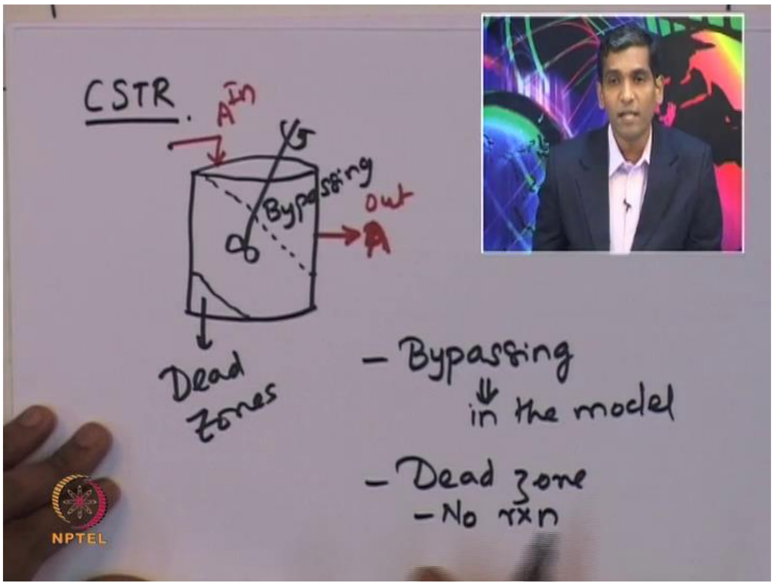

CSTR.

- Bypassing
  ⇓
  in the model

- Dead zone
  - No rxn

Suppose, we take a well mixed CSTR, so CSTR is a tank, that is the tank and it has a mixer. So, let us assume that it is rotating in this direction. And if the species is actually entering through, entering into the reactor; suppose this is the feed stream, species A is entering into the reactor at the feed via the feed stream. And let us say that the outlet of this reactor is at this location. So, this is the out and this is the in stream. And what happens is that, often the inlet and the outlet streams of the reactor make actually be placed close to each other for various reasons. And because of that, what happens is that, some of the fluids would actually quickly, some of the fluid that is entering this CSTR, would actually quickly leave the reactor. And in fact, that process is called as bypassing.

So, the some of the fluids which are actually entering into the reactor would actually bypass and leave the reactor. And as a result, what is created is; some of the some locations of the reactor are actually underutilized or unutilized and those zones are called as the dead zones. So, what is been observed is that, there is bypassing of fluid stream and because the inlet and outlet may be placed close to each other and so, some of the fluid particles will quickly bypass. And of course, if 1 needs to model such kind of a reactor, this has to be incorporated in the model.

The second problem is the presence of a dead zone, where the reactants are actually, where there is no reaction occurring in a dead zone. So, there is no reaction. And not just that there is no reaction, there is actually no exchange of materials from the dead zone to the well mixed zone.

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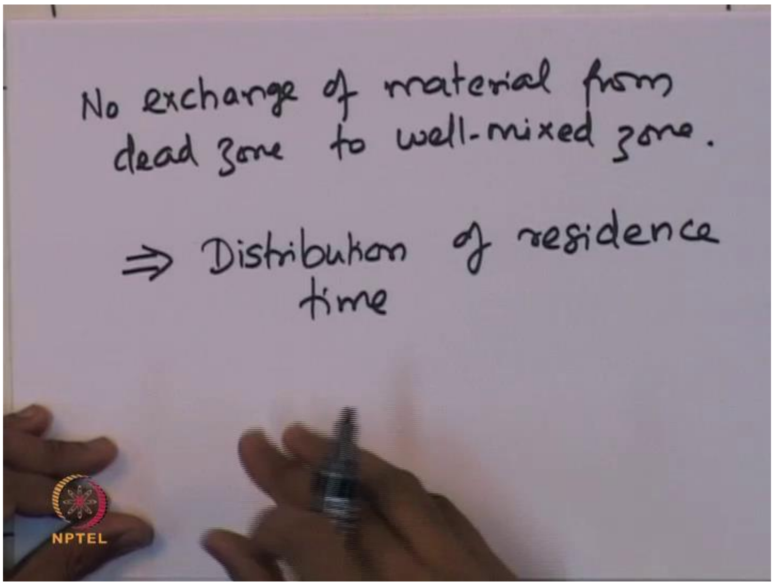

No exchange of material from dead zone to well-mixed zone.

⇒ Distribution of residence time

So, in addition to that no exchange of material from dead zone to well mixed zone. So, clearly this suggests that, there will be a distribution of residence time. So, there will be distribution of residence time even in the case of, where there is a CSTR with bypassing occurring inside the reactor.

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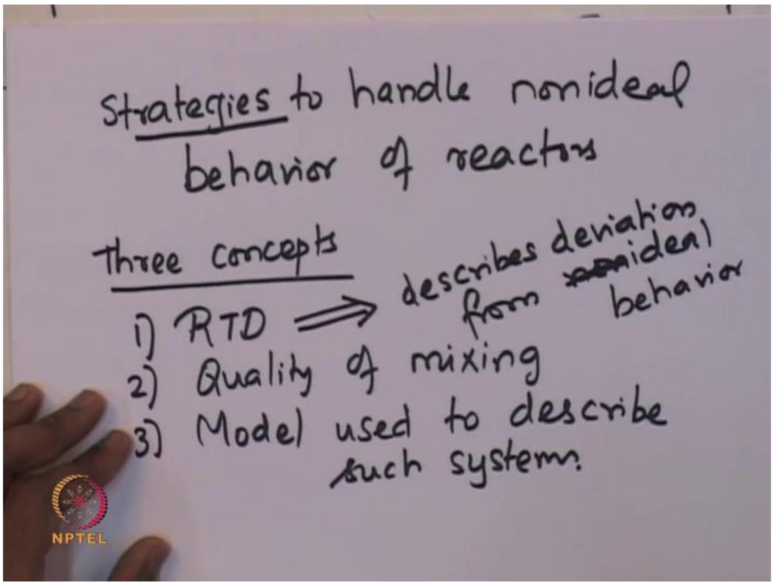

Strategies to handle nonideal behavior of reactors

Three concepts

1) RTD ⇒ describes deviation from ideal behavior
2) Quality of mixing
3) Model used to describe such system.

So, all these 3 examples are actually a good motivation to think that, there is a requirement for strategies to handle non ideal behavior. So, it is important to come up with strategies to handle the non ideal behavior of reactors. And this is very common, because the ideal reactor such as the plug flow and the mixed flow reactors are commonly not they are not a good representation of the real world reactors, they do not behave exactly like the plug flow and the mixed flow. And in fact, we will see in 1 of the in the future lectures that the 1 can actually clearly show using the residence time distribution, that the real reactors do not necessarily behave like a plug flow or the mixed flow.

So, there are 3 concepts which are involved here. There are 3 concepts that 1 need to understand in order to come up with strategies to handle the non ideal behavior of reactors. So, the first 1 on that is the residence time distribution. So, that is the amount of time, that is actually it has spent by a given fluid particle inside the reactor. And the distribution says; how much time different fragments of the fluid particles are actually spending time inside the reactor.

Then the second important aspect is the quality of mixing. So, what is the extent of mixing that is actually undergoing inside the reacted due to various reasons. So, 1 needs to understand and characterize the nature of extent of mixing, in order to be able to understand the non ideal behavior of reactors. And then the third aspect is; basically to model used to describe such systems.

So, 1 needs to come up with ways by which 1 can actually model such kind of non ideal behavior. And so, we are going to see that, what are the various ways, by which, we can characterize the non ideal behavior using these 3 concepts. And several examples will actually be shown to explain each of these concepts. And in fact, the RTD; the residence time distribution, is actually you is used to describe it describes the deviation from non ideal behavior from ideal behavior.

So, the residence time distribution actually it describes the deviation or it sort of captures the deviation from the ideal flow behavior. So, we are going to look at how it captures in a short a short while.

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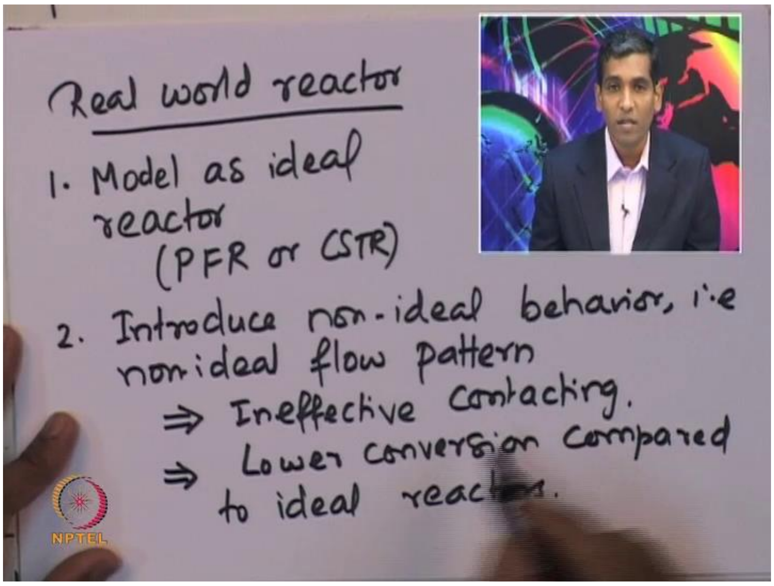

Real world reactor

1. Model as ideal reactor
   (PFR or CSTR)
2. Introduce non-ideal behavior, i.e non-ideal flow pattern
   ⇒ Ineffective contacting.
   ⇒ Lower conversion compared to ideal reactors.

So, the first step towards handling this handling a real world reactor, that is, the actual reactor which may be present in an industry. So, the first step is basically to model them as an ideal reactor. So, the first step is to assume that the reactor is an ideal reactor. What it means is that, it needs to be modeled either as a PFR or a CSTR. So, 1 can actually model it as a plug flow reactor or a CSTR reactor.

Remember that, even in a CSTR the residence time is not same for all the particles, that actually goes through the reactor. However, it is a thoroughly perfectly well mixed system. So, it has certain ideal properties and we will see in a short while how to characterize them. And, then suppose if this model does not predict the actually behavior of the reactor, then 1 needs to actually introduce the non ideal behavior that is the non ideal flow pattern.1 needs to introduce the non ideal flow pattern. And in fact, in order to introduce a non ideal flow pattern, 1 has to actually account for the ineffective contacting, while some of these fluid …

For example: let us take the packed bed reactor case, the some of the fluid actually enters and leaves the reactor immediately because of the channeling effect. And so, the contact that actually these fluids stream has with the catalyst particles present inside the reactor is not very effective. And therefore, 1 needs to account for such kind of ineffective contacting. And also 1 needs to affect account for low conversion compared to ideal reactors.

So, 1 needs to account for these 2 factors if, 1 has to introduce the non ideal behavior into the ideal reactor model. So, once we know that the reactor behaves like a non ideal reactor, then we need to account these 2 be these 2 aspects into the model to capture the dynamics or the behavior of the reactor. Now the question is how do we account these 2 factors.

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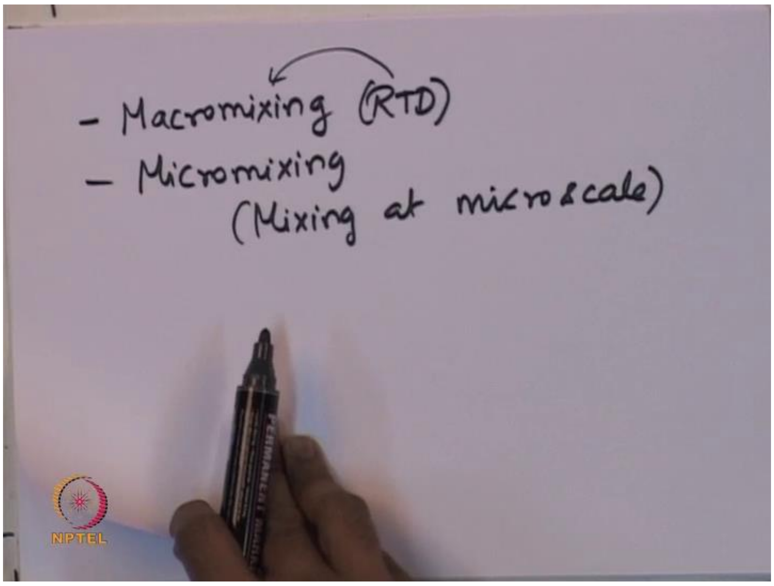

- Macromixing (RTD)
- Micromixing
  (Mixing at microscale)

So, the first, so 1 needs to actually look at the Macromixing, which is basically the residence time distribution, which captures the Macromixing, 1 needs to account for macromixing in the system. And the other aspect is the micromixing, that is, the so this is the mixing at microscale. So, 1 needs to account for these 2 factors. And in fact, these 2 factors will actually help in characterizing the non ideal behavior of the reactor. So, let us first look at the residence time distribution, which actually account for the macros Macromixing.

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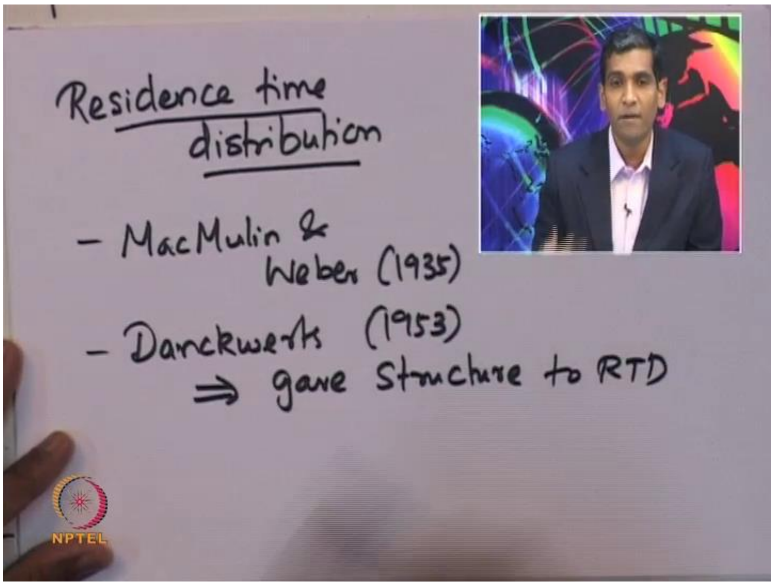

Residence time distribution

- MacMulin & Weber (1935)
- Danckwerts (1953)
  ⇒ gave structure to RTD

So, the residence time distribution was actually originally proposed by MacMulin and Weber, in 1935. However, it was actually ignored for nearly 2 decades. And later Danckwerts came and actually gave a special structure to the residence time distribution and defined various types of possible distributions. So, it was Danckwerts in 1953, gave structure to RTD.

So, in fact, he came and took the idea of MacMulin and Weber and developed it further and gave some special structure to RTD. Therefore, most of the RTD work is actually attributed to the seminal work done by Danckwerts in 1953. So, now, we said that the plug flow reactor is an ideal reactor. So, why is it an ideal reactor?

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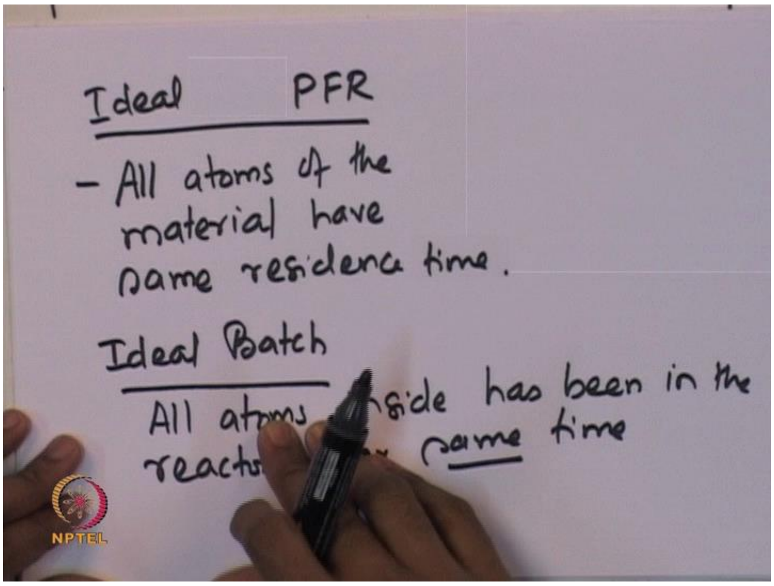

Ideal PFR

- All atoms of the material have same residence time.

Ideal Batch

All atoms side has been in the reacto same time

So, let us look at the ideal plug flow reactor. So, plug flow reactor can actually be as an ideal under certain situations. So, what are the properties of an ideal plug flow reactor? So, in an ideal plug flow reactor all atoms and material, all atoms of the material have same residence time. So, suppose there is a fluid which is actually flowing through a plug flow reactor, then all fluid particles that are actually entering the ideal plug flow reactor, they spend exactly the same amount of time inside the reactor, before they leave the plug flow reactor.

So, that is an important characteristic of an ideal flow reactor. And what about an ideal batch reactor? So, ideal batch reactor is 1 where, all atoms inside has been in the reactor for same time. So, all atoms that are actually present inside the batch reactor ideal batch reactor, they are actually have they have been there, all atoms have been there for exactly the same amount of time as each other.

So, therefore, the time that is actually spent by these atoms inside the reactor is called the residence time. And both these ideal plug flow reactor and the ideal batch reactor, they actually have all the molecules inside, they have exactly the same residence time. So, there are actually only 2 classes of ideal reactors. In fact, there are only 2 classes of reactors in which the residence time can actually be same. So, suppose what happens in the CSTR? CSTR is something that has been commonly studied in this course in many different in the first course of the reaction engineering.

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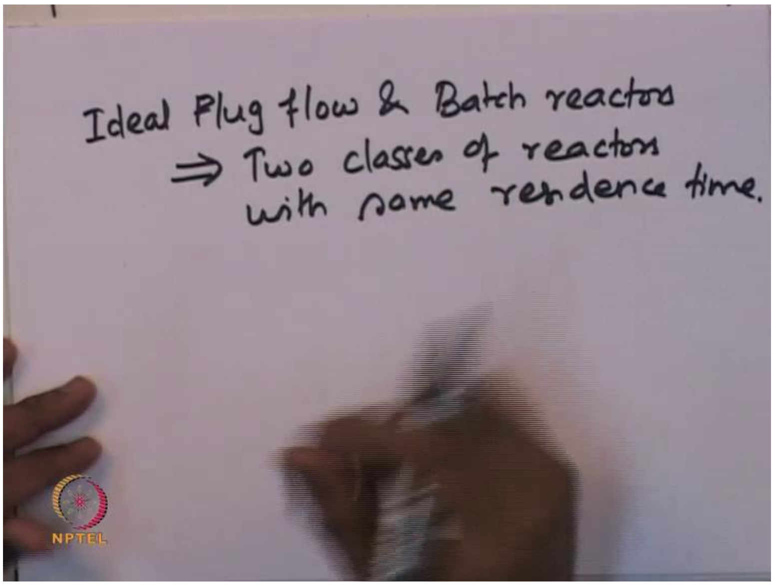

Ideal Plug flow & Batch reactors

$\Rightarrow$ Two classes of reactors with same residence time.

So, it is the ideal plug flow and the ideal batch reactors; 2 classes with same residence time. So, all other reactors, there is going to be a distribution of residence time including CSTR.

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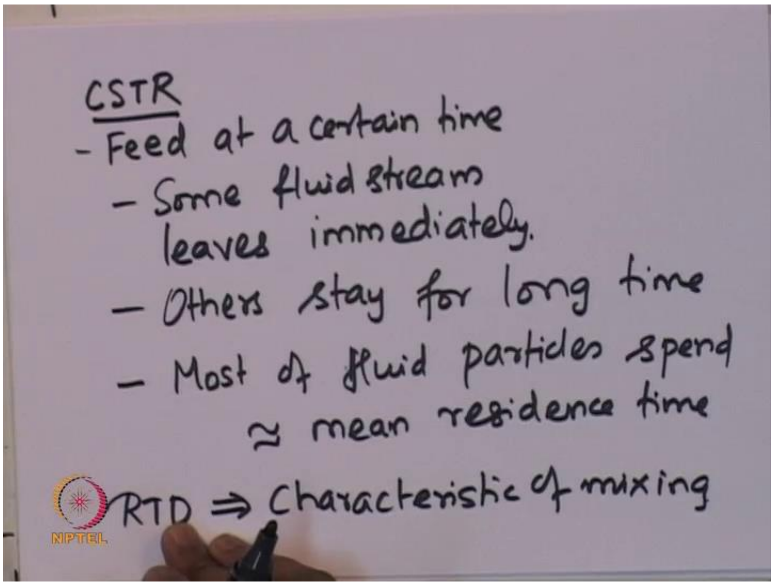

CSTR

- Feed at a certain time
  - Some fluid stream leaves immediately.
  - Others stay for long time
  - Most of fluid particles spend $\simeq$ mean residence time

RTD $\Rightarrow$ Characteristic of mixing

So, what happens in a CSTR? How can we describe what have what is the nature of the residence time distribution in a CSTR? So, suppose if we take a tank and then we feed a certain species into the tank which is undergoing a reaction. So, if we consider the feed at a particular time, suppose we look take at the feed at a particular time, then as the feed stream actually enters into the reactor, the feed stream because it is a CSTR, the feed stream immediately gets completely mixed with the materials which are already present inside the reactor. Now not just that the there may be a small fraction of a feed stream, which is actually carried along with fluid stream and it leaves the reactor.

So, therefore, it is possible that, some fluid stream leaves immediately. And so therefore, the residence time of these fluid stream, which actually leave the reactor immediately is going to be very small. And in fact, it is going to be different as compared with the residence time of other particles, which are actually staying inside the reactor. So, other particles, they are going to stay for a much longer time. And in fact, most of the particles, it is been observed that most of spend approximately the mean residence time.

So, most of the fluid particles; the amount of time they spend inside the reactor, is approximately equal to the mean residence time. So, therefore, the residence time distribution actually characterizes the extent of mixing. So, in a CSTR the some fluid stream leaves immediately and the others they stay for a longer time, which means; that there is going to be a distribution. And in fact, the residence time distribution; it characterizes the extent of mixing inside the reactor. So, that is an important aspect; it is a characteristic of mixing. So, residence time distribution henceforth will be referred to as RTD and its actually a characteristic of the mixing which is happening inside the reactor.

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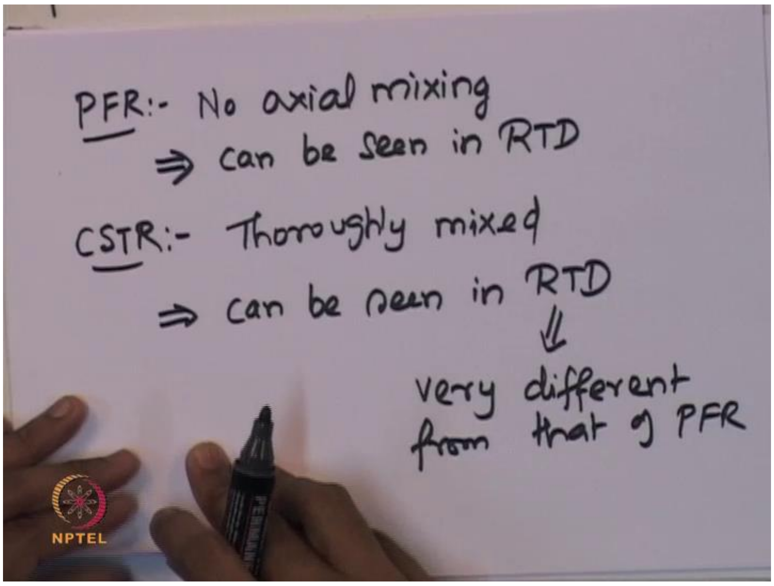

PFR:- No axial mixing
$\Rightarrow$ can be seen in RTD

CSTR:- Thoroughly mixed
$\Rightarrow$ can be seen in RTD
$\Downarrow$
very different
from that of PFR

So, now if I take a plug flow reactor, there is no axial mixing in a plug flow reactor, which means; that the, if there is a tube and if it behaves like a plug flow reactor, then the fluid stream which is actually entering inside, they actually move like a plug, which means that, the fluid particles which is actually entering the reactor at a certain time, they do not mix with the fluid particles which are actually entering just after it or just before it.

So, therefore, there is no axial mixing of fluid particles inside the reactor, if it behaves like a plug flow reactor. And this can actually be seen; this behavior or this aspect of no axial mixing can actually be seen in the residence time distribution. And it will be shown in 1 of the lectures in the 1 of the future lectures, that for a plug flow reactor there is actually no axial mixing and that can be deciphered from the residence time distribution curve itself. And let us look at CSTR.

So, the CSTR is actually thoroughly mixed, which means; that the concentration of the species inside the reactor is going to be uniform at all times. And so, it is a thoroughly mixed system. And that can also be seen in the residence time distribution of the reactor. So, now and in fact, 1 will observe which we will see in 1 of the future lectures is that, the RTD of CSTR is actually very different from …

So, the residence time distribution observed for a CSTR is going to be very different from the residence time distribution of a plug flow reactor. So, at this point 1 needs to also know that, not all residence time distributions are actually unique to the reactor type. So, it does not mean that every reactor type has a unique residence time distribution and there is no 1 to 1 correlation, there is no 1 residence time distribution for a for a particular reactor type. So, what it means is that, different reactors can actually show identical residence time distribution. In fact, different reactors of completely different configuration, they can all show very similar residence time distribution.

So, residence time distribution can actually be used to decipher the nature of the functioning of that particular reactor or nature of the non ideality that is present inside the reactor. So, now, the question is how do we detect these non ideal behave, how do we detect the residence time distribution experimentally?

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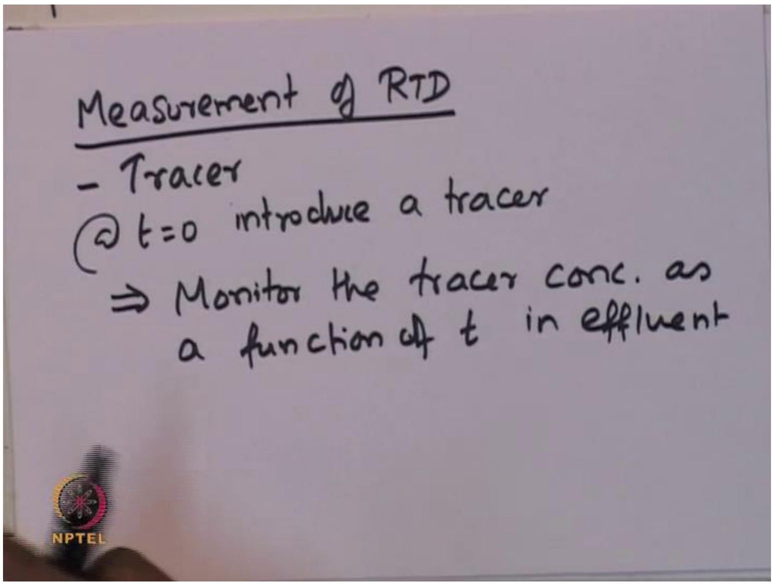

Measurement of RTD

- Tracer

@ $t=0$ introduce a tracer

$\Rightarrow$ Monitor the tracer conc. as a function of t in effluent

So, it is actually possible to measure the residence time distribution. And in fact, it is a experimentally determined using what is called a tracer. So, suppose if there is a reactor, a fluid stream is flowing through this reactor which is actually participating in a certain reaction, which is getting consume to form products. Now in order to find out what is the residence time distribution, in order to detect whether the reactor is ideal or non ideal, we need to know what is the residence time distribution and the way to do that is basically to use a tracer.

So, what is done is at time t equal to 0, a tracer is introduced. So, an a tracer chemical is actually introduced. And then monitor the tracer concentration as a function of time in effluent. So, 1 can actually measure the tracer concentration; allow that actually is going to flow along with the fluid. So, the tracer is introduced at the inlet of the reactor and the tracer is now going to be taken forward taken by the fluid along with the reactor and then it is going to leave the reactor.

So, 1 can actually measure the concentration of the tracer material, as it leaves the reactor and that way 1 can actually construct the residence time distribution. Now it is not possible to conduct such an experiment with any kind of tracer, the tracer has to have certain properties. So, for example, the tracer must actually satisfy certain important, must have certain important properties, in order for it be used to measure the residence time distribution.

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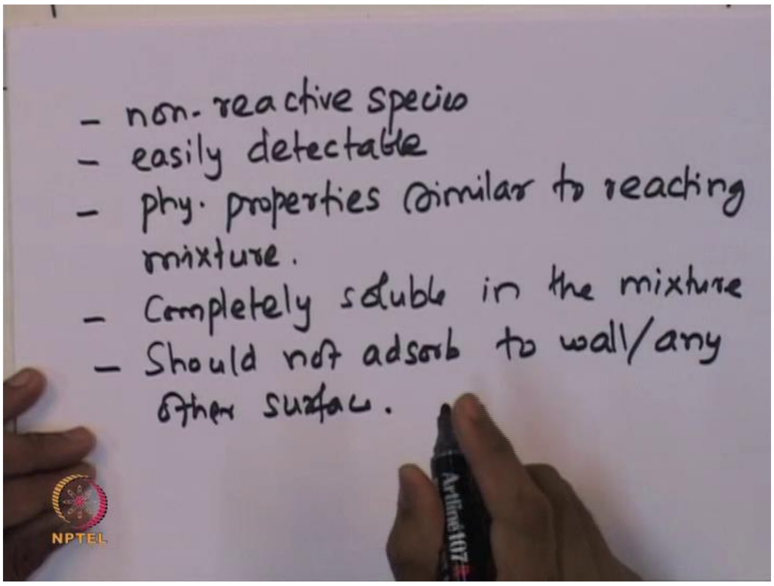

- non-reactive species
- easily detectable
- phy. properties similar to reacting mixture.
- Completely soluble in the mixture
- Should not adsorb to wall/any other surface.

And these properties are basically; they have to be non reactive species, they have to be non reactor, otherwise it is going to get consumed inside the … otherwise it is going get consumed because of some reaction. And if it is a, if it gets consumed, then 1 cannot observe the non ideal behavior or non ideal flow pattern using this particular tracer. And then it must be easily detectable.

So, tracer chemical must be easily; that means, that there must be methodologies well established methodologies in order to measure the concentration of the tracers in a very short time, which means; that the equipments must be sensitive enough to distinguish the small concentrations of the tracers.

The physical properties should be such that, similar to that of the reacting mixtures. So, if the physical properties are not similar, then it does not reflect the exact flow behavior of the reacting mixture, which is this of which is of interest to actually study. So, now in addition to that, it must also be completely soluble. It must be completely soluble in the reacting mixture. And it is actually should not adsorb to wall or any other surface of the reactor.

So, it should not adsorb to wall or any other surface, because if it gets adsorbed, then the some of the species are a being consumed and that is not going to help in actually measuring the residence time distribution of the reactor.

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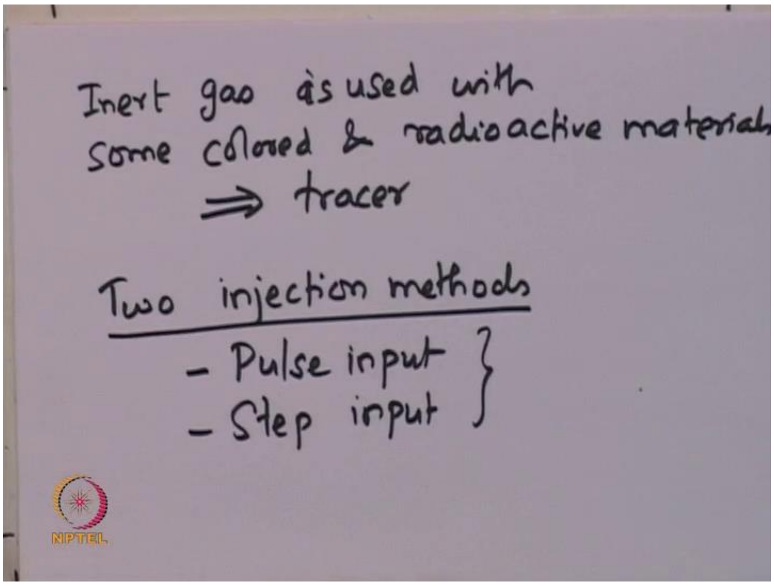

Inert gas is used with
some colored & radioactive material
⇒ tracer

Two injection methods

- Pulse input
- Step input

So, typically colored and radioactive materials along with the inert gas are actually commonly used as tracers; so inert gas with some colored and radioactive material. So, these are all commonly used tracers for actually finding the residence time distribution. So, there are actually 2 common strategies for injecting the tracer; so, 2 strategies or methods. So, there are 2 methods for injecting the tracer, in order to study the residence time distribution. The first one is the pulse input and the second one is the step input. So, these are the 2 classical methods of tracer injection, in order to detect the residence time distribution. So, which is what is we will see in the next lecture.

And what we have seen today; is basically to introduce what is the non ideal behavior and that to appreciate that real world reactors do not behave like the ideal reactors, such as the plug flow and the mix flow reactors; that we have studied in the past. And what are the definitions, that is, the residence time distribution definitions that are actually involved to characterize such kind of non ideal behavior. So, what we will see in the next lecture; is to look at what is this pulse input and the step input method, in order to track the residence time distribution of a given system.

Thank you.