Multiphase Flows
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Lecture – 01
Multiphase flow introduction

Welcome everyone this course is about the multiphase flows and in this course what we are going to learn is what is multiphase flows and how this multiphase flows basic principles we can use in industry and solve the industrial level problems also to solve some of the academic and research related issues.

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Course Plan

Week #	Topic/Outline
Week -1	Multiphase flow introduction, Fundamental definitions and terminology used
Week-2	Flow-pattern map for fluid-fluid (gas-liquid and liquid –liquid) and flow regime map for fluid-solids flows
Week-3	Pressure drop and Volume fraction calculation for Homogeneous regimes: Using Momentum balance equation from equation of motion and empirical correlations
Week-4	Pressure drop and Volume fraction calculation for Segregated/Separated regimes: Using equation of motion and empirical correlations.
Week-5	Multiphase Interactions: Drag, lift, virtual mass force, Basset force, one way, two way, three-way and four way coupling and mathematical formulation of the same.
Week-6	Modelling Methods for Multiphase Flows: Mixture Model, Euler-Euler Model and Euler-Lagrangian Model
Week-7	Multiphase Reactors: Bubble Column, Fluidized bed
Week-8	Multiphase Reactors: Binary Fluidized Bed and Circulating Fluidized bed

So, what we are going to cover in this course I have already given the course plan in the course subject itself that again briefly discuss we are going to cover about the multiphase flows introduction, fundamental, definitions and terminologies and this I will try to cover about the basics of the multiphase flows the definition and terminology we generally use in the multi phase flows.

Then week 2 I will be shifting towards the flow pattern map and we will see the flow pattern in gas liquid liquid, liquid liquid solid gas solids flows and we will try to understand that what are different regimes available in the multiphase flows of these kind of a flow behaviour. Then we will see some basic behaviour calculations for the pressure drop, volume fractions for the different types of flows by using the basic momentum equation and continuity equation.

Then we will try to see the different forces which actually very important in multiphase flow and to understand the multiphase flow like drag, lift, virtual mass, biceps forces. And then we will try to understand the modelling methods which is generally used in the multiphase flow and advantage and disadvantage of each modelling methods. And we will also try to see the equations which is being used and we will try to reduce those equations for a particular process.

And then finally, in last two weeks I will discuss the different type of multiphase flows reactors like bubble column, fluidized bed, binary fluidized bed, circulating fluidized beds to give the examples that whatever we have learnt how to use those example this things fundamentals in the basic course, in the basic reactor design or in the basic process understanding.

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So, with this will start the flow and why we want to study? So first thing the first question for always come this that why multiphase flow is important and why I should studies? So if you think about nature or if you see all around you will see that you are actually everywhere you will see the multiphase flows you are surrounded by the multiphase flows.

So, be it Niagara fall or any waterfall. So, if you see any waterfall you will see of mist formation like you can see in this figure this white colour mist is coming out and that is nothing this white colour mist is coming out and that is mist you are seeing this colour because it is a multiphase flow there is some water droplet which is suspended in the air. And because of that it becomes white colour you see the white colour things, so, it is a typical example of the multiphase flow.

You must have seen the dust storms and you see something this kind of a cloudy dust and that is again nothing, but a multiphase flow. Because the solids are suspended in the air and then you might have seen some ferries or boat or ship is moving in water then again it is a multiphase flow over a solid object is actually moving in the water even the blood flow our RBC and WBC particles are actually moving in the blood which is a of made of the plasma fluids and these are again a typical example of the multiphase flow.

Even this fish movement if whether is a sharp or it is a dolphin which is moving inside the water it is a again the multiphase flow, where a solid object a fish living object is moving inside the water they also take a breath, they also take the air and then they actually leave it out.

So, all these are the typical example of the multiphase flow even when Virat Kohli hit 4 that is again is a multiphase flow examples because the ball is actually suspended in the air and there is a forces which are acting there we are going to discuss those forces because of that the ball actually crosses the boundary, but most of the time what we are interested as a engineer is multiphase flow in reactors.

So, this is the process where we are going to be more worried and we will discuss more in detail. So, this whatever we will discuss which equally hold for the nature's whatever you see around, but our focus will be concentrated on the multiphase flow in reactors where the two phases are comes in contact with each other to do the reaction or some physical contacting for mass transfer applications.

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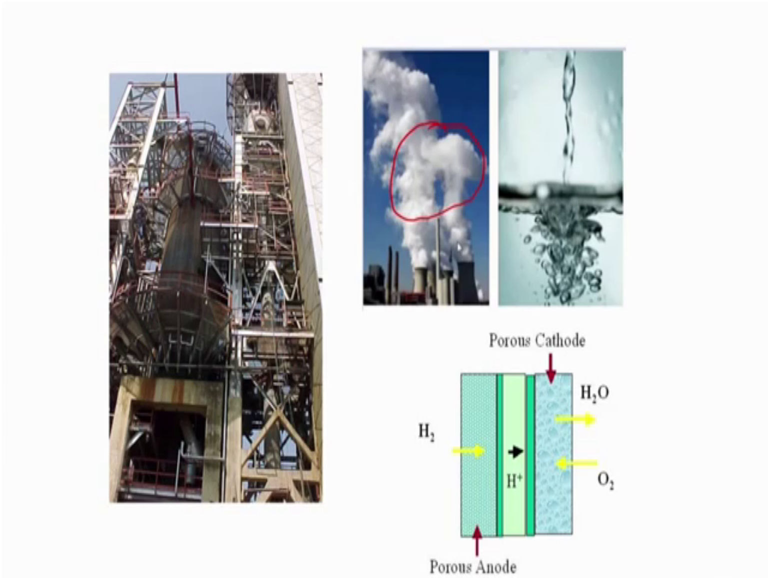

So, what we are going to discuss? We are going to discuss more about the industrial applications. So, if you see the industrial application; so, if you see that from any stake the fumes are coming up and that fumes is actually looks white in color and that is mainly because water is being suspended in that in the air and that makes the colour white. So, this is a typical example of a cooling tower and the fumes coming out of the cooling towers; you can see this colour this is the water which is suspended in the air and because of that you are seeing the water colour white colour.

So, that is the typical example of the multiphase flow and what we are more interested is actually this is called a risers reactor or csf this fast catalytic cracking reactor. So, this is a typical is the heart of any petroleum industry at CCU is the common name. So, if you see that they are some solid and gas is flowing together or some liquid is flowing together and what we are doing we cracking the liquid the petroleum product the crude oil and we are getting the different fractions. So, if you think about the crude oil; we are having a liquid which is a crude oil in presence of some catalyst, we crack the crude oil to get the different fraction in terms of the gases as well as the liquid.

So, this is a typical example of the multiphase where all the three features are present. So, we are more interested in these kind of application; similarly if suppose there is a anode and there is a porous cathode if the hydrogen is passing through this and you are getting a typical fuel cell. Hydrogen is passing through it is converting into the H plus it goes to the cathode; it do the get a electron, it makes the water in the presence of oxygen, it makes the water and generate some electricity.

So, these all are a typical multiphase flow applications which we see in a it is very important a very critical in industries.

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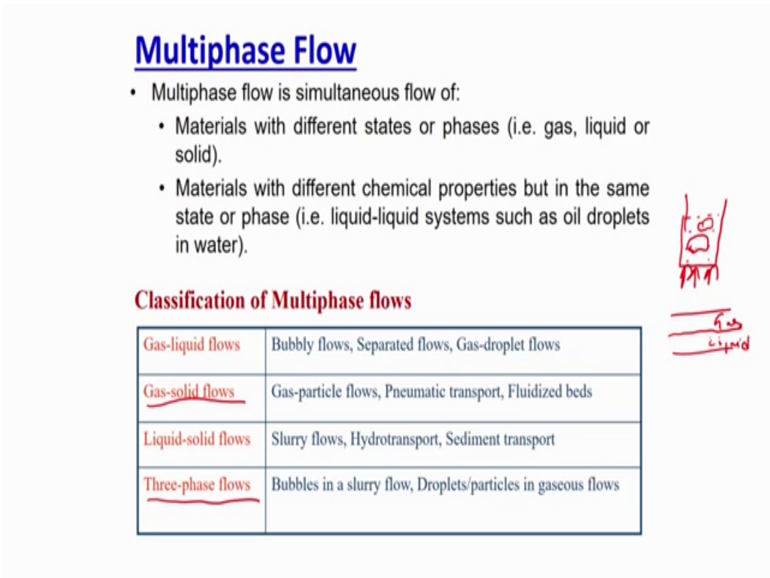

So, now formally if I want to introduce what is multiphase flow; so, the multiphase flow is the flow of is the simultaneous flow of two different material which has a present in the different state. So, it can be the same material which are present in the different state or phases or is the two different material which are present in this different state of phases. So, once I say different states I means gas liquid or solid.

So, suppose if it is the water and air which is flowing together they are of two different states that is called multiphase flow. So, flow of air and water together is a multiphase flow like the rain or I have told about the mist which is moving inside the year. So, that is called a multiphase flow; now there can be a possibility that the two materials with have a different chemical properties, but in the same mistake they are also considered multiphase flow like such a system is the liquid liquid system or I can say that more common example for oil industry is that oil water flow.

So, most of the time once we explore the oil from the reservoir we inject the water or steam as a secondary fluid or as the fluid or motive fluid to push the oil from the reservoir and outlet whatever we get is actually a mixture of oil in water. So, that is a typical example of oil water flow a typical example of the multiphase flow which is widely used in petroleum industries. So, this is the formal definition of the multiphase flow reactors. So, either the simultaneous flow of two different states material which are having in two different states or material which are having of different chemical properties.

So, based on this multiphase flows is actually divided and classified in four parts; one is called gas liquid flows the gas liquid flow means it is a simultaneous flow of a gases and the liquid phase which are moving together. These are the typical examples like bubbly flows, separated flow or gas droplet floor; it means what? Bubbly flow means if suppose there is a water a liquid is filled inside the tank or water is filled inside the tank or any liquid filled inside the tank and you are (Refer Time: 08:40) air from the bottom of the column.

So, what you will see you will see a bubble air will comes in form of the bubble and this is called bubbly flow. The separated flow means like oil water flow if suppose there is a pipeline where we are using oil water flow and there is the gas oil water flow is there which may be separated because of the density or because we are discussing here the gas liquid floor. So, suppose the gas and liquid is flowing inside a pipeline now is also typical example in petroleum industry because some of the crude also have a in forms of a gas some fraction is there in terms of the gas.

So, if we are trying to flow that crude oil then what will happen? You will see that because of the buoyancy or density difference the gas is the following on top and liquid be flowing on the bottom of the tube. So, that is called gas liquid separated flow and then there is a this that the droplet are suspended in the gas that is called gas droplet floors. Similarly there is another kind of flow that is called gas-solid flows in which the solid is actually suspended in the gas and they moves together. So, the typical example is fluidized bed in which solid is initially packed and once you pass the gas the solid get suspended in the gas.

So, these kinds of reactors fluidized bed are widely used in many industries; we will discuss the applications of the fluidized bed in due course of time. Similarly in pneumatic transport like suppose if you have to transfer the solid from one place to another place there is two ways you use some conveyor system; the belt conveyor a bucket conveyor or you use some physical transportation systems like truck or something to transport the solid from one location to another locations, but many times it is very difficult to transport it in this way particularly for a very short distance. So, in that case what we do we pass the air at a very high velocity and suspend the solid inside and that is called pneumatic conveying. So, we are conveying with the pneumatic pressure of the gas that is also typical example of the gas solid flows.

Similarly, the liquid solid flows are there; so, sedimentation transportation or hydro transportations, slurry flow flows these all are a typical liquid solid flow system. Like if you see that face wash cream with some solids are suspended in a liquid mixtures of that is typical liquid solid flow system and if this system and then there is another system which is called three phase flows it means all the three phases gas, liquid and solid they are moving together.

So, multiphase flow is generally classified into these four different parts and we will try to understand that what are the different forces which are acting in these type of reactors, how these reactors are different from each other and then how to model this kind of reactor and how to understand the basic hydrodynamics inside?

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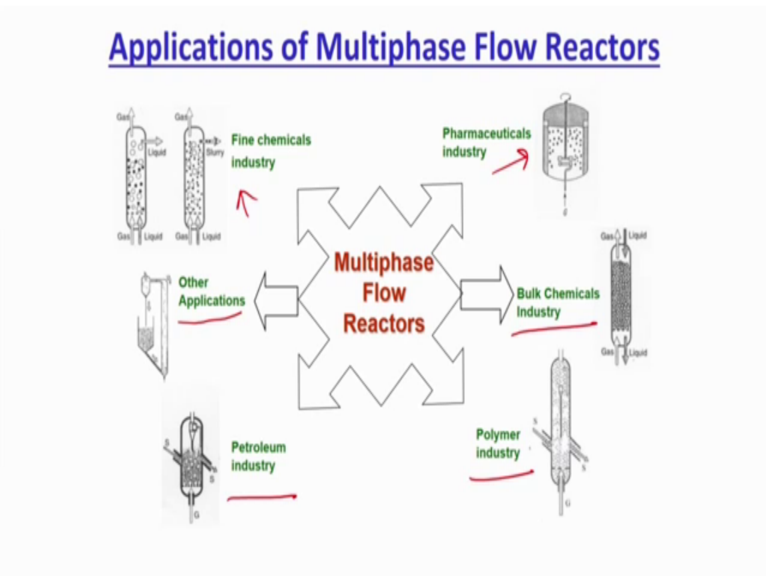

So, another question that these all are multiphase flows, but why I should study this why I should study the multiphase flow? So, multiphase flow reactor actual heart of any chemical bulk chemical, petroleum, pharmaceutical industries; so think about industries the multiphase flow reactors will be the heart of that industry and it will be widely used in that industrial particularly for petro chemicals and chemical bulk chemical fertilizer industries.

So, you can see that the spectrum is available and the spectrum application of the multiphase flow is almost everywhere. So, whether it is a fine chemicals, it is a pharmaceuticals, it is a bulk chemical industries, polymer industries, petro chemical industries think about any other industries and you will always find a multiphase flows is there where you are reacting more than one phases together or you are having a mass transfer between the two phases like fluid industry is also there which is a typical example where the multiphase flow reactors are used.

So, you know think about any industries and you will see the multiphase reactors all around. So, it means the success or successful operation or continuous operation or trouble free operation of any industry depends on the understanding of the multiphase flow reactor.

So, if you understand the multiphase flow reactors; you understand the industries well and you can have operate the industry, you can do the troubleshooting and even you can come up with the new innovative idea of new concept of the pharmaceutical reactors or the noble reactors. So, there is lot of scopes available and that is the reason that why this subject is very very critical and very interesting.

So, you can do lot of things is still lot of the scope is there and you just changed one of the reactor performance and you will see that you are improving the profit by million dollars per day or per month. So, like petroleum industry if you are suppose increase the cracking performance by 1 percent or 2 percent; you will increase the profit by more than a million dollars in a month or in a year time depending upon the capacity of the industry.

So, this is the scope and that is why this reactors or this multiphase flow as a chapter or a course is very very critical. And the understanding of the multiphase flow is required for successful operation, troubleshooting as well as the design of the new reactor concept.

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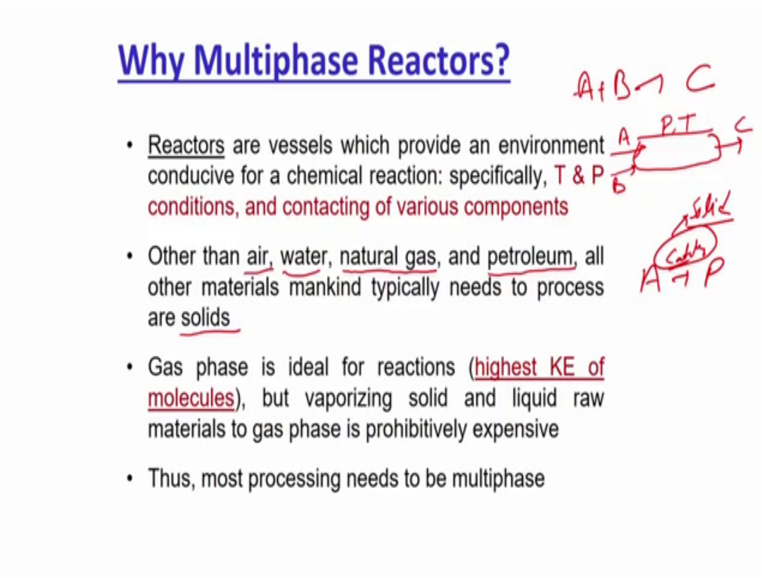

So, think again the question comes that why this kind of a reactors are very very critical? Why these are so, important and so, critically used in everywhere? So, what is the region? So, region are very simple that reactors first thing I would discuss the what is reactor? So, reactor is nothing, but a vessel in which you maintain a specific temperature and pressure conditions with a particular contacting parameters or contacting patterns which you need to perform any reaction.

So, that is called reactors; so, it is nothing, but a vessel in which you are actually putting some of the reactant together, you are maintaining a desired temperature and pressure and if there is some contacting pattern you put that inside that is called reactor. So, it can be a plug flow reactor if plug flow reactor is there you have maintaining the reactor suppose at if you are putting the inlet say reactant A and B; if they are forming A plus B say is forming reactant product C.

In a plug flow reactor what I am going to do I am going to inject the A, I am going to inject the B and then they will react I will maintain a process temperature and pressure condition inside and I will get a product C outside. So, that is the vessel where you do all this is called reactor.

Now why multiphase flow reactor? So, if you think about the materials which are available around you; so, you will see that what are the commonly known material which is available around you. So, first thing is air very popular we all know then water then other example which is very critically very critical and understand the this kind of used a lot is natural gas, then they are some petroleum products like diesel, kerosene all those petrol all those products are there these are the products if you think about the gas and the liquid products. So, these with these things whatever you will think.

Now, once I say about the acetone and all those organic chemicals it is all derived from the petroleum products. So, I am including everything in the petroleum. So, you think about any chemicals organic chemicals you see that that is being derived actually from the petroleum products. So, if you club all these four together and you think about anything else whatever you will think you will find that it is nothing, but a solid.

So, other than these products and the derivative of these products everything else is actually we see or we use every day in daily life is solids ok; so, and that is the reason. So, if suppose I have to do any reaction between the two materials A and B. So, if A is say any of these petroleum product or natural gas or water or air other than that whatever you will process will be actually solids.

So, it means you are going to involve the multiphase flow for all your practical applications. So, whether it is a catalyst which most of the catalyst is actually in the face of the solids. So, if you are forming A is forming say P a product P and most of the time to enhance the activity of this reaction or enhance the selectivity of these reactions; we use some catalyst.

And most of this catalyst are in the solid form to increase the surface area. So, that my rate of reactions can enhance and these all are basics of the chemical reaction engineering, if you see that we generally increase the rate constant or increase the reaction rate what we do we increase the surface area. And to increase the surface area we make the catalyst of the solids so, that we can suspend it we can increase the surface area or we can put the force inside.

So, for all goes processing what you need is actually at the end of the day is the solids it means what you need to process any of this five four five components which I have written outside along with some of the solids. So, it means you are going to have a multiphase flow reaction or multiphase flow reactor or multiple contactors and that is the reason that why multiphase flow reactor is very critical. Then another which is very interesting example is that the reaction. So, suppose the reaction engineer or reactor engineer or as a chemical engineer if want to do the reaction what is my wishlist? My wishlist is that my reaction should be as fast as possible if the reaction will be very fast my throughput will be high because I can do more reaction it means more product formation.

Now, we know that the reaction if we do the reaction in the gas phase because of the highest kinetic energy of the molecules the diffusion very fast. So, what will happen your mass transfer limitation will go out and your rate of reaction will be actually in enhanced. So, it means you can have more process you can do a lot of processing if you do the reaction in the gas phase.

So, you always desire of a gas phase reaction because that is give me the enhance productivity and remove the mass transfer limitation, but the problem is that if we want to as I discussed that we have almost everywhere solids. So, if you want to vaporize the solids then it becomes very very difficult. So, you require lot of energy to vaporize the solids. So, suppose if I am doing the reaction with copper and the oxygen actually is being reacting with the copper to make a copper oxide. And I want to do these reactions in the gas phase then I have to actually works with the copper oxide.

Now, evaporating that will actually be very very costly because you have to increase that enhance the temperature like anything. So, it means what? It is almost sometimes of most of the time it is very expensive to do all the reaction is the gas phase. So, what we want we want always do that in the combination. So, maybe one phase in the gas one phase in the solids like copper oxide oxidation; if I say or copper oxidation or copper oxide say reduction if I want to do and we make we want to make the pure copper.

So, anything of out of this if you want to do this suppose if you are doing the copper oxide the reduction you want to produce the do it in presence of the CO or any other reducing gas say hydrogen; what will happen copper oxide will be in form of the solid and the CO or hydrogen will be in form of the gas and they will react each other to form a pure copper.

So, these all are the examples that you need to actually deal with the different phases; though we always want to deal with the gas phase, but we do not have the option because vaporising the solid or the liquid material into the gas phase is very very expensive. So, that is the reason that why the multiphase flow is again needed and that is why it is been widely used in all the industry. So, suppose like if I discuss about the food industries and I am making a chips and I want to deposit some flavour on the chips the onion flavour. So, what I need to do? I will have to pass some gases or some over the chips and they will be some in the gases some flavour will be mixed one, they will pass those flavour will be actually uniformly deposited on the chips surface we will have a onion flavoured chips.

So, these kind of processing need to be done or I make a milk powder I spray the milk into the air and then make it in terms of the powder. So, there are several such processing is being used and that is the reason that why the multiphase flow reactors are used. So, that is the reason that multiphase flow reactors are widely used it gives you the enhanced performance and it allow you to contact the materials which are existing in the different states and that is the reason that why it is so, popular.

Now, what are the variables which we use in the multiphase flow reactors?

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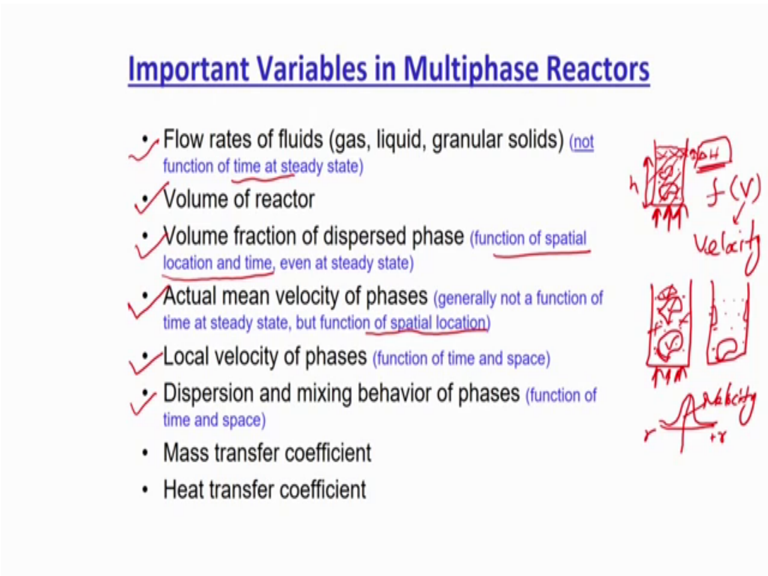

So, suppose if I have to operate a multiphase flow reactors what are the variables? The first variable will be is with the flow rate. So, if I am flowing a gas, liquid or solid or any of these two together or all the three together; I should understand that; what is the flow rate at which I am injecting the gas, liquid or solid inside my vessel. Now I am saying vessel because it can be a reactor where the reaction is taking place or can be any contact that is why the mass transfer is taking place. So, these flows this flows of the different fluids or flowing inside. So, if I was going inside I should know the; what is the flow rate.

Now, most of the time the floor it is actually at a steady state condition does not depend on the time and; obviously, it is not going to be the function of position two at least. So, in that way this is measuring this quantity is relatively easier provided you are flowing all these gases or all this material in the pure form and that to be separately. So, they are separate injection they are not mixed together earlier before injecting into the reactor or the contractor or the process vessels.

So, that is the one important parameter then the second important parameter is the volume of the reactor that what is the volume of the reactor you are using? Now why the volume of the reactor is the question because one can always say that volume of reactor is nothing, but the size of my vessel the actually that is not true. Because in mass most of the multiphase flow reactors because of the presence of the second stage, we need to give some extra volume to accommodate the second space the expansion cost because of the second space phase. So, suppose there is again I will say that a column which is say filled with the water.

Now, suppose initially the height of the column water in the column was h; now if I start injecting some of the air from the bottom then what will happen the air will form a bubble and they will rise up. Now because of this bubble injection or the air injection the volume expansion we take place because now in the same volume the bubble will also occupy some of the volume.

So, what will happen you will see that the liquid level rise is as you really increased by say delta H. So, it what happened that it means your volume of the reactor initially was this much; initially was say this much, but now you have a extra volume added in this. And why it is more critical to understand the volume of reactor because this delta H is actually going to be the function of velocity; this is velocity. It means what? If I increase the more and if I push more and more air inside the column then what will happen the increasing the height will be higher and it we keep on increasing because now you putting more gas fraction inside; so, the volume expansion will take place. So, it means volume of reactor is also going to be the function of the flow rate of the discrete phase which were playing inside.

So, that is why is the one of the important valuable is to understand the reaction mechanism or to understand the contacting mechanism is that what is the volume of my reactor. Then there is a volume fraction of the dispersed phase; now what is volume fraction we will introduce it in the latter classes, but the for just giving a brief introduction the volume fraction is nothing, but the fraction of that phase divided by the total volume of the reactor.

So, suppose if I am having gas and the liquid which is flowing inside the actors I will say that volume of the gas divided by the volume of reactor is nothing, but the volume fraction of the gas. So, that is the way the volume fraction has been defined. So, it means what if I am injecting the liquid say gas inside the same column if I consider then what will happen that the volume fraction it means the phase distribution of the gas phase suppose if I am talking about that is called the phase fraction of volume fraction.

Now, the problem is this volume fraction is actually the function of both location as well as time. It means what? Suppose the same example if I am filled the tank with water and I am injecting air from the bottom. So, what will happen? The bubbles will form now with the time the bubble actually will move upward. So, what will happen? That the fraction of the bubble is changing with the time because your bubble moves upward the new bubble taken that place to know your number of bubble will actually increase.

So, it is going to change with the time and they will be bubble at the centre and say there is no bubble at this place. So, there is no bubble at this place, but there is a bubble at these places. So, it means what the fraction of the gases is also going to change with the position. So, it is volume fraction which is actually the function of both special location and position even for a steady state operation.

Now, what does it mean? So, suppose I am putting the gas which is at steady state condition, I am injecting the gas which is the velocity of the gas or the flow rate of the gas is not changing with the time, I have operated the reactor for a sufficient long time still you will see that the phase fraction is going to change with the time and with the location. So, at a steady state condition also you will see that the volume fraction is going to be the function of a special location as well as the time. So, that is one of the important variable that we need to understand about the volume fraction.

Similarly, the mean velocity of the phases; so, mean velocity of the phases suppose if I am talking about gas phase to the mean velocity of the gas phase or the liquid if I am talking about liquid then the mean velocity of the liquid phase. Now the thing is that this mean velocity is actually the function of the position. So, this also is vary with the function of the positions of the position the mean velocity will vary it is the special location, it will keep on changing; with the time it will not change because the time average mean velocity ones we are saying.

So, what will happen? Why this is a function of location? Because again the same example a bubble column which is filled with the liquid a bubble which is passing through at the centre of the columns so what will happen? At the centre they will be some bubble velocity while near the wall because there is no bubble is there the bubble velocity is going to be 0.

So, how the graph will look like? If suppose I plot it from minus r to plus r minus r to plus r, the bubble volume velocity then what will happen; you will see that here the velocity is very low it will be very high at the centre and again it will be very low; so, this is the velocity. So, you see this kind of graph, so, that is the reason that mean velocity of the phases are going to be the function of the position though they may not be the function of time.

So, that also becomes a very critical parameters then the local velocity of the phases it means suppose if the gas is moving up. So, in form of the bubble the velocity of the bubble is going to change with the location with the time because the forces dynamics will keep on changing. So, that is the reason that local velocity of the phases is also very important variable to understand the multiphase flow reactors.

Then dispersion and mixing behaviour of the phases; so, if suppose I am injecting a gas of a particular type which is very highly dispersive; then the mixing behaviour will be different; if I am injecting that gas in the liquid where this very low this thus percept in the mix in behaviour will be different. So, we need to calculate the dispersion and mixing behaviour of the different phases and that is again going to be the function of time and space. So, that becomes again a very critical parameter; important parameter in the multiphase flow reactors. And then there after mass transfer coefficient and heat transfer coefficient is also going to be the very critical parameters to understand the multiple flow reactors. Now why these are the critical parameters; because finally, we are looking for enhanced mass transfer or enhanced heat transfer or both together in a multiphase flow reactors.

So, there are whatever the variables is there now why we need to study the force even after widely used such a wide application why the multiphase flow reactors are still very kind of purely understood. And particularly the design and scale up of these columns are they still state of art rather than a state of science or what is the reason behind this. If I try to see that what is the reason behind or what is the issues in the multiphase flow reactor which I still unresolved and people are trying to work to understand or to resolve those issues.

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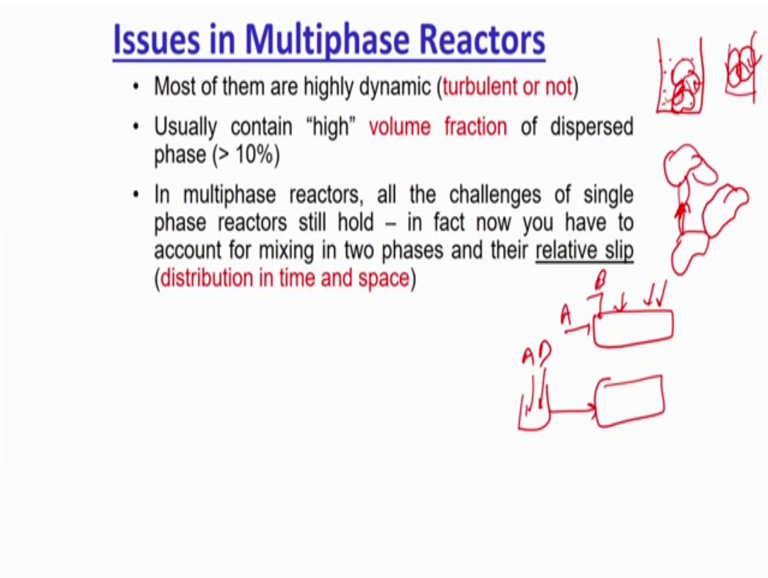

So, one of the issue is that most of these lectures are highly dynamic in nature. So, you are actually having either you are having a turbulent flow or you are not having a turbulent flow; the system is very very dynamic which is not correct in case of the single phase system a single phase flow system becomes very dynamic once the flow is turbulent.

While in multiphase flow even if a system is operated at a very low velocity is still there very dynamic. Now to explain that again I will go to the same example that there is a liquid column a liquid is filled inside the column and a gas is passing through. So, let us assume that a single bubble is being injected inside. Now the single bubble is injected inside what will happen?.

The bubble will rise and as the bubble with rise there will be some weight formation behind the bubble ok. And because of that some liquid will be pushed inside and liquid will start moving up near the bubble and down far from the bubble. So, you will have a circulation pattern in the mean average sense, you will get something like this you will see that this kind of. So, it is going up down near the wall and there is weight formation too.

Now, because of this weak formation some of the liquid with be actually sucked inside or it will push the bubble up. Now at the same time if suppose I inject the other bubble what will happen? The other bubble in presence of this weight will actually move very fast; suppose this is the weight of the bubble and if I inject the another the bubble here then because of the presence of this weight the bubble will actually move very fast and they will actually combine and form a even bigger bubble.

So, it makes the system very dynamic. So, there was initially one bubble there was a weight of the bubble that itself is a very dynamic system. Then if you inject the second bubble the if the second bubble comes in the weight of the first bubble, then it will get sucked and they both will trying together in form of bigger bubble capable.

So, what will happen? You will soon see the distribution of the bubble size. So, what will that will going to make that is going to make the system very very dynamic? Because you are having now a different length scales in what or different time is scales in not because you are also having eddies. So, understanding this angle system even for the low velocity where you will inject 1 bubble or 2 bubble or 3 bubble together only it make the system very very complicated because of a dynamic nature, then most of the time the chemical engineering perspective.

If we think about the multiphase flow reactors our volume fraction of dispersed phase fraction is more than 10 percent. So, what happens more the dispersed phase fraction more the interactions will take place and you will see the different kind of a distribution. And that distribution will also depend on the interactions of the phases which is taking place.

So, interaction between the two phases and interaction between the two bubbles or you can say the two of the different discrete phases which are still discrete have the same material, but the interaction between them. So, like in this case if I discuss that one bubble is getting sucked and in the wake of the other bubble and forming a big bubble that is the interaction which is taking between the two dispersed phase material.

So that is that kind of interaction is increases rapidly if your volume fraction is increasing and that makes the reactor whole opaque and is very difficult to analyse those reactor with the naked eyes. So, you need to have advanced measurement techniques to understand this kind of a reactor.

Now, another problem with the multiphase flow reactor is that; so, whatever the problem of the single phase flow reactor is there that is still holds. It means if you want to understand the reaction kinetics you should know that what should be the contacting pattern say A and B is contacting with each other both of the liquid phase, but how we should contact with each other whether we should flow it together where we should first mix then flow or we should inject the B at different locations.

So, we can have either both A and B can be fled together A can be fled together and B can be injected. So, A can be fled at one place and B can be injected at several other places. So, that can be all one possibility is that you mix A and B together in tank and then you feed A plus B mutual inside the reactor.

So, for all these cases the contacting patterns is different and because of that the reaction kinetics will also be different or performance of the reactor will also be different. So, your all the challenges of the single phase flow reactor will still intact. And there are many challenges in the single phase flow reactor like how what type of reactors it is whether it is a CSTR whether it is PFR, whether the flow is laminar, whether the flow is turbulent.

If the flow is turbulent how much is the thickness of the boundary layer, how they are developed whether they are developed or not developed flow? So, all these challenges are we still hold in the multiphase flow and what the extra challenge you get is that the mixing in two features. So, suppose now I have two phases I have to also worried about how these two phases A and B are mixing with each other.

Once they are in the same phase the mixing is going to happen it is a issue, but it is not a issue which is going to dominate the performance of the reaction. But in case of the multiphase flow the mixing of the two phases is very very critical and that mixing of the two phase as well as the relative slip between the two phases; they are very very critical and they are actually distributed in time and space it was there going to change with the time and with the space.

Now to understand that; why this is very critical the mixing of the two phases again the same thing.

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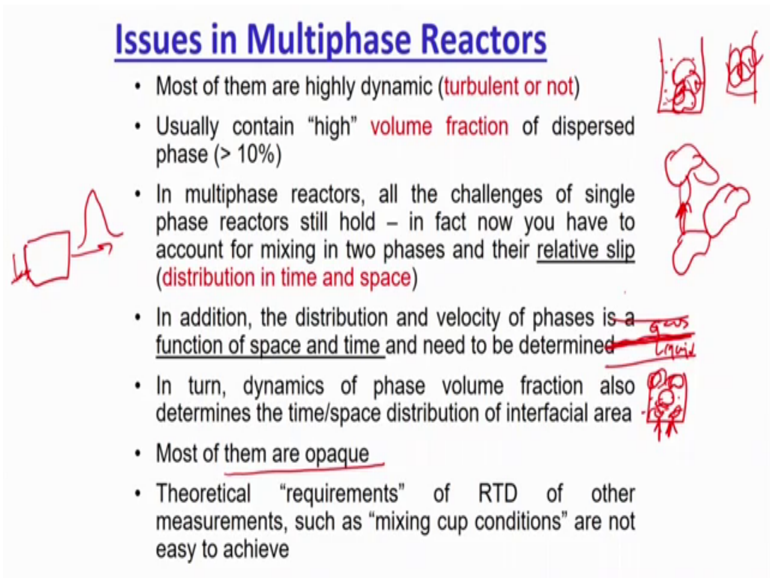

Suppose there is a gas which is flowing outside in a pipeline and liquid which is flowing down side of the pipeline. Now because they are separated the reaction will happen only at the inter phase suppose if these two are reacting you will see the reaction at only interface.

Now, if I mix it the gas somehow in the liquid suppose if I take a bubble column similar whatever we are discussing I take a column I fill it with the liquid I injected the air from the bottom and I have suspended several of the gases inside. What will happen now? Now the dispersed phase concentration changes the mixing of these two pages is going to change and now the reaction will take place inside the bulk of the liquid at the interface of the gas and liquid. So, you actually enhance the reaction right or you will enhance the overall phase.

So, the mixing of these two phase flow and the relative slip between these two flows are very very critical to understand in the multiphase flow reactors, but the problem is understanding these details are not very easy and lot of people are you still working on to understand the mixing behaviour inside the multiphase flow reactor. So, that is again issues the multiphase flow reactor and it is not very easy to quantify that so, that makes the problem even more complicated.

Now, again in this case in addition to the distribution of the velocity of the phases is also a function of space and time I need to be determined. As we already discussed that the multiphase flow reactor the distribution they are distributed the two phases of mixing as well as or the relative set is distributed in the space and with the time it means it changes with the location and with the time.

Similar thing is true with the velocity of the phases which is the function of space and time which means the velocity keep on changing if you change the space and the time with the time it keep on changing like a small bubble they merge with the two small bubbles form a bigger bubble. So, what will happen now the bigger bubble velocity will be quite different compared to the two smaller bubbles.

So, there velocity has actually changed; so, that is also an issue in the multiphase flow reactors that the velocity of the phases is going to be the function of the time and the location inside. So, that need to be determined to understand the multiphase flow reactor and that becomes a major issue too.

So, again in turn of the dynamics of the phase volume fraction determining the space this distribution of the interfacial area. So, it was all because the dynamic volume fraction; the volume fraction itself is a very dynamic as we discussed that there is one single bubble now the two two single bubble suppose is moving together. Once the second bubble comes in the wake of the other bubble the first bubble they actually get served in the form of bigger bubble.

Now, because of that the volume fraction is actually being modified and because the volume structure is modified your distribution in terms of the space as well and in terms of the time is also going to be modified. So, it means what it is a very dynamic system where everything keeps on changing with the space with the time and that is make the problem more complicated and difficult to understand ok.

Then another problem is most of the stem most of the multiphase flow reactors or contactor opaque in nature. Now this is a major problem because if we see something we are able to feel that what is happening inside, but if you are not able to see anything inside that what is happening it is very difficult to assume or to understand or to believe that what is happening.

So, suppose if I eat something and I do not know where it is going actually. So, to understand all those things you need to do the scanning because I cannot see what is happening inside my stomach. So, once I eat a apple; I do not know how the apple is going to be digested what the process which is actually going inside. So, we understand the body very well.

So, that is why you can predict that what will be happening, but suppose inside the reactor which is not visible at all from the outside and if you put something some reaction is happening; how you will find that the reaction will happen or this is happening inside. So, the problem is that that most of the systems are opaque in nature and that is why getting a feel of the system is also very difficult.

Now, why they are opaque? So, it is not like because all the walls are made of (Refer Time: 39:20) or all the walls of made of the metal. It is not because of that because you can put the when the windows screen or you can make the column of completely of the glass. So, even if you do that you make the column wall transparent because of the very high dispersive why is high dispersed volume fraction the pH kind of one fraction that dispersion of the light was very very high diffraction and dispersion of light is very very high and that makes the system opaque.

So, though you make the wall transparent, but if you say volume fraction of the gas inside a gas liquid system which is made of the glass if the volume fraction of the gas is more than 10 to 15 percent, you will not able to see through inside because to see through inside the light should pass through the system we should not allow it to do that. So, that is the another major challenge that most of the systems are opaque in nature and has to get a feel of the system or to major the system is major to develop the understanding of the system or do any kind of measurement is very very difficult and you need to depend on the advanced measurement technique to understand these details.

Now, another problem is that the theoretical requirement of RTD measurement such as mixing cup conditions are not easy to achieve. So, like what does it means mixing cup model; so, if you suppose you do the RTD in a system to find the behaviour of the reactors which is a popular in single phase flow. So, supposing in single phase flow I have a black box or a column say I will say it as a black box and I want to find it out what how it is behaving whether its CSTR or its the PFR or it is close to CSTR or close to PFR. So, what I will do? I will inject a treasure inside I will inject a treasure inside and once I will inject the treasure say I will see the response of that treasure at outlets.

So, depending upon suppose the response of the treasure; I can calculate the dispersion number and we can find it out based on the dispersion number value that whether the system is pure PFR or it is pure CSTR. So, if the dispersion is very very high it means it is going to behave like a CSTR and if the dispersion is very very low or 0 which is going to behave like a PFR. So, I can find it out the RTD curves; now for RTD it is very important that before it is inlet entering to the system the treasure is entering to the system they are perfectly missed; so, open cup mixing cup conditions is being satisfied.

Now, in case of the multiphase flow it is very difficult to expect that that the mixing cup conditions are going to be satisfied. Because the different phases which are flowing together; so, that cannot trap actually or cannot track both the phases and that is the reason that doing even RTD experiment in the multiphase flow reactors are very very difficult. And that is the make the problem to understand the reactor behaviour because we cannot find that how it is your dispersion number or what is your dispersion values to quantify that whether the multiphase flow reactor is more towards the CSTR or it is more towards the PFR.

So, these are the another issues which actually we face while understanding the multiphase flow reactors then there is a scale issues. So, now, what does a scale isssue means? So, multiphase flow reactors are pretty much the performance that depends on the scale. So, suppose if you are operating of multiphase flow reactors at a smaller scale say laboratory scale. And you are trying to do the scale up from the laboratory scale to the multiple to the palak plant scale the behaviour may change. Now why the behaviour change, because the dispersion nature of the phases actually changes and that changes with the space, with the time.

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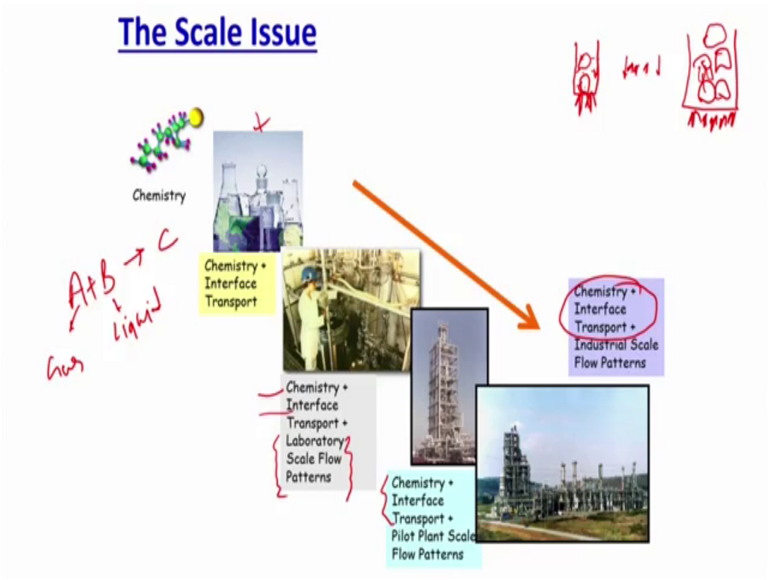

So, now if suppose I am injecting is bubble or air at this column in a column which has been having a very very low diameter and the liquid used say filled inside; so, what will happen the bubbles will form and they will move up and because of this movement you will see some velocity. Now if the column diameter is very very small what you will see you see that bubble may fill the entire column diameter or it will form say it fills 70 or 80 percent of the column diameter.

So, what will happen? The liquid around 70 to 80 percent will move up and very small amount of the liquid will be moving down near the wall. So, the velocity of the negative velocity may be higher, but the location or the area for that negative velocity will be very very low.

Now, if I increase the diameter of the column and if I again inject the air what will happen? Though if I proportionally increase the air velocity what happened the bubbles will form. So, multiple bubbles will form, but as I said that because of the wake of the first bubble, the second bubble may go and stick with the first bubble and actually do the colassions and form of bigger bubble. So, what will happen because of that bigger bubble fraction the velocity distribution now may be entirely different compared to what you are getting in a very small column.

So, though I increase the Reynold number or you can say that I maintain the Reynold's number of the injecting gas still you will see entirely different profile. So, the behaviour of the multiphase flows is actually depend on the scale and that makes the life really complicated and that is the region that is still there a lot of scope to improve the design of the multiphase flow reactors. And there lot of scope of developing understanding or doing some novel things to improve the overall technology.

So, why this is a scale issues? What is dependent? I told you now to formally say that suppose if I have a chemistry with me. So, I develop some chemistry say A plus B is forming C this forming C I have a developed a chemistry now giving (Refer Time: 45:03) to the guys who developed the chemistry; most of the time this chemistry are you develop at a flask scale experiment.

So, it means what you do? You actually to develop the kinetic; so, will take a very small amount we mix A and B together we mix it at a certain temperature, pressure, flow conditions, mixing education (Refer Time: 45:21) and all and to develop a chemistry. Now the chemistry developed is combination of the chemistry plus interface transport. Now interface transport means suppose there is two phases how the two pages are transferring the mass with each other at the interface? So, that is the way the chemistry is being developed.

Now, once the chemistry is passed what we do? We transfer the technology from the lab scale with a flask scale to a laboratory scale set up we make a very small setup and we start flowing dnb into a continuous reactor we always want to operate a continuous because I want a higher yield. So, if there will be continuous I can process more of the fluid and I can have more air and more profit.

So, if I transfer it to a laboratory scale set up even suppose that a batch scale; even if I do not go for the previous flow now what will happen? Now the mixing characteristics will be different because; now you have a little bit larger setup. And if you are flowing through the setup: if suppose you want to convert from the flask to a continuous system now you are flowing through.

So, it means what? Contacting of A and B will depend on the mixing pattern or the flow pattern at laboratory scale set up which we generate ok. So, now whether the floor is laminar air flow is turbulent say so, the A and B is gas and B is a liquid. So, whether both gas and liquid are flowing inside; both are turbulent one is laminar one is turbulent both are laminar what are the combination.

Now depending upon your flow pattern was developed and that flow pattern is actually going to you will see some other result. And that other result of the different which you get the result in the result or in the product yield or in the convergence or in the final concentration that is mainly responsible because of the chemistry, interface, transport which are going to be pretty much same whatever you have developed provided your maintaining the same conditions, but you will see the changes only because of the laboratory scale flow pattern which is being introduced extra ok.

Now, what happened? Suppose the process is got successful, you have seen some conversion some change we will see, but say it is within the acceptable limit. So, what we do? We convert we make a pilot plant scale set up. So, we covert this small scale to little bit bigger scale now what happened again here at this scale. Because now you change the column dimensions again whether you are laminar both are laminar one is laminar one is turbulent how they are interacting; how the bubbles are interacting with each other, you will see the different flow pattern.

And what will change actually from the laboratory scale to the pilot plant scale the chemistry is going to be same, interface transport is going to be the same only the laboratory scale flow pattern will actually now modify to a pilot plant scale flow pattern why? Because I have already discussed that it is going to be the function of the diameter ok. So, again you maintain the Reynold's number of the injection same because the physical dimensions has increased and we know that the phases distribution is changes with the location, with the time you are going to see a change in the flow pattern. And because of that new flow pattern or modified flow pattern I will say you will see some other conversion, you not see the conversion which you have actually started with a laboratory scale set up at the setup.

Now, if suppose this is also successful and we got some result then what we do? We modify it we go for a full industrial scale plant. Now once we do the full industrial scale plant; again the chemistry and interface transport remain same, the flow pattern changes because the dimensions are changed the processing is changed the throughputs are changed.

So, again the final conversion of final value whatever you will get the concentration or the reaction kinetics or your overall product selectivity or it; now will depend on that what is the flow pattern you are getting at industrial scale. So, what was the problem? The problem is that all this things before patterns is keep on changing with the dimensions. So, it is going to be changed with the scales and because it is changing with the scales that makes the problem more complicated more interesting more challenging.

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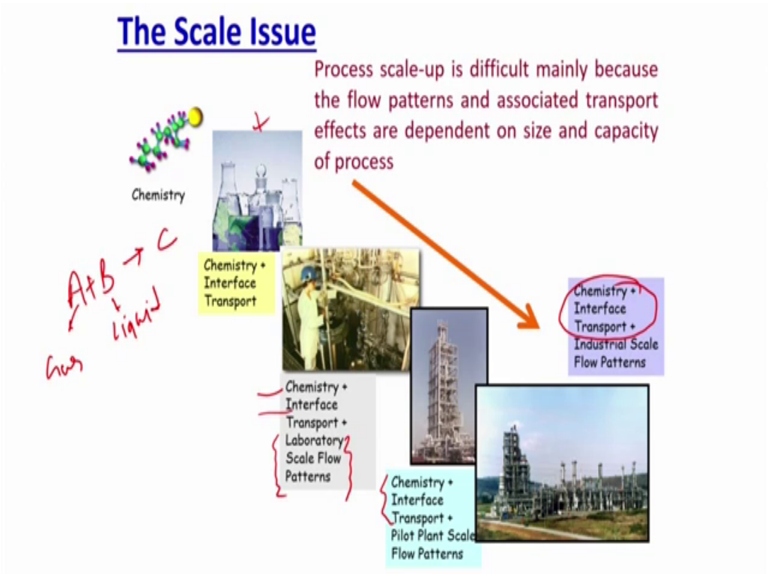

And why? Because, we know that the flow patterns are actually dependent on the size and the capacity of the process, you increase the capacity or increase the size your flow pattern is going to be changed.

So, it is very important to understand that how this lock pattern is a function of the size of the reactor of the capacity of the reactor. And to understand that you need a very sophisticated measurement tools as well as the modelling tools and moreover before that you should understand the system in great detail. And that is what we are going to do in this course that will try to see that how the flow pattern of different reactor take place, how this flow pattern depends on the size of the reactors as well as for the different throughputs?

If I change the throughput how my flow patterns are going to change? How to model those flow patterns? How to write the equations for the different type of flow patterns and how to predict the behaviour of the reactors in the flow and what are the forces which are going to act and at what level which courses are going to be dominating. So, that will be entire thing what we are going to cover and that is the basic motivation that why the subject itself is very critical very important and very interesting to understand.