Fluid Flow Operations

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Module – 12
Multiphase flow phenomena and its application – Part 1
Lecture - 30
Introduction to multiphase flow

Welcome to massive open online course on Fluid Flow Operations. In this lecture, we will discuss about the Multiphase flow phenomena and its application and this will be a module 12. And under this module, we will discuss the Introduction to a multiphase flow and also a some hydro dynamic aspects of the multiphase flow, some typical example of multiphase flow will be discussed in the subsequent lecture with its application. And here, we will try to just introduce what is that multiphase flow here in this lecture.

So, we have already discussed the phenomena of a single phase flow whether it is laminar flow or turbulent flow or how it will be behaving with the phenomena of what is that is there any drag force or any lift force or not. Even there are several, I think governing equations that we have given for discussion of single phase flow in different type of conduits and also we have discussed the flow measuring devices the for the measurement of flow rate of this single phase flow in the devices.

Now, in this module we will try to discuss that instead of single phase flow what should be the multiphase flow system. Except single phase flow there may be more than one phase they are several applications of this multiphase flow in our chemical even biochemical industries and also other several operations. They are this more than one phase is really applicable there. And in this case, you will see then; we will then discuss what should be the actually basic understanding of that multiphase flow systems. You know that if you are considering that there will be more than one phase, then only it will be multiphase flow.

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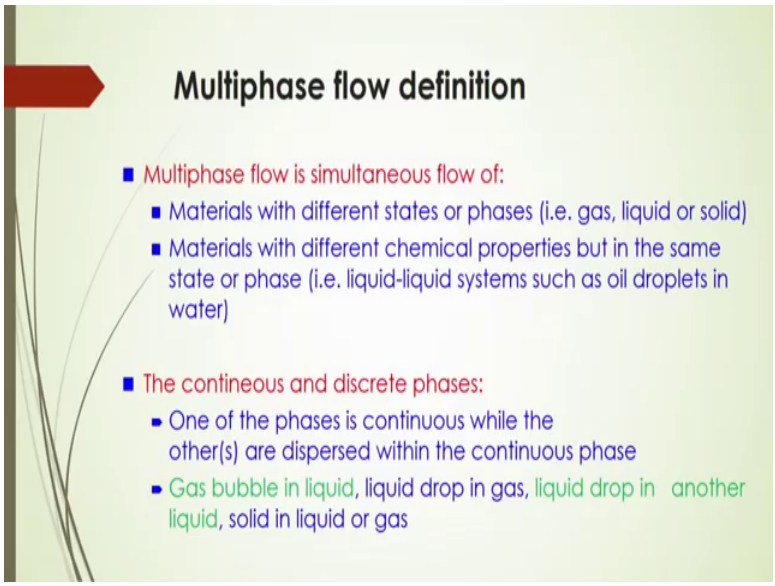

But there should be a certain definition of that of course; that we can define in this way of this multiphase flow that it will be a simultaneous flow of materials with a different states or phases like gas liquid or solid. So, in this case gas liquid even combination of gas liquid, combination of liquid solid or combination of gas liquid solid simultaneously will be flowing in a system for a particular process. So, in that case, the based on these multiphase flow phenomena the process will be designed and then accordingly what will be the performance of the process, that what would be the yield of the process that will be actually calculated based on the flow phenomena of this multiphase flow.

Now, this we can define this multiphase flow in other way. Sometimes you will see there will be more than one phase, but there may be miscible to each other. So, in that case, you have to consider that there will be two components of that, particular single phases. But sometimes you will see that there are single phase, but there will be immiscible to each other.

In that case, also it will be considered as a multiphase flow sometimes the different chemical properties will be there and on the same state or phases that is where they will be they may be the immiscible to each other like kerosene and water both will be flowing through the pipe. In that case, you will see they will be simultaneously flowing and they are immiscible to each other.

So, in that case, those flow will be considered as a multiphase flow. And the separate phases simultaneously flowing that will be multiphase flow even material. So, the different chemical properties, but the same state or phases then it will be called as multiphase flow, like liquid-liquid system. They are such as oil drop plates in water like this. And you will see whenever this combination of this phase like gas liquid or liquid solid or gas liquid solids simultaneously or liquid-liquid that is immiscible to each other. Whenever it will be flowing, then you will see one phase will be in a certain manner whenever it will be flowing in a condoled.

So, upon these two phases, one of the phases will be continuous while the other phase will be dispersed. Like if you consider that there will be a gas is flowing through the liquid like, gas cannot be flowing in a column as just in a just on a what is that in a single phase in such a way that it will be continuous it may be there sometimes. So, inverted column in the core of the column there will be a flow of gas. Whereas adjacent to the wall, there will be a flow of liquids, so, there will be a flow.

So, in that case both phase may be continuous, but generally you will see the immiscible that is which fluid will be lighter than other that fluid will be dispersed in our continuous liquid. So, whenever gas is dispersed in a liquid as a dispersed phase of bubbles, then you will see the flow will be multiphase flow and in that case the gas will be as dispersed phase and a liquid will be continuous phase.

So, whenever multiphase flow phenomena will be considered you will see one phase will be continuous another phase will be dispersed. Like solid and air suppose particulate or solid particles is flowing in a atmosphere. So, in that case, particles are dispersed whereas, gas or atmospheric air will be as a continuous phase.

Now, some examples here, you will see that as bubble in liquid sometimes liquid drop also in a gas whenever you will see in a spray column in chemical engineering operation you will see for absorption purposes you will see. The liquid will be sprayed for the column, there and from the bottom of the column there will be a gas will be flowing up. So, in that case liquid droplet will be sprayed and the continuous air.

Also you will see may be if there is a kerosene and water flow rate, you will see the kerosene is lighter than water. So, in that case, kerosene droplet will be moving through the continuous water there. And also solid in liquid or solid in gas, those are will be the

multiphase flow phenomena and in this case one phase will be the continuous and another phase will be the discrete or dispersed phase.

So, we are having the definition here what would be the multiphase flow phenomena do. You have to remember that materials with the different states or phases, it will be called as multiphase system. There may be more than one phases like gas liquid even liquid solid gas liquid solid. So, two and three phases generally is considered as the multiphase flow system. So, in that case, one phase will be of course, discrete another phase will be continuous. So, any phase you can make discrete or disperse and another phase should be what is that continuous, but you can make it reverse through a also based on your system design.

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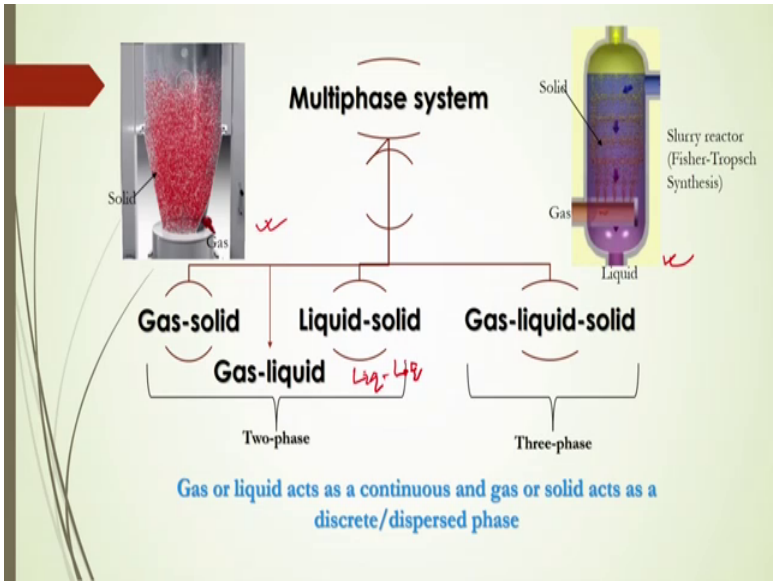

Now, here see, then we can classify this multiphase system as here what is that gas-liquid, liquid-solid and gas-liquid-solid. Even the two phase one can categorized into two phase and three phase in two phase, you will see gas liquid, liquid solid and gas liquid even you can have here liquid and liquid also liquid-liquid. Though it is one phase, but since its physical properties are different from each other, so, it will be considered as a multiphase flow. And here three phase flow; it will be there what is that gas liquid and solid. See here on the figure it is shown that in a continuous gaseous medium solid particles is dispersed there. So, it will be gas solid operation on two phase flow.

And in this figure, you will see there will be a continuous liquid phase and whereas, liquid and gas will be dispersed in the continuous liquid phase like a slurry bubble column reactor. In that case, solid particles solid and liquid will be made as slurry and in that slurry liquid will be continuous and solid will be dispersed in the liquid. And on that the slurry system, gas again will be a dispersed through the distributor as a dispersed phase of bubbles. So, that is why this three phase will be considered as gas liquid solid flow and phase and it will be considered as there are slurry bubble column reactor.

Now gas or liquid acts as a continuous and gas or solid acts as a discrete or disperse phase generally it is considered in the two phase or three phase systems.

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Now, here see video that some from our experimental condition and even in our laboratory see this is one type of bubble column reactor. This gas liquid operation, here see gas is dispersed and the liquid continuous liquid medium as a dispersed phase of bubbles and see how it will be moving up from a bottom through a Spurger through a distributor gas distributor ah. Here this is gas distributor. So, from this gas distributor gas is just coming out at a disperse phase of bubbles. So, here it will be called as gas and liquid flow.

It is one type of multiphase flow system. Even in these systems, you will see you can use that slurry system also because here if you are using that liquid as a slurry, there just mixing some solid amount of solids there and then you make it slurry. And then if you

are supplying the gas in the slurry medium as a disperse phase of bubbles, then you can consider it as a slurry bubble column reactor. And here another examples, in this figure, you will see there will be a operation of gas and liquid flow. So, there you will see sometimes for trying purposes or roasting purposes even sometimes, you will see there will be a absorption purposes suppose gas is absorbed to the solid a bed. Then that case gas and solid will be dispersed in the column and then you will see, there will be a absorption from the gaseous medium to the solid medium.

And in other applications like if you consider that our coffee bean you will see, they are what in our daily life we are taking the coffee. In that case, you know that how this coffee is being roasted. And you will see; the green coffee after roasting, it will be becoming a brown coffee and after that it will be making as a dust and then that is powered then you are mixing and you are making the coffee what is ready for you.

Now in this case how this coffee green coffee, it is being roasted and after that it will be making a powder. Now before going to make it powder, you have to roast it. Now what is that operation, roasting operation and it is of course, the multiphase operation because here. Two phase systems are working; one is air as a gas another is what is that coffee bean as a solid particles. Then you will see what air to be supplied that is certain temperature to fluidized that coffee bean and then you will see after a certain period of time. Then you will see continuous operation of this supplying of this hot air this coffee bean will be converted to the roasted coffee bean, it is brown color.

You see this video, then you will understand how this. This is the green you will see this green coffee bean this green coffee bean is taken in a column and in this column, you will see from the bottom there will be a supply of hot air at a certain temperature and you will see that how coffee bean is being actually fluidized whenever that hot gas is supplied or water is supplied they are.

Here start supposed at for 3 minutes, you will see how it is coming. They are start of roaster 3 minute at 310 degree Fahrenheit, then you will see how this coffee bean. These are see green after the certain time, you will see it will make brown color; that means, here it will be roasted see here. So, hot air is just roasting this coffee bean and baking it brown color that is simply a frying.

So, this is simple two phase operation of gas and solid and after a certain times, you will see all this green coffee will be becoming a what is that brown color coffee. And after that it will be made that what is that dust or powder and then it will be used for your coffee. So, this is one type of operation of this multiphase flow. So, it is called two phase flow that is gas and solid.

You will see another here one video here you will see, there is another operation that is three phase flow gas liquid solid. You will see how gas is distributed from the bottom of the column whereas, this gas is dispersed as a displace disperse phase of bubbles in a slurry medium that is liquid and solid mixture.

So, liquid and solid mixture, it will be called as slurry. So, in this slurry the gas is supplied from the bottom of this column as a dispersed phase of bubbles. So, this type of operation is here, you will see pressure drops synthesis for a particular temperature. Then how the different gaseous products is made from the liquid, then how at a particular catalyst, then this type of operation will be called as a pressure drops synthesis. This is a fluidization operation and in the energy section in petroleum industry. This type of operations is used. So, this type of operation, we have already discussed in I think other courses that fluidization operation there.

We have discussed all those operations there. And another important this slurry bubble column; see how bubbles are forming from the bottom and it will be continuously moving up and then there will be certain process for products there in industry there using. You will see some examples of gas liquid operation like suppose carbon dioxide gas is to be absorbed in a liquid medium. So, how to actually operate and how to get this product of the reduction of the carbon dioxide from the atmosphere by this operation?

So, this is one type of multiphase process system in that case you will see carbon dioxide gas to be supplied in carbon dioxide gas to be allowed to pass through this sodium chloride solution as a disperse phase of bubbles. So, that bubbles will be forming in that case, bubbles will whenever it will be dispersed in the liquid form liquid-liquid medium, then, there will be a formation of interspatial area between bubble and liquid. So, through that interspatial area, there will be a transfer of carbon dioxide molecule to the liquid. So, this is one type of mass transfer operation for this absorption process. So, this is called two phase flow operation.

This is physical processes even other processes also you can say some reactions also. If you suppose example as an, example if you want to do the advanced oxidation there in a bubble column, you can also do. In that case, you will see suppose if you want to degrade or what is that or oxidized that pharmaceuticals products or suppose phenolic compound, organic compounds into its derivative, then you can use ozone gas that ozone gas as an advanced oxidation that ozone gas as a ozone bubble through in a bubble column reactors through the distributor. Then you will see there will be a reactive mass transfer and also reactions as well as mass transfer will be there.

So, this type of operation that is called what is that two phase that is in reactive two phase flow. So, these type of operation are being done in waste water treatment even some other particular product to obtain that product. Even in slurry bubble column reactor, you will see that if you want to make suppose chlorobenzene or benzene chloride you can say.

So, in that case so, what you have to do? In the benzene liquid medium, you have to supply the chlorine and also you have to use some catalyst there. So, in that case catalyst and the liquid that will be slurry and then slurry medium if you supply the chlorine gas will see, there will be a reaction and at a certain temperature and pressure you will see there will be a product.

So, this type of operation to make the chloro benzene this slurry bubble column reactor is used. Even start tank reactor also that is sometimes for gas liquid and catalyst particles slurry column also, it is being used. They are gas is supplied from the bottom or some other means us as a disperse phase of bubbles and you will see, there will be a formation of interfaces through which there will be a reaction and mass transfer out there.

So, this type of operation is there multiphase flow operations. Also you will see in floatation column in mineral industries, one of the very important process for which the separation of the what is that particles or you can say beneficiation of the particles that is mineral particles in the what is that floatation column.

There also this is three phase operations some you will see that ore particles or suppose coal beneficiation coal particles will be actually be you know, that synthesized or gas will be produced from the coal particles; they are and different gaseous products can be

used by what is the combustion of coal. So, the that type of operation also it is two phased flow that is gas and solid and you will see in floatation column, you will see coal.

Suppose you want to reduce the sulfur from the coal, you have to actually fluidized that coal particles by what is that you know that by ozone gas or some other gases. So, that that sulfur can be converted to some other what is that the compound chemical compound and so, that you can easily separate that the compound.

So, this type of operation is called three phase flow system. Even for separation of the particles in floatation column if you allow the gaseous or air bubble from the bottom in a suspected medium or floating agent of rotation column, you will see there will be a separation of the particles from this mixture of different particles and this type of operation is called that three phase flow. So, multiphase flow systems those are applications. So, any real process any chemical engineering process or bio chemical process is also there also use this multiphase flow system.

Anyway that the single phase flow may not be there may be mixture of phases. So, that will be operated in a particular process. And so, whenever we are talking about that multiphase flow system, there are several applications in the real our that is particle life that whatever products we are getting. All those products are coming through a process and that process may be what is there may of course, there will be a process that is involving that more than one phases.

So, multiphase flows several applications in chemical bio chemical even a processing civil engineering also they are operating. Suppose you will know that operation of the soil that soil mechanics. They are also you will see that there will be different components of the soil particles and how to process that soil part soil to get its different types of products.

They are also it is an also removal of contaminants from the what is that soil that you can have by this multiphase operations with a certain process. And so, this is now basically what are those combination of those gas-gas, what are the different operations. Let us have some idea of that two or more than four phases here.

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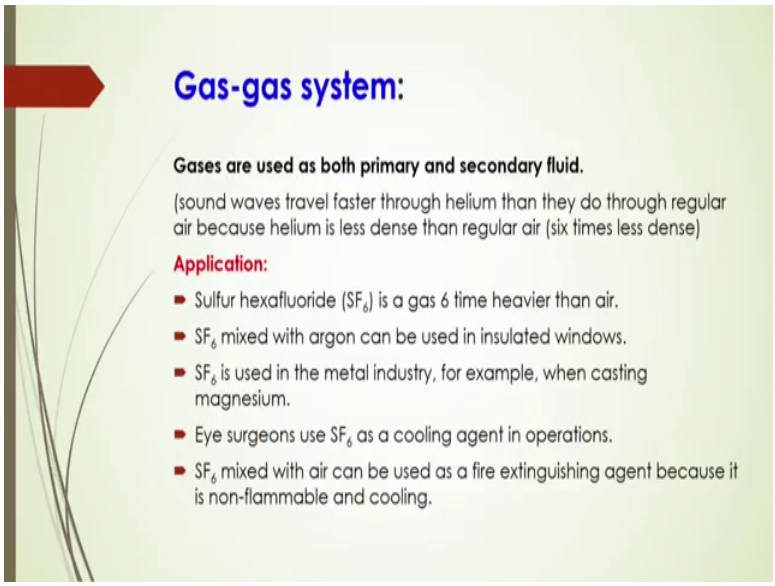

One by one let us consider that gas-gas system. There is a operation of gas and gas that is both gas two gases will be use simultaneously for a particular processes. In that case, gases are used as a both primary and secondary fluid here. That is one phase will be continuous another phase will be discrete. Now, sound waves travels faster through helium than they go through regular air because helium is less densed than what is that regular air. So, in that case helium gas will be what is that will be forming a helium gas bubble in a air system. So, you will see, there will be a formation that is discrete helium gas should be discrete particle as a discrete in the air.

So, this is one things and another that sulfur suppose hexafluoride this F 6 is a gas which is 6 times heavier than air. So, this is what is that this is immiscible to gas system and if you mixed this sulfur hexafluoride with argon and this mixture of this sulfur hexafluoride and argon that can be used in you know that insulated windows. And also this sulfur hexafluoride is used in the metal industry for example, when a casting magnesium there. And also I suggestions use sulfur hexafluoride as a cooling agent in the operations and it will be mixed with air and this mixture can also be used as a fire extinguishing agents because it is non flammable and cooling agent.

So, this type of operations some examples that how this gas-gas systems are working. So, this is one type of multiphase flow system. Now gas liquid flow systems let us see that what is the example for that. Now in this case gas is used as a dispersed phase and liquid

as a continuous fluid which are most important form of multiphase flow and is found widely in industrial applications.

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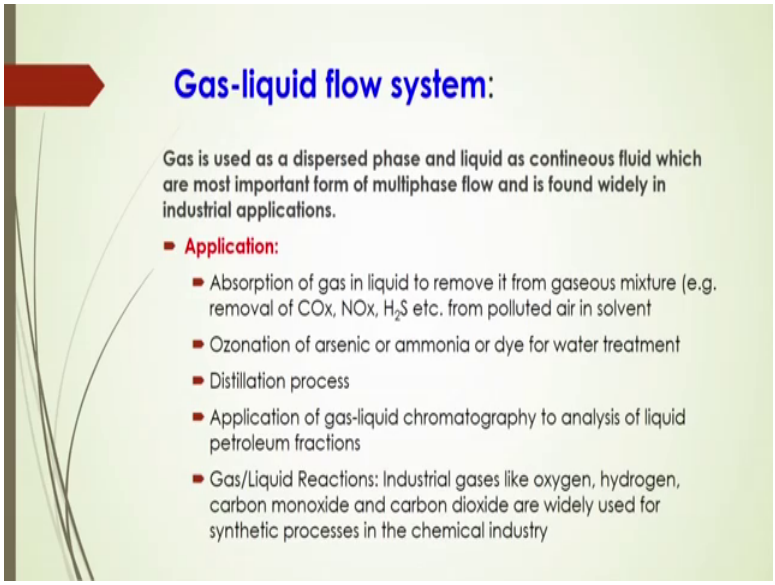

Now, some applications like here you know that absorption of gas in liquid to remove it from gases mixture and removal of carbon dioxide, removal of nitrogen dioxide even hydrogen sulfide from the polluted air in solvent that is one important operations for the absorption. So, this is one type of gas liquid flow operations that is multiphase flow operation.

I have already told that there will be some ozonations systems. So, you will see the ozonation of arsenic or ammonia or dye in water that is you can see the for the treatment of the water having this arsenic ammonia, then you have to donate it or advanced oxidized it so, that you can remove the arsenic or ammonia from the water. So, this is also one type of gas liquid operation.

Even distillation process the heart of the chemical engineering process in a refinery industry, you will see whatever while products we are getting after refinement of the crude oil. Those are actually basic process is called distillation process is there. So, by distillation process we are getting different type of a products of a gas even heavy lighter different one whatever you know that Mobil kerosene all those products that we are getting by distillation process. They are also it is the two phase processes even three phased processes are there.

Also you will see application of gas liquid chromatography to analyze of liquid petroleum reactions there and also you will see gas liquid reactions like industrial gases like oxygen hydrogen, carbon monoxide, carbon dioxides are widely used for synthetic processes in the chemical industry. So, from this you know that oxygen by oxygen hydrogen carbon monoxide, there are several products can be synthesized from these gases that is obtained based on the gas liquid reactions. So, these are called reactive two phase processes of gas and liquid system.

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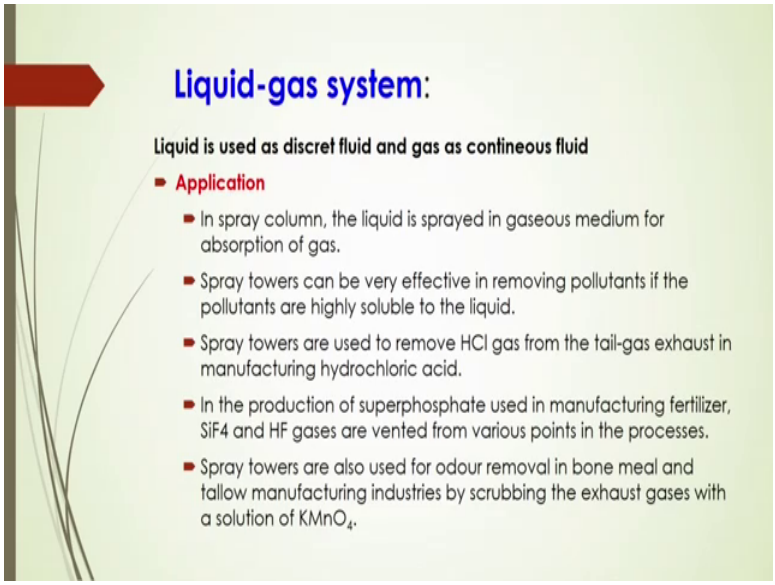

Now, another here: liquid and gas system. In this case, liquid will be discrete fluid and gas will be continuous fluid. So, this is two phase flow. Here again in spray column, you will see the liquid is a sprayed in a gaseous medium for the absorption of gas. Even a spray towards can be very effective in a removing pollutants; if the pollutants are highly soluble to liquid here. Even a spray towers are used to remove hydrogen chloride gas from the tail gas exhaust in manufacturing of hydrochloric acid.

This is another one important example. In the production of super phosphate that is used in manufacturing fertilizer that is silicon in that case silicon hexafluoride and hydrogen fluoride gases are vented from the various points in the processes. This is one type of liquid gas operations. So, multiphase systems and also the spray towers also used for odd or removal in the bone metal and you know that talo manufacturing industries by

scrubbing the exhaust gases with the solution of potassium permanganate. So, this is one type of two phase systems of liquid gas.

So, this is also called the multiphase flow operations. Now let us see that how this gas and solid systems are used for several chemical and other processes. Now in this case, there will be a 2 processes; one is physical process, another gas solid reactions processes.

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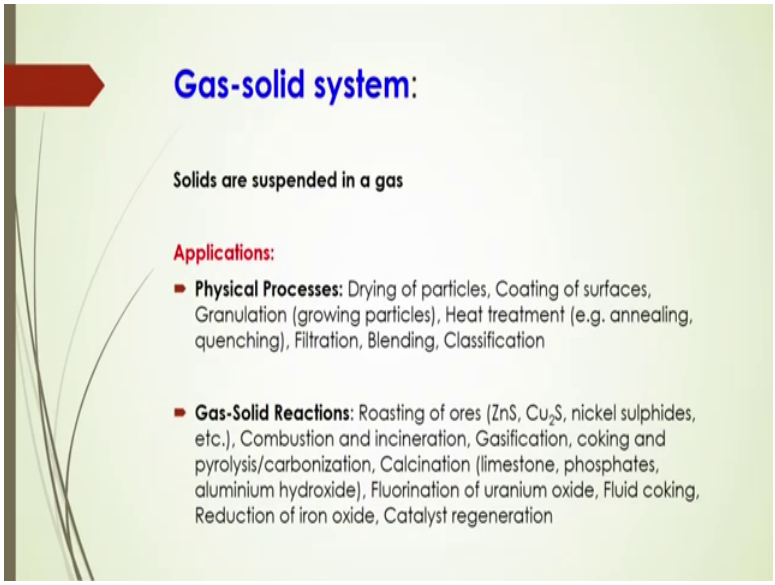

Here you will see some drying of particles there. Hot air to be supplied through the wet solids so, that at a particular temperature, it will be fluidized in a hot air medium or hot gas systems then the particles will be dried. So, this is one type of two phase system gas solid operation like coating of surfaces some solid particles to be coated with the some other polymeric substances. So, in that case you have to fluidized, you have to fluidized the solid particles in a space system so that the particles will be being coated by the other materials.

Even granulation process is also one important process where the particles may be growing from these what is that molten to the particles there. So, like in urea production you will see the molt in urea would be sprayed through a spray nozzle in a column and it will be sprayed in a what is that cooling gas. So, that molten urea will be converted to what is that granular urea there.

So, this is also one type of two phase flow system that will be gas solid operation heat treatment process, annealing, quenching and also filtration, blending, classifications. All those operations are physical processes of these gas solid operations. Now you will see roasting of ores even using sulfide copper sulfide, nickel sulfide etcetera. In that case, for this type of production you will see these gas solid reactions.

This is gas solid operations would be there. Combustion and incineration of the coal gasification of the coal coking and pyrolysis or carbonization even calcination process like limestone calcination, phosphate calcination, aluminum hydroxide production. There all those operations are basically gas solid reactions are there; so, multiphase systems of gas and solid. Fluorination of uranium oxide even you know that fluid coking reduction of iron oxide even catalyst regeneration; all those operations are gas solid operations.

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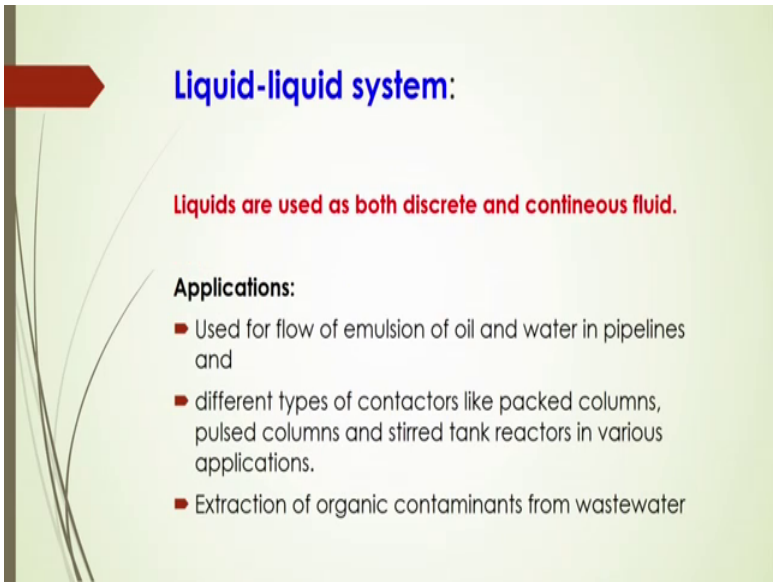

Now, let us have an example of liquid-liquid systems. Suppose liquids are used as a both discrete and continuous liquid here. Suppose one example, I am giving suppose; if you want to extract or remove what is that acetic acid or propionic acid from the waste water or some water where this acetic acid or reached there. So, you have to extract those acetic acid what to do.

So, what you have to do this acetic acid or propionic acid reached to water to be in contact with some other organic solvent, like you know that your decanal or you can say that paraffin or kerosene. You will see if you allow this paraffin or kerosene in that in this

continuous liquid that is reached with that propionic acid, then what will happen? You can extract that the propionic acid from the water to the what is that decanal or what is that paraffin or kerosene what is being used there.

So, in that case, the liquid-liquid operation will be there. In this case, this paraffin or what is that kerosene or decanal all those will be lighter than water. So, in that case this lighter liquid will be what is that dispersed in this continuous water. It will be as a drop of what is that a droplet of paraffin or kerosene or decanal which one you are using that is invisible liquid will be a passed through that continuous liquid as a dispose phase of droplet. So, in that case, this acetic acid or propionic acid to be actually extracted from that liquid to that paraffin; so, in that case there will be a mass transfer of this propionic acid from this liquid to the paraffin.

So, this is what is that mass transfer operation by which you can you remove that acetic acid or propionic acid from that water to the paraffin. After that you can boil it that paraffin or propionic acid, then you can easily separate those acetic acid or propionic acid from the paraffin. And so, this is the separation processes that is liquid liquid separation processes. So, one solvent will be used that will be immiscible with the water and then from the water, you can easily separate those components. So, this is liquid liquid multiphase systems.

And other applications like used for flow of emulsion of oil and water in pipelines and different types of context like packed column, pulsed columns and start tank reactors in various applications also are being used this liquid liquid operation. And also extraction of organic contaminants from waste water that I told here that. So, these are the several applications of this liquid liquid system.

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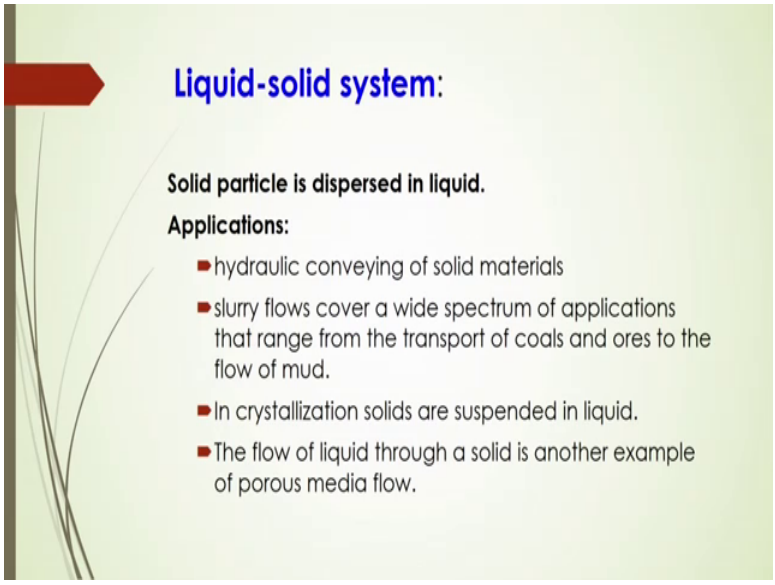

Now, liquid solid system; these are also one important operations where this solid particles will be dispersed in liquid. So, in this case like hydraulic conveying of solid materials to the liquid even slurry flows cover a wide spectrum of applications that range from the transport of coals and ores to the flow of mud. And, in crystallization process that solids are suspended in the liquids in that case how thus, what is that organic compounds or solid particles are actually suspended in liquid in that crystallization process and this mechanism.

And the flow of liquid through a solid is another example of porous media flow there. So, you will see the porous media suppose some liquid components to be actually extracted and it will be supplied through the porous media so, that to get the more contact of that of other solvent or other liquid. So, it can easily be even some liquid suppose components some contaminants to be adds on solid particles, then you have to supply that liquid through the solid particles then it will be liquid solid operation.

Now, these are all two phase systems that is gas liquid, gas solid even liquid liquid; liquid solid. Now, what about the three phase systems? Some examples like here what is that gas liquid and solid system like performing of gas liquid reactions in presence of solid materials like catalyst.

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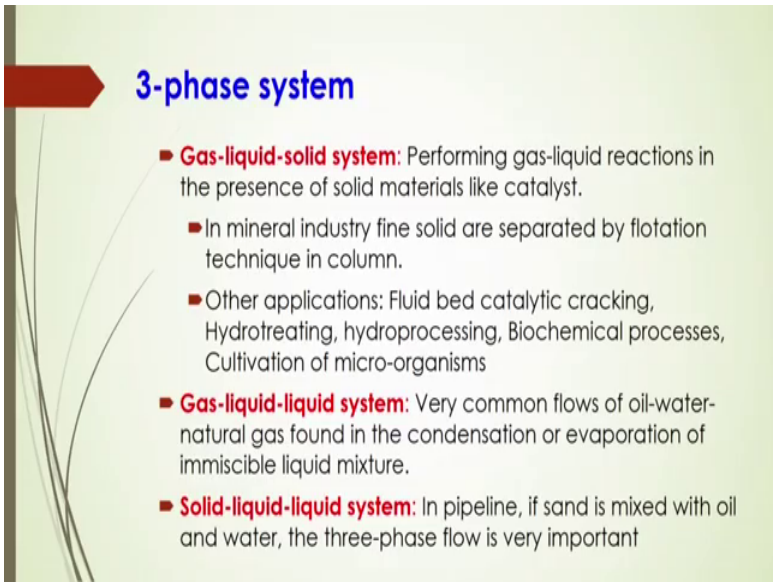

In the mineral industry, you will see fine solid particles are separated by the floatation techniques in column. So, this is one of the important process in mineral industries and these are gas liquid solid operation. Other applications like you know catalytic cracking, hydrotreating, hydroprocessing even biochemical processes cultivation of micro organisms. All those are three phase systems operations. These are all the heart operations or you can say that main important operations in the chemical industry where you are getting different types of several products in our daily life what we are being used.

Gas liquid liquid another important three phase systems there. In this case, the very common flows of oil water natural gas that is found in the condensation or evaporation of the immiscible liquid mixture there. So, this is gas liquid liquid system. Even solid liquid liquid system in pipeline, you will see if sand is mixed with oil and water the three phase flow is very important there. So, these are three phase systems and have you heard that the four phase systems. Any anything any examples of four phase systems? There is also one important process that is called as the four phase systems like liquid liquid gas solids.

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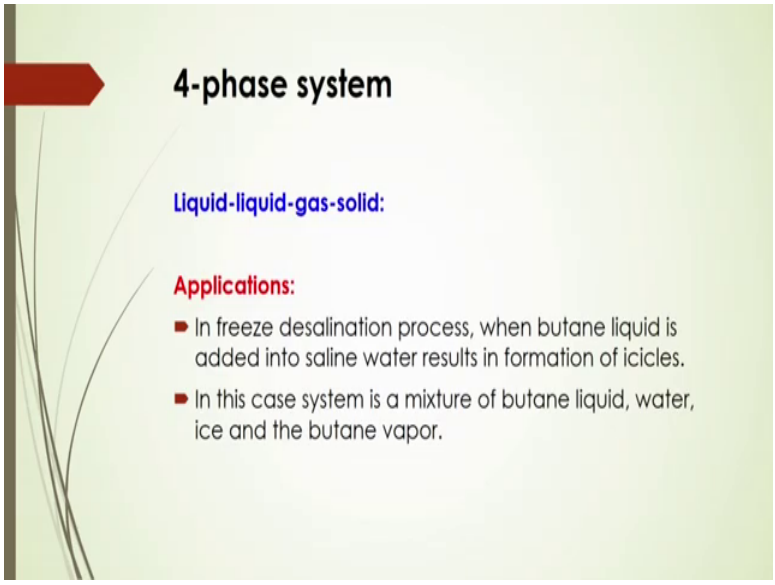

Suppose in freeze desalination process what will happen? The when butane liquid is added into the saline water that will results the icicles; so, in that is this type of operation is called what is that liquid liquid gas solid. In this case system is a mixture of butane liquid, water, ice and the butane vapor. So, this four phases will be there in the what is that systems. So, that is why this is called that four phase system.

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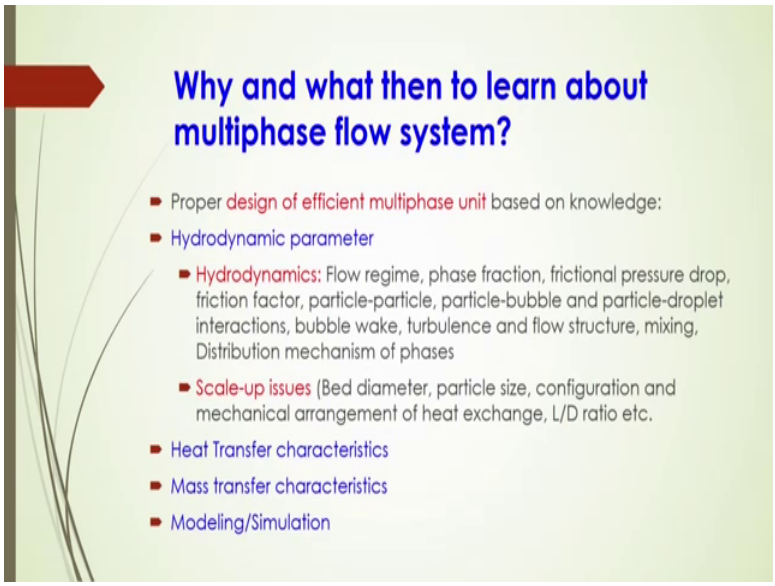

Now, question is that all those ok operations regarding this multiphase flow systems that you are having, now what to learn or what more components you have to move for the process of this multiphase systems? So, that is why suppose if any processes that is involving in this multiphase systems, then what you have to do? Whether you have to do

design, how to design that multiphase flow unit based on the multiphase flow phenomena? Then only you will be able to make the product by a certain process in that particular unit.

So, you have to know the proper design of efficient multiphase unit based on the knowledge of multiphase flow systems, multiphase flow behavior. Till now whatever we have discussed up to this a lecture number 29, we have discussed all those operations based on the single phase flow system. So, you have to know something about the multiphase flow systems also; multiphase flow phenomena. Whenever there will be a process, how this multiphase flow will be behaving and based on that flow behaviour how the product of that multiphase flow processes are yielded.

So, in that case, some components of that multiphase flow system you have to know. Though the there will be no more details of that, but we will try to discuss the subsequent two-three lectures. The some basic aspects of that, basic phenomena of the multiphase flow system here and it will be several courses for this multiphase flow operation with examples, but here still you will try to know something of fundamental of multiphase flow system.

Now to know that you know multiphase flow systems you have to know some hydrodynamic parameter or hydrodynamic characteristics of that multiphase flow systems. Like how this whenever two phase flow or three phase flow will be flowing through the conduit or pipeline or in a column, what will be the regime, what will be the pattern of the flow that whether it will be that is bubbly flow or it will be slug flow or it will be a stratified flow or it will be a Chan turbulent flow. There are the several different types of flow patterns will be there will be discussing in the next lecture that different types of flow regimes or different types of co pattern of two phase systems.

This is happening because whenever you are simultaneously passing this gas and liquid, you will not see that the single liquid will be separately flowing and liquid only gas will be say gas and liquid both will be separately flowing. But whenever there will be a mixing of this two phases, then you will see there will be a certain phenomena of that two phase systems or three phase systems. So, that is called the flow pattern how it will be there.

There may be sometimes you will be see some forms whenever gas will be flowing through the liquid as it is first phase of bubbles. In a certain flow rate of the gas, in a certain flow rate of the liquid in a continuous medium, you will see the gas bubbles which are forming that will not be a uniform in size. There may be sometimes elongated bubbles will form, sometimes you will see is very fine bubbles will form, sometimes you will see different shapes like you know that oblate type of bubbles will be bullet shape of bubbles will be forming. So, these are the this you will that some pattern of that formation of that gas discretization in the continuous liquid.

Even you will see that there will be a certain flow phenomena of the phases, there will be you will see that if you get this: what is that liquid liquid flow how the slug will be forming. And also whenever gas is flowing over the liquid, you will see there will be interface that interface how it will be wavy there. So, this is wavy term type of flow pattern. You will see some other flow pattern like you will see that Chan turbulent, you will see that gas and liquid both will be mixing in certain way that you will not follow a certain fashion of that flow that all the molecules are in the gas was an liquid.

You will see it will be arbitrarily mixing in the column and there will be a formation of circulation cell inside the column and then you will see there will be a certain manner of that flow that type of it will be called as Chan turbulent Chan formation; churning phenomena will be coming. So, it is called that Chan turbulent flow and other things.

And also you have to know for that particular processes what amount of actually dispersed phase to be supplied in that particular process that there will be called as phase fraction. Or suppose if gas liquid flow is there, how much gas volume in the total gas liquid mixture that will be called as gas volume fraction or it is sometimes called hold out gas hold out of the system. So, you have to know that phase fraction or gas hold up or liquid hold up or solid hold up in the particular column that will give you the process output as a particular you know that efficiency.

So, these things also you have to know; how this phase fraction will be changing and how to control all those phase fraction. If you increase the phase fraction, what will happen? If you decrease the phase fraction, what will happen? Is there any pressure drop will increase or decrease if you supply more energy more gas or you will see there will be a formation of Chan turbulent condition?

If there is a what is that bubbly flow then whether is there any frictional resistance of the pressure drop or not? So, we have already learnt that the friction of pressure drop in what is that single phase flow whenever it will be flowing through the pipe, but what about the frictional pressure drop when that more than one phases will be going through the pipe. That depends on the gas hold up has been other things also flow pattern also.

And friction pattern that friction pattern, it will not would be exactly the same as what single phase will give you in the pipe, but for two phase flow that friction pattern will be different from that single phase flow. So, in that case you have to know that pressure drop friction pattern phenomena in this multiphase flow systems. Even particle particle systems also how this particles will be interacting with the other particles, how this particles will be interacting with the liquid even gas that phenomena you have to know.

Even sometimes you will see when a gas will be supplied as a disperse phase of bubbles in the liquid, you see the some bubbles will be coalescing to each other. It will be joining to each other and making a bigger bubble some phenomena some energy will be transferred or high flow rate of the gas you will see. Some gas bubbles will be you know that splitting into a smaller biggers gas bubbles will be splitting into a smaller bubbles. So, in that case, you will get more surface area there. Even qualysense if it is happened; you will get less or surface area there.

So, this phenomena you have to know what you have to know that degree of qualysense, degree of what is that wreck of phenomena of that particle particle interaction, particle bubble interaction, even particle droplet, even droplet droplet interactions there. Because in that case, you have to operate you have to operate the process in such way that you have to have more interfacial area to a particular process output.

And also whenever the phases will be flowing through a in a another phase, you will see some wreck will be formation in a turbulency condition and then turbulence and the flow structure will be changed there. And mixing intensity will be there where mixing is one of the important actually phenomena of this multiphase process. Because, that mixing sometimes it will hinder the a process efficiency sometimes you know that give the better process efficiency that is particular process that dependence on that what type of process is there.

Suppose if you want to transfer the heat; if you want to warm the some other phases in that cases, you have to mix more that phases. So, that the heat transfer will be from one phase to the another phase in more way. Even mass transfer operation sometimes, you will see gas liquid mass sometimes; you have to have the more mixing there. So, that the transfer of the mass from the gas to the liquid or liquid to the gas there.

So, this type of things even distribution phenomena of the phases suppose discrete phase or solid particles, gas particles or gas; they are distributing in the continuous liquid. How it will be distributed? Whether all the particles will be same in size or there will be certain ranges of the bubble that in the process, then that bubble size distribution or particle size distribution will give you the that is process efficiency there. Even based on these multiphase processing, you have to actually scale up the what is that processes from the laboratory to the industrial scale.

So, for that you have to design the column in such a way that based on your experimental data, based on their geometry, based on their what is the particle size, based on their configuration. And, the mechanical arrangement of the heat exchange even some other aspect ratio, even some other what is that similarity laws to be used to scale up all those processes based on the phenomena of the multiphase flow which is studied in the laboratory.

And other operations like these are all actually a hydrodynamic characteristic. So, you have to know these hydrodynamic characteristics to get or to analyze, the process efficiency for the particular operations. And all those hydrodynamic parameters we will actually may govern, there may control the process output there.

So, that is why hydrodynamic characteristics is important to study before going to design of the system, design of the unit even to calculate the output of the process. And then some operations, you will see you know that some heat transfer characteristics is very important to their. So, you have to know the heat transfer characteristics of the multiphase flow phenomena also.

Mass transfer characteristics of course, if you are going to apply some multiphase flow processes like absorption of the carbon dioxide in sodium chloride, sodium hydroxide solutions. In that case, you have to move the mass transfer characteristic there are how mass transfer and that mass transfer coefficient how it depends on several variables there.

So, you have to know even you have to do the modelling simulation for that you have to know the hydro dynamic characteristics particle particle interaction, friction factor, phase fraction; is there any wreck formation or not, even is there any energy distribution, how it will be there, what will be the turbulency all those things distribution of the phases even what is that flow pattern of the systems there you have to know. So, based on which you can model or simulate you can predict the flow phenomena in the multiphase flow system.

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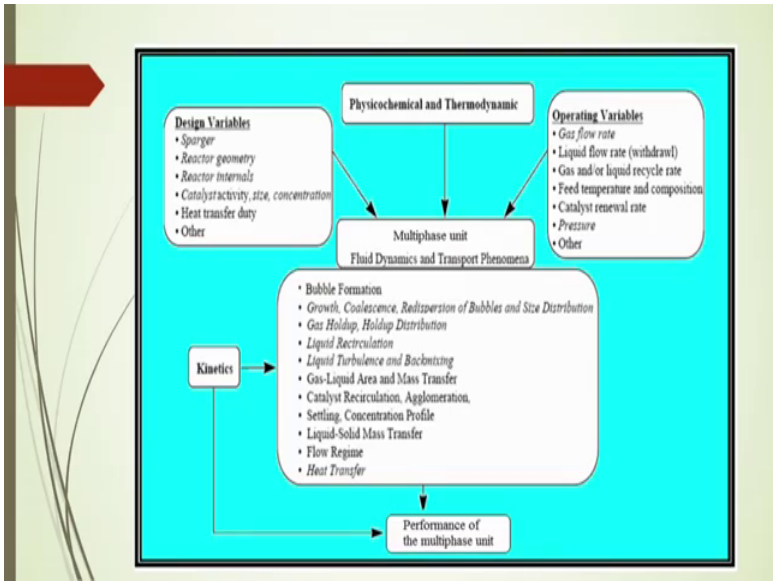

Now, to get the performance of the multiphase unit that you have to know all those things; first of all like some design variables like a sparger reactor geometry in a particular column. If you are operating that multiphase flow system for particular system, then you have to know their design parameter like sparger, reactor geometry, reactor internals even catalyst activity even size of the catalyst concentration of the catalyst, heat transfer duty, even aadhar. Suppose some surpectant you are using, then what would be the dose of that surpectant. All these things you have to know.

Even you will see some operating variables sometimes you are allowing that gas, what will be the flow rate of the gas, what will be the flow rate of the liquid, what will be the, what is that recycle is there, is there any recycle their gases back you are using, even liquid will be recycling, then what would be the rate of that recycle and also feed

temperature composition; everything you have to know catalyst renewal, rate pressure you have to know.

So, these parameters, these variables you have to know because all those variables we will cover we will actually affect the performance of the multiphase systems. Even the fluid dynamics and transport phenomena; if you want to know that what would be the bubble formation, how this bubbles are forming, what type of distributor will be used to form this bubble even growth coalescence, even re dispersion is the what will be the dispersion phenomena of the bubbles or particles.

Even what will be the size of that particles, what its distribution, gas hold up hold up distribution, liquid recirculation. Even liquid turbulence or what is that back mixing is there or not that you have to know. Even gas liquid area you have to know, mass transfer effective area of the mass transfer surfaces that you have to know. Catalyst recirculation, is there any agglomeration is happened or not in this gas liquid solid operations.

Even settling characteristics of the solid particles that you have to know, concentration profile of the solid particles, how it will be distributed in the column have to know that liquid solid mass transfer, even flow regime heat transfer. All those things you have to know under this flow hydrodynamics of fluid dynamics characteristics. And design variables operating variables you have to know even some thermodynamic variables also like temperature pressure, what is the temperature to be maintained, what is the pressure to be maintained all those things that you have to know.

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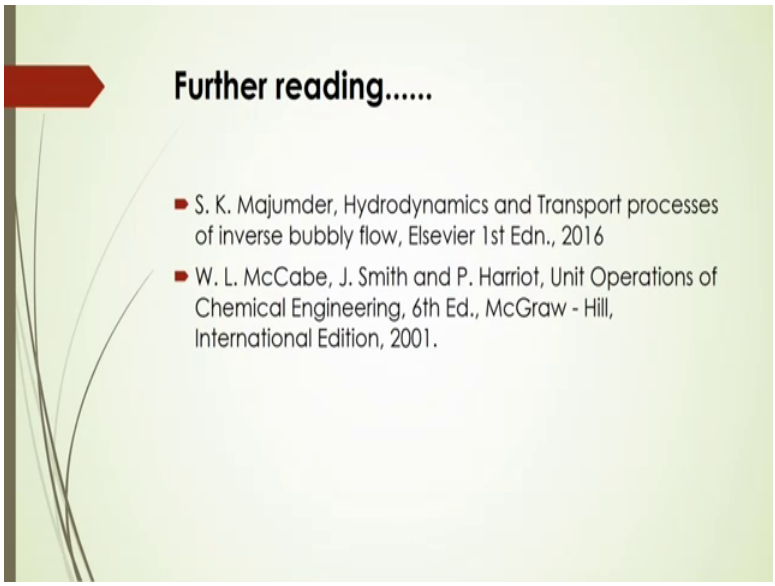

So, I want to actually conclude here that for multiphase flow systems, based on that single flow operation whatever we have learned basic equations governing equations same things. Also it will come in multiphase flow system governing equations. All these things how it will be derived and all those things though it will not be covered in this courses, but some ideas some phenomena of this multiphase flow basic understanding of that flow pattern, we have to know. And based on which we will be able to develop our skills in the multiphase flow operations in any particular real operations for particular processes to get particular yield.

So, I would suggest you to go further of this books that is the written by me actually that I have published this books that Hydrodynamics and Transport processes of inverse bubbly flow systems. You will get lot of informations in these books and you can follow for further understanding even as per your interest you can go further other books also like Unit Operations of Chemical Engineering McCabe Smith. Several multiphase flow phenomena is described there.

So, thank you for giving attention. Next lecture, we will discuss about that multiphase flow pattern and with some video how that different types of multiphase flow patterns are forming and then you will get some idea about that.

Thank you.