Multiphase Flows
Dr. Rajesh Kumar Upadhyay
Department of Chemical Engineering
Indian Institute of Technology, Guwahati

Lecture – 22
Summary

So, welcome back now we come to the end of this course and I thoroughly enjoyed this course I hope that you might have also enjoyed the course if you have any problem. Please let us know let we will try to solve your issues and you try your problem, I would know quickly want to revise the course or I will summarize the course that; what is the main base? An aim of the course, what we have tried to do and you may have got benefited with some of this content.

So, what we initially did? The main motive of the course was as I said that multiphase flow reactors a heart of any chemical process industries. So, if you go for any process you go for any industry, petroleum industry, pharmaceutical industry, food industry, treatment places to go for bulk chemical industries. You go for fine chemical industries you go for power plants any places any chemical related industries you go for mining you go for steel processing you will see that every where there is a multiphase flow which is taking place ok. And the multiphase flow is generally the heart of that industry you will see that whatever the reactor or the processes they are using the most critical processes actually the multiphase flow process.

And we said that the multiphase flow process this is very ongoing research topic very hot topic of the research and why it is still ongoing topic and very hot topic of research is that; the phenomenon governing in the multiphase flow depends on different parameters and that most critical parameter is that it depends on what type of fluids you are handling? Whether the; you are using gas solid whether you are using liquid solid whether you are using gas liquid whether you are looking liquid liquid and all.

So, it depends on that type of the liquid it depends on the column geometry whether you are operating a vertical column; whether you are operating a horizontal column it depends on column dimensions,, whether you are operating a 1 inch column 2 inch column 1 meter column 5 metre column which depends on the column inclination also whether you are using a say vertical or horizontal whether if the column is inclined at 45 degree or.

So, there are lot of parameter is depends on and; that is the reason that the design and scale up of these problem or this kind of a processes is still a challenge and most of the time it depends on the art rather than the science. So, what we have tried to do in this course? We have tried to remove the art part of it that we come over the empirical correlation we try to see, that how to do the basic force balance? Basic material balance basic rewrite the transport equations in such a way that we can understand the dynamics of the bed. So, we what we did we first started with the basic introduction of the course we introduce the different terminology.

I can introduce that what is the void fraction number density, what is autocorrelation function? What is the mixture density and also we started with very basic definitions of the multiphase flow. We tried to understand different kind of flow pattern which take place. Now, once we are going with the flow patterns; which is very very critical, because again the behaviour of the bed depends on that; what regime you are operating? So, say for the gas liquid whether you are operating in the bubbly regime whether you are operating the slug flow regime churn turbulent regime and all. So, so on each kind of each interaction have different regimes and your bed behaviour is largely depends on that what regimes you are operating.

So, we have tried to discuss the regimes of operation for the gas liquid for the liquid solid for the gas solid and for the liquid liquid both. So, all these things we have try to understand the different regimes we have tried to see that; why? How this regimes are dependent on the column geometry it means the column inclination and column dimensions. So, that makes the life for the complicated that these regimes are dependent on the column geometry inclination and as well as the column dimensions and the fluid type if you change the fluid type the; your regimes will change.

So, we have tried to classify the regimes we have try to understand that for different processes, what type of regimes you should operate? What is the advantage of each regime? What is the disadvantage of each regime? What is the typical characteristic of each regime?

Then, we started with the your first principle equations, we started with the basic force balance, we have tried to do the basic force balance, we have tried to drive the Reynolds transport theorem from Reynolds transport theorem. We derive the Navier–Stokes equation or momentum equation and then from both the momentum equation. We have simplified it for the one dimensional domain. So, that we can easily understand, the dynamics removing the critical part of the mathematics so that we can focus more on the force balance centre.

So, we have done that single dimensional equation, we have written for again, we started with the gas liquid, we have done it for the separated flow, we have done it for the homogenous flow, we have done it for the bubbly flow, and we have done it for the annular flow. We have written the basic equation mathematical equation starting from the first principle of the force balance or momentum balance we have developed the equation for the pressure drop of all this condition so that you can see that how the different regime pressure drops will be different.

We have also discussed some of the empirical correlations like Lockhart Martinelli equation which may not be very accurate, but gives a very good idea about the pressure drop in a very short time. So, we have tried to blend it both the first principle as well as the empirical equations together to understand the hard core knowledge or to understand the physics of the multiphase flow and also to keep the calculation handy ok. So, that we can easily calculate it is not like you need to wait for 1 month for 10 days or 20 days to get the first hand calculations. So, that is why we discuss the in blend of both we blended it the first principle as well as the empirical correlations together.

We have again developed the particle tracking equation for the single particles we have keep on increasing the flow that forces we complicate the problem. We first initially that only particle is falling down, then we are saying the particle is moving horizontal. First, we started actually with the horizontal were only drag was there then we said that the particle is moving downward it will settling down drag and gravity was taking a place, then we introduced buoyancy forces. Then we introduce the any other forces like the electro forces, forces electrical forces; that if it is there how the particle motions will be there and we try to see that how the particle tracking can we take place in the Lagrangian tracking domain.

Then once we have done for the one d models what we have done we have started moving to the more complicated mathematical model which is kind of a current state of the art. So, once you understood the one dimensional model the; now we tried to introduce the basic part of the mathematics also to see that; how we can do it in the three dimensional domain?

So, we introduce the different models which is being critically used in the industry or in academe to understand this kind of reactor behaviour we started with the Lagrangian track which we have already discussed then algebra slip model. We discuss about the model equations the major assumption for which the model has been developed and the limitation of each model. So, we discussed the algebraic slip we discussed the Euiler Euiler we discussed the Euiler Lagrangian model for both gas liquid gas solid and liquid solid all three this phases we have discussed and simply it is also applicable to the liquid liquid.

So, we discussed the different mathematical model which is being there we discuss the advantage and disadvantage of each model limitation of each model capabilities of each model, what you can expect from the model results where you cannot use where you can use and all. So, all those things we have tried to discuss and then we found that all these models are still not kind of; you can say the matured enough that you can surely depend on the model predictions particularly for the multiphase flow. And therefore, you need a experimental validation you need experiment input to see that, and why it is the state? Because, several these models use several empirical developed correlations and we do not know whether those empirically developed correlations are correct.

So, to understand that we discussed the different forces which is being used in this model like, drag force, left force, virtual mass force, (Refer Time: 08:24) history forces all those forces we have tried to see and we have discuss the different correlations available for these forces which mean some of these correlations are developed empirically were with like some other drag; we have discussed about the Gledart force Shyam Lal say Sciller Neumann in the gas liquid flow mostly Alexander for the gas liquids. So, we have (Refer Time: 08:44) the spectrum of the drag forces we have seen that how this drag forces are being developed empirically develop actually.

And once you are using these developed drag forces in a numerical model definitely a production of the numerical model is going to depend on the, what is the accuracy of your drag model? And to understand: whether your drag model is valid there or not, you have to have the experimental validation. Drag is a very simple example, that is why I am giving, but there are several other correlations also which we have used like for the gas solid we have used the solid as a continuous say in the Euler we have developed several empirical correlations like for the solid viscosity (Refer Time: 09:19) Lunet et al., and all. So, bulk viscosity this will this all those things we have discussed developed and those things you need a serious experimental validations.

So, we discuss all those parameters then we also discuss about the drag that how the single particle and multi particle drag will change and how the (Refer Time: 09:36) correlation comes into the picture how the drag can be written in form of the beta of k m f like different books for this different correlations.

And, then we move towards the experimental validation that how you can do the experimental validation, what are the different techniques available current date as of? Now, we developed some briefly on this part and we try to understand the limitation and advantage of each technique it means capabilities of each technique, what again similar way? What you can expect from this technique? What is will be the accuracy whether it can be used for the validation or not.

And there after we started with the different type of reactor. So, initially what we have done we have discussed about the bubble column reactor. We have discussed again that; what is the bubble column reactor? What is the application of this? How the hydrodynamics in the bubble column depends? How to calculate the bubble diameter? How to calculate the bubble velocity? How this coalescence will change the bubble behaviour? What is the different type of the bubble column reactor available?

What is the advantage and disadvantage of each reactor? And, we will again use the basic principle to calculate the first principle; whatever the way we have developed the single dimensional equation, we did the force balance we tried develop the equation for the bubble velocity we developed the equation for the bubble diameter calculation all. So, all those things we have done and we have tried to develop that do the basic force balance. So, that you can in a reactor you can do that force balance whatever we have done.

Then they move to the gas solid reactor we discuss the first the packed bed reactor. Again, we discuss the advantage of the packed bed reactor then from the basic first principle again. We did the force balance with see that how the force balance take place in the packed bed reactor for different velocity, low velocity and higher velocity we have discussed about the pressure drop how it will change. So, we have discussed the Kozeny–Carman equation. So, we discussed the Burke-Plummer equation and then the combination of that is actually called Ergun question. So, we discuss about the Ergun equation that, how it is been derived? how this (Refer Time: 11:32) the particle shape take a role in that a (Refer Time: 11:36) play a role in that we discuss all those things and then finally, the move towards the gas solid fluidized bed reactor or say fluidized bed reactor.

We discuss the advantage of the fluidized bed reactor what packed bed like better heat and mass transfer coefficient. We discuss that how critical it is to operator a fluidized bed and how the hydrodynamics places a such a critical role, as while discussing we said that the hydro dynamics of the bubble fluidized bed. Actually depends on many parameters like column inclination, column angle, column geometry, whether it is a vertical or conical then this gas velocity or the fluid velocity I will say.

What is the particle size? What is a particle density means? The Geldart classification of the particle; what group of the geldart particle you are using? What is your particle size distribution; whether you want to operate a circulating bed or you want to operate a batch reactor bad or mean say I will say that from the till the turbulent bed.

So, all those things changed your dynamics and what we have try to understand that to, how to analyze the system? What is the critical parameter once you do that system and how to calculate the minimum fluidization velocity?

So, inherently in this course the idea was to expose you with the different kind of a multiphase flow reactors the problem which you phase in different type of multiphase flow reactors. How the basic principles can be used? The basic force balance or maybe say momentum balance can be used to analyze those kind of a problem. What you should look for in these reactors? What are the critical things which you should analyze while designing this reactors and all.

So, this was the whole idea to introduce you about the multiphase flow different reactors used in the multiphase flow and to give you idea that how critical they are and how by using the very basic first principle you can analyze this system. I hope this course will be enjoying for you must have enjoyed this course I just hope this. And if any problem is there please feel free to contact us. With this I rest this course.

Thanks a lot.