Measurement Technique in Multiphase Flows

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Lecture – 12
Summary

Welcome back. Under this course of multiphase flows measurement techniques or measurement for multiphase flow, what we have done? We have already studied about the different measurement techniques available and what I am going to do today? I am just going to put the summaries the course whatever we have learnt and whatever I have tried to tell you and then if any doubt is there, we can have further discussion.

So, what is the whole motive of this course is as I said that multiphase flow reactors a heart of any industry whether it is pharmaceutical industries, petrochemical industries, petroleum industry, bulk chemical industry or any industry you think about, even food industries, any industry you think about. Multiphase flow reactors will be the heart of that industry and every process is most of the processes will involve multiphase interactions.

Now, designing of these reactors is still mostly is an art compared to a science and why this is the state because the understanding of multiphase flow reactors even in the current date is not up to the mark where the scientific input on the scientific understanding can be used to design or scale up of these reactors though we have improved the lot, but still there is a long way to cover the long way to go ahead. Before we come up to a situation, here we can say that we can design the multiphase flow reactors based on the science, not only the based on the experience. So, currently it is mostly towards the experience combination of the science and experience, but what is the way forward is to have complete understanding; detailed understanding. So, that we can come to a situation where we can based on our understanding, we can design the new reactors, we can come up with the new concepts and we can understand the existing reactor in great detail.

So, to do that there is a to approach as I discussed earlier, in the beginning that you can have do it by save this technique or you can say that numerical techniques and you can do the same by the experimental techniques. Now numerical technique; though it has several advantages like you do not need to kind of do lot of experiments money; why it is

very good because you do not need to spend this much money which you will be spend if you do perform the experiment. So, you have to make the experimental setup you have to kind of stall the techniques which we have discussed then we have to perform the experiment. So, it is more intensive.

So, it is more involving simulation wise it is relatively cheaper because you just need a server and the softwares or kind of your own code and you can do it, but the problem with the numerical techniques is that they are not still that much advance that you can rely on the results of the numerical technique without validating it with the experiments. So, that is the bottleneck because of multiphase flow numerical techniques or safe detecting technique is not that much advance and why they are not that much advance because they are several inherent heuristic assumptions which may or may not valid for the case of out the system for which you want to design or you want to understand and therefore, you can use the numerical techniques to understand the process, but you need a experimental validation.

So, multiphase flow measurements on multiphase flow experimental techniques measurements experimental methods are compulsory or you can say that is pretty much required if you want to develop the understanding in multiphase flow reactors. So, the experimental techniques is pretty much needed and you cannot bypass them even if you are doing the numerical simulation, you need experimental measurements to validate those numerical simulation results and then only you can say that or you can have a confidence on the numerical predictions.

So, numerical measurements in multiphase flow is pretty much required and to do the measurement they are several techniques available, but the problem is as I start, keep on saying this from the beginning that there is no single measurement technique which can give you all the required parameters with similar accuracy and each skill and for all kind of a system and that is the major bottleneck in multiphase flow that you do not have a single technique available which can solve all your problems you can which can give the results with equal accuracy at all the scale which works with the similar accuracy at laboratory pilot plant and distance industrial scale reactors, further these not a single technique available which can be used for all kind of a system like gas solid base gas liquid base liquid solid base or gas liquid solid base at all the skills.

So, this kind of a technique is not available at that is why is still, it is a very hot cake where lot of research are going on to develop a new experimental measurement techniques. So, till we are not coming up with our dream that this one single technique available which is going to solve all our problem the prove a head is to understand the experimental measurement techniques which we already have which is being used in the literature in detail try to understand their accuracy, try to understand their limitation and try to understand that where their performance can be utilized and what you can do with that system and what you cannot do with that system.

So, this distinction is pretty much important and that is the origin that why we have floated this course which is multiphase flow measurement techniques. So, the idea is this course was to introduce the different techniques which is widely used in the multiphase flow research or academy or some industry and give your background of each technique let you understand that what is the advantage of each technique what is the disadvantage of each technique, what is the working principle of each technique, what kind of a reconstruction algorithm you used to reconstruct the data and what kind of a post processing one can do.

So, what I have done in this course, I have tried to divide the technique actually into 2 parts one is volume interaction measurement technique or you can say phase fraction measurement technique and another is velocity measurement techniques and why I have done. So, because if you want to understand about the multiphase flow reactors these 2 parameters which you need to understand at the variation in these to parameter with the time with the position you need to understand in detail to predict the behavior of any multiphase flow reactor and that 2 parameters are velocity v and you need.

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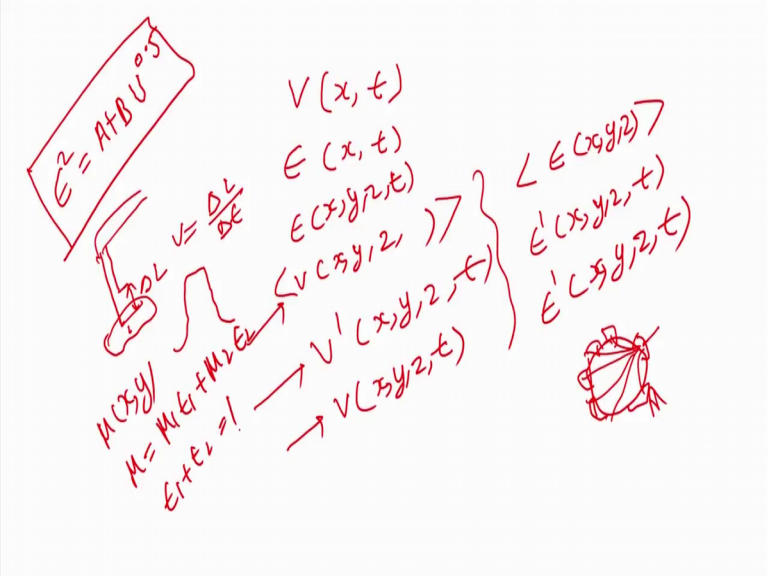

How it is changing with the position and how it is changing with time.

And similarly you need volume fraction of phase fraction epsilon and you need that how it is changing with the position and how it is changing with the time was I say a position x, I am writing x, but it will be actually epsilon with x y z and t, if I am going in the Cartesian coordinate and similarly V with x y z and t right all this what we need is this and what we need is not the only mean value we do not want that only the mean how it is changing, we also want that how the fluctuation or changing with the locations with the time and with the time once we are saying the mean definitely the time will go out of the picture if you are talking about the time average velocity, it will be how the time average velocity is changing with the position ok.

So, we need local information. So, we need v local how it is changing with the y z; x y z and t, we need mean information we need local information and we need fluctuation formation for velocity and similarly, we need mean with information epsilon how it is changing with the x y z, again I am going to seeing mean it is the in sample average oh sorry time average then I am talking about that how the fluctuation is going to change of epsilon with x y z and t and how the local phase fraction is going to be change with x y z and t and you need a technique which can do both the job if possible and if a single technique can do that they will be nothing like that, but what we have found as I said earlier there is no single technique available which can solve the problem, both the

problem same time with equal accuracy at all their skills for all kind of a system and therefore, a divorce technique is available of different techniques are available which have different capabilities.

So, we started with the velocity measurement techniques and we understood about the 2 different technique in the velocity measurement one is invasive another one is non invasive as I said earlier that invasive means where you are including some probe or something inside the reactor vessel or inside your process vessel to major some quantity now that quantity can be a direct measurement like, it can measure velocity directly or can be indirect measurement which may measure something else and which can be converted in terms of the velocity like we used pitot tube, we use optical fibre probe, we use hot wire anemometer as a inclusive technique to measure the velocity of the flow. Now pitot tube one can say that it is a direct measurement it gives you delta p which is directly calculated correlated with the velocity in the hot wire anemometer, we discuss that what you measure is actually in that the current or you measure the temperature.

So, we operate it in the constant temperature mode we operated it in the constant current mode based on that you measure the voltage change because of the change in the resistance or because of the change in the temperature and that voltage change is correlated with the velocity by using the kings law. So, use e square is a plus b into velocity u raise to the power 0.5.

We use this correlation King's law and we calculate the velocity, we measure the voltage change and calculate the velocity and then we try to understand the limitation and the major limitation was that usually considered the heat loss through the wire by convection.

Now other heat losses like radiation natural conduct convection and conduction you neglect and therefore, the velocity of the fluid need to be very high generally for velocity more than one meter per second only, you can use hot wire anemometer and then what we have discussed is about optical fibre probe which is the obvious development ones of optical fibres what kind of developed and by using the optical fibre probe, what we do? We use a 2 point optical fibre probe or 4 point optical fibre probe and 1 fibre probe is emitting the light and based on the reflection principle each phases have a different refractive index.

So, there reflection index will be different, the reflection intensity will be different identify the phase, we have the say to needles into needle probe these is a gas liquid system, if I injured these 2 needle probe, optical fibre probe for the liquid the intensity of the reflection will be different. So, light intensity recorded on the photo detectors which is connected with these probes will be different and if it is the bubble which comes; what will happen?

The in refractive index of the air is different from the water the light intensity now recorded on the detectors will be different, you can identify the face, you can note down that how much time, it is taking the bubble is taken to reach from this needle to this needle we know delta l, we know delta t that how much time it is going to take we can calculate the velocity by delta l upon delta t ok.

We can use optical fibre probe and we can measure the velocity of the bubble can use 4 point optical fibre probes to have all the three direction of velocity of the bubble or you can also use optical fibre probe to measure the diameter of the bubble. So, all these thing is possible, you can even possibly measure the volume fraction. So, we have discuss about optical fibre probes and we understood the problem with optical fibre probes is mainly the piercing and that is why the signal which you record on by piercing was the bubble pierce the this needles you do not get and on and off signal you get some signal which will be of the sieve.

So, calculating the exact delta t for this 2 peaks is becomes an issue and another issue with both optical fibre probe hot wire anemometer and pitot tube is you are going to change the velocity at the point of measurement itself why because you are including something inside if I include something inside the change in the velocity will be very high and major point is that velocity change or the dynamics changed will take place at the point of measurement itself.

So, that is the major disadvantage of any invasive technique for the velocity measurement same will be true for the volume fraction measurement then we will go ahead and we discuss about the non invasive velocity measurement techniques we discuss about the Laser Doppler anemometer, we discuss about the particle image velocimetry we discuss about the radioactive particle tracking with discuss about the positron emission particle tracking. Now the 2 first to Laser Doppler anemometer and

particle image velocimetry, they are very accurate, but they are based on the optical measurement and optical range now because of the optical range frequency they are operating, you cannot use this technique for opaque system.

Now, once I say opaque and I keep on telling this that opaque does not mean that only all need to be opaque the system itself can be opaque. So, if suppose there is a gas liquid system get gas production a bubble fraction is more than 20 to 20 percent, the system will count completely into the opaque system you cannot able to see anything inside because of the refraction of the light.

So, that is called also opaque system or supposing that gas solid fluidized bed, you will not able to see what is happening at the centre because all it will reflect back all the light of diffract all the lights. So, this system turn to the opaque and therefore, any discrete phase fraction which is more than 5 percent you cannot use these techniques though this techniques are very accurate they are temporary resolution is very high there is spatial resolution is also very high temperature region resolution becomes very high if you use a very high speed camera for the p i v that temporal resolution can be increased, but if you use the double pulse laser for the p i v of temporal resolution will not be that good.

So, you will not able to get the time resolved velocity profile, but with the current generation of Cmos camera high speed camera where you can acquired the data at 4 thousand 5 thousand even 10 thousand frame per second you can have a very good temporal resolution in the p i v, but the major disadvantage of both l d a as well as the p i v is that you cannot use it for discrete phase, if the discrete phase volume fraction increases more than 5 to 10 percent and that is the major limitation because most of the time the multiphase flow reactors, we operate in industry is having a very high discrete range volume fraction because we need higher throughputs. So, we operate for higher gas velocity we operate for higher solid loading we operate for higher solid flux in the solid is also in the continuous and that make the system opaque, even if you make the glass wall of the glass is the system will be opaque by its own.

So, that puts the major limitation, but still this techniques are very popular and why because you can have a real time analysis almost you can see how the particles are moving and you can have a very good spatial resolution in p i v if you use a high speed camera you can have a very good time for resolution too. So, that is the major advantage

of the technique now to overcome this limitation that you cannot use it for the higher solid volume fraction radiation this technique is being develop and that is mainly 2 technique which is being used and that is positron emission particle tracking and radioactive particle tracking I am again saying that this is only mainly 2 there is other technique like x p t v x ray particle tracking velocimetry that is also based on the radiation, but what we do in these techniques, actually, we use the radioactive sources now we know that is this is a radioactive source, whether it is a x ray or gamma ray their penetration power will be very high and therefore, to the major disadvantage whatever was there when you operate in the optical range or optical frequency range will go out and says the gamma ray can penetrate almost anything.

So, you can use this radiation based technique for the higher diameter system for the opaque system even for high denser system even the wall is opaque or the system itself is opaque you can use all this techniques. So, that is the major boost in the radiation based technique in the positron emission particle tracking what we do we use a positron source and with the annihilation of the positron with the electron we generate 2 back to back gamma rays. Now these 2 back to back gamma rays are detected and we calculate by using the reconstruction algorithm which I have discussed the triangulation method we calculate the position of the particle.

And we get the Lagrangian particle track and from there we calculate the velocity that is the major advantage the advantage again comes with a gamma ray that you are not limited with the opaqueness of the system, but in positron emission particle tracking as I said that you are generating the gamma ray by annihilation and we generate to back to back gamma rays which are one hundred eighty degree apart you need a detector system which can detect the simultaneously detect both the gamma rays, if they are not able to do that; you cannot considered that recording as an event and you cannot use it for that measurement and that makes the whole detector system very complex and the cost of the system goes very high.

Further the problem another problem with the positron emission particle tracking is that because you are generating the gamma rays which annihilation your inertia of the gamma rays safe and that is 5 1 1 k e v. So, you cannot use this system this technique for a very big system with a diameter of the column is very high. So, suppose if I want to use positron emission particle tracking in the industrially skill boiler with a diameter maybe

of several metres you cannot use this technique because your source energy or gamma ray energy is very low and it may get attenuated within the system itself or it may be scattered with the system itself. So, therefore, you will not get a gamma rays which is directly coming from the source or you cannot consider those event has a measurement and therefore, you will not able to measure anything. So, that is the major limitations in the positron emission particle tracking.

Now, to overcome that radioactive particle tracking is used where we used directly a gamma ray source now because of gamma rays source directly using your not generating the gamma rays because of the annihilation the safety voice this is a major concern there you are using a beta source or positron source which is not that harmful because the beta can be stop with a small shielding even clock can shield the beta glass layer can shield beta, but once you are using gamma rays directly gamma ray source your inner you are safety requirements is very kind of increase you need special gadgets special led apron led goggles led gloves you all need all those things you need the survey metre monitoring meter to monitor the radiation. So, all these things you need to do which makes the technically will be complicated and you need proper approval before you use this technique.

So, that is the major problem in this technique, but the advantage is because you are using the gamma resource directly there is no limitation of any system diameter. So, if suppose my system diameter is big if I want industrial scale boiler to be studied I will use the energy gamma rays which energy is very high. So, I will you say some cobalt as a source where the energy will be in the range of 1200 or 1300 k v. So, we can use those high energy gamma resource we can use higher activity of the gamma ray. So, that the number of accounts emitted will be very high. So, the probability of this detection will also be very high. So, we can use all those things that gives lot of flexibility and; that means, the radioactive particle tracking technique as a very versatile technique which can be implemented at all the skills.

But the problem is your safety requirement that is the first problem second problem the temporal resolution the spatial resolution is obvious take this technique is not as high as you can get from the l d a or p i v and this makes a limitation that you can get the velocity profile you can get low velocity profile for any system, but once it comes to a very high temporal resolution very high spatial resolution this technique does not full fill

that requirement and that limits the application of this technique particularly say if you want accuracy a system where you want to have map of accuracy we say point zero one m measurement or you want to use this in the micro reactor you cannot use it because the spatial resolution is relatively higher compare to the p i v and l d a. So, that limits the application, this limitation of this technique is you cannot measure the gas which you cannot track the gas phase because it is almost impossible to make a solid tracer which can be literally bind with the gas and therefore, the r p t treatment can be used to track the motion of the liquid to track the motion of the solid, but you cannot track the motion of the gas.

So, the next technique was m r i which is very accurate technique will be used a very high magnetic field source to change the spin of the electrons in which the odd electron number is there which is this spin we give the r f frequency, we relax them and then we measure that how much time it is taking back to come back to the original position and from there we calculate the velocity and we also calculate the phase reaction because each phase will have their own magnetic field resistance. So, there and their food because of that this phase will be different. So, we use that technique that technique is very accurate you are going to the molecular label the special resolution is very high temperature solution is very high, but the problem with the technique is you require a very big magnetic field.

So, to scan a 2 inch column you require round 5 Tesla magnetic field and that is very very high and therefore, you cannot use this technique for scanning the column which is of higher diameter say anything beyond 2 inch or 2.5 inch you cannot scan that column by using the m r i technique because the magnetic field requirement will be very very high and generating that magnetic field will be very difficult and even if you generate it will not be safe to use that magnetic field.

So, therefore, the application of this magnetic resonance imaging m r i in multiphase flow reactor is pretty much limited you can scan the smaller diameter you can get lot of information, but it cannot be used at all the skills at that limits the applications of the m r i. So, whatever the velocity measurement technique we have discusses I keep on telling that there is some limitation of each technique we have tried to discuss that we have tried to discuss the measurement methods the principal the reconstruction algorithms and all. So, that you can get a clear idea and based on your own application you are doing

research or if you are working in industry or if you are going to work in industry you can recommend some of these techniques depending upon; what is the requirement till what label accuracy you need what is your system.

So, that is what we have tried to discuss with the velocity measurement then we have done the same thing for volume fraction measurement technique and what we have done there we have divided the technique again into 2 part one is your invasive techniques another one is non invasive techniques again the same invasive means you are including some probe inside to measure the volume fraction in non invasive you are not doing anything you are not disturbing the flow.

So, definitely the accuracy of non invasive technique is much higher compared to the invasive technique now under invasive technique what we have done we have discuss the 2 technique mainly one is capacitance probe and another one is optical fibre probe in capacitance probe I said that what we measure is the capacitance that with the basic principle is that the capacitance property or permittivity of each mat phase is different and utilize that concept to measure the conductivity between the 2 place if the we use the 2 place we give some electrical current and we know that depending upon the phase project between these to place the conductivity will be different.

And that will actually give that how the phase that a particular page is changing there at that location with the time. So, this gives kind of a volume fraction measurement with the time and it with the at a particular location because this technique is a point measurement technique at a particular location we get, but the problem is if you use 2 plate conductivity meter, then it is size is very big and therefore, its intrusive nature is very high and it disturb the floor and that has been well proven by several researcher therefore, a needle based or capacitance probe has been developed they only one needle is being used the body of the probe is used as a ground electrode and he tried to measure that once the needle comes into the contact with rich material and that material conductivity.

So, in that way we measure the volume fraction then the time with the position at particular these technique are point source. So, if you want to measure with the position you have to use several such poor's probes are you up to put this probes at different location at different type, but at the in what is going to happen that this technique are

invasive it is going to change the flow field further we know that the conductivity or permittivity is also the function of mini parameter like moisture content temperature in the particle breaks all those parameters will also play a role and which limit the application of this technique because if they will be certain moisture your whole conductivity will be different ok.

So, that actually limits the application of this technique and then we go to optical fibre probe where we use either the transmission method or back this back is scattered method now in the back is scattered method is exactly same as we have done in the velocity measurement you put a laser light and we know that refractive index of each material is different. So, whatever the intensity recorded on the detecting fibre will be depending upon that what is the material through which the light is being reflected. So, you can find it out that material presents at that location and how that material presence is changing with the time.

Now the only problem with the back the scattered is that your measurement domain is not fake as I discussed that suppose if there is a small amount of bubble present then the light whatever you have send I just signal from the light emitting fibre can travel longer distance if you are kind of operating in a very dense system then the light from a distance will be very low. So, getting that where you are measuring the phenomenon is very very difficult in the back is scattered mode and therefore, the transmission mode is being develop there to probes are injected like this one probe is emitting the light another probe which is little bit far from that perfectly and line is receiving the light and we see that how the light is being reflected based on that phase of whatever the page is present.

But the problem here is because you are working on the transmission mode now we are including the 2 probes your size of the system increases and that is why the inclusive nature of the system is increases and that is no it means the probe get disturb in a large way second problem is that the alignment becomes very big is too because suppose you are using in a bubble column there the bubble is going and hitting this probe. So, what will happen if the velocity of the system is very high in the alignment can mismatch and the moment the alignment miss will mismatch you will see entirely different results.

So, that is the limitation of this technique and therefore, the non invasive technique has been used and mostly non invasive technique is based on the tomography measurement.

So, what we have done in tomography measurement, we have discussed ionizing measurement non ionizing measurements in ionizing measurements we have discussed about the actually tomography and gamma ray tomography in non ionizing measurement be up discuss about the electrical capacitance tomography and magnetic resonance imaging now magnetic resonance.

I have already explain in electrical capacitance tomography it is similar to the capacitance probe use the same principle that the permittivity of the different pages will be different and instead of now putting the electrode inside the floor we put the electrodes outside we sensitize each electrode one by one different kind of we put the electrodes all around the wall support this is a top view we put the electrode all around the wall with sensitize the electrode one by one. So, suppose we forces sensitize this electrode, we see that how the permittivity is the signal is being recorded on all this detector or all this flow which is now acting at the receiving.

Then we sensitize the other probe and. So, on we keep on sensitizing the other probes all other electrodes we record the signals and that signal is going to be proportional to the phase present in that and then we can use the algorithm l b p particularly to reconstruct the position major advantages that this algorithm can give you on time measurement of real time measurement. So, the temporal resolution of this technique is very very high, but the problem is they special resolution is very low because of the reconstruction algorithm which is being involved with shadow; now which is not able to see the difference sharp changes in the phases suppose there is a bubble and there is next to the bubble there is a liquid you not see the sharp changes; what you will do it will shadow down ok.

So, if you see certain things kind of a structure which will be between the bubble and the liquid and that actually limits the spatial resolution of this technique. So, the temporal resolution is very high, but a spatial resolution is very low. So, that actually made the technique of application limits the application of the technique only for the phenomenon where you need a very high temporal resolution like if suppose you want to see how one phase is mixing with the another phase and how that mixing coefficient is changing with the time how the particle is moving kind of if suppose you are operating a trickle bed reactor where you are giving the pulsation you are giving the liquid load in the pulse station and you want to see that once you give a purse how much waiting efficiency you

are getting you can use this kind of a probe which we give your accuracy with temporal accuracy.

But special accuracy is not be that good. So, what we did we move towards the ionizing technique we discuss about the gamma ray based or x ray based technique. Now as we discussed that both the technique work in the same principle both are transmission tomography principle, we have one source and one directors or several source and several detectors are used depending upon what type of beam you are using a what type of projection method you are using and the system of interest will be placed in between record that innovation recorded on the detector with the source and detector is outside side system of interest is inside you first scan the empty column then you spend the column at insitue condition record the attenuation recorded on the detector for each projection line and then by using the suitable preju; this reconstruction algorithm like a r t algebra reconstruction technique of filter back method you reconstruct the position on this kind of attenuation fact on this coefficient.

So, what you will get you get that how the attenuation coefficient mu is changing with the position and you get that new distribution or the distribution of the different phases this mu is nothing, but the attenuation coefficient of the phase. So, the phase at attenuation coefficient distribution is directly proportional to the phase fraction. So, different this you can calculate and did you know that this mu is actually written as mu one epsilon one plus mu 2 epsilon 2 for a 2 phase system and epsilon one plus epsilon 2 will be equal to one. So, you can get the volume fraction distribution the only problem is a spatial resolution for this technique will be very high, but the temporal resolution will be very low because you need sufficient time are sufficient statistics at a particular location to say that this projection is the projections which you will get ok.

Or this is a final projection because this is gamma ray you need you will be noise in the system to come up to increase the signal to noise ratio what you need to do you need to wait for the longer time you have to wait for the sufficient statistics and therefore, the temporal resolution will be very poor, but the spatial resolution will be very high and the technique can be used for 2 phase and three phase system in the three phase system what you need to do you need to put up another source. So, you will have dual source tomography.

So, that is the advantage of this technique, but the disadvantages I said that you will not have a very good temporal resolution then we have discussed about the different radiation this technique which is used widely in the industry for the trouble shooting to find the leak in the heat exchanger to find that whether my reactor is working as per my expectations.

If suppose there is some internal inside the reactor that internal is falling down how you recognize this all this things you can do with the radio tracer based technique you can measure the liquid label and all those things in opaque systems and you can also do the pipe is scanning you can find the pipe blockage all this things you can do with the radiator of a technique which we have discussed and then finally, we discuss the pressure measurement technique which is very straightforward taking very widely used can be used to measure the overall volume fraction or you can say the volumetric average volume fraction between the 2 probes.

So, this way we have discussed about each technique advantage disadvantage and limitation of each technique and I hope you might have enjoyed this course and if there is any problem please feel free to contact me, I will try to resolve your issues and I hope this course has given you a clear idea about the advantage disadvantage of district different techniques and the capability of each techniques. So, you can choose the technique based on your requirement and that was the main objective of this course with this I would like rest this course for any discussion please feel free to contact me.

Thank you.