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

Lecture - 19
Bubble Column

So, welcome back yesterday whatever we were discussing is about velocity measurement techniques which is being used in multi phase flow. Now, today I am going to explain about volume fraction measurement technique and like velocity measurement technique; volume fraction measurement technique is also being divided in two part. One is invasive again it means something is included inside the flow. So, it will relatively lower cost, but what will happen that the flow can change at the point of measurement itself.

Then another one is non invasive; non invasive means you are not disturbing the flow you are measuring the phenomenon from outside. So, in this case you are not disturbing the flow at all now invasive techniques is generally lower cost; it is cheaper than non invasive technique, but the accuracy of non invasive technique is better than the invasive technique most of the time ok.

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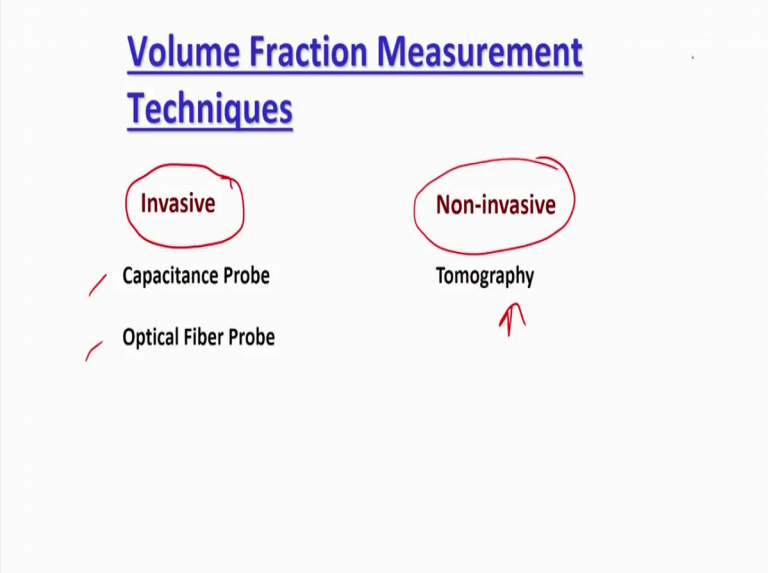

Now invasive, non-invasive technique under that volume fraction measurement the major class is tomography and we will discuss what is tomography. And before that I will briefly discuss about what is capacitance probe and optical fiber probe. Now, optical

fiber probe we have already discussed while discussing the velocity measurement. So, it the principle remains same the one thing will be introduced here in the intrusive and that is capacitance probe. Again this is not the complete list this is the list which is widely used in the industry or in academia for the research purpose; there are many other technique which is being used to measure the volume fraction.

So, I am not covering the whole list and giving you just a glimpse of the critical technique and the brief overview.

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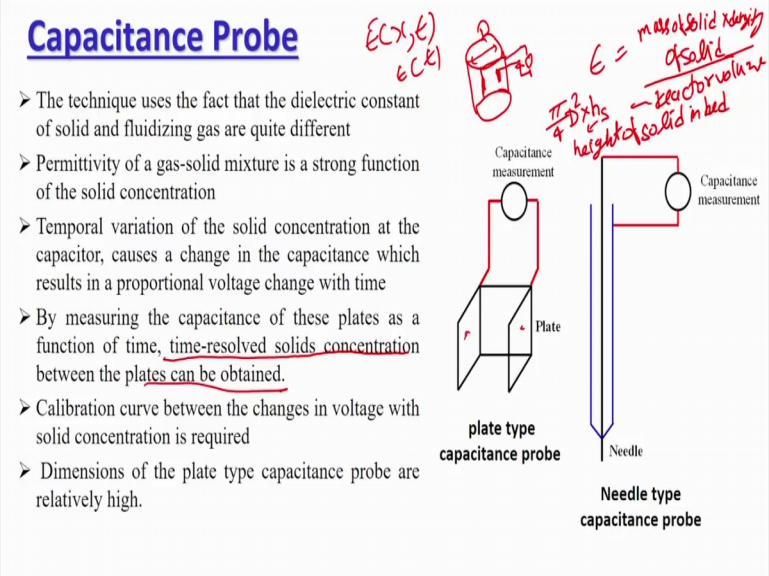

So, now start with the capacitance probe what happen in the capacitance probe; we use the permittivity of different material we know that the permittivity of different material is different and we use that principle to calculate the volume fraction. So, what we do here we take two plates; this two plates we take and between these two plates we give certain voltage.

Now, we measure the capacitance suppose some materials will come the capacitance between these two plates will change. And the change in the capacitance will be proportional to the permittivity of material which is coming inside. So, what we do here we kind of we insert these two plates inside the flow. So, suppose this is my system of interest what we do? We insert these two plates and these two plates are say connected to a measurement device which measuring the capacitance or in terms of the voltage we are doing that.

So, what we know that different material will have a different dielectric constant and because of different dielectric constant their capacitance will be different; capacitance properties will be different. So, once the flow will take place then what will happen the material comes between this flow will be changing. So, using this plate different material will come or the combination of different material will come.

So, what we will do? For different material different capacitance change in the different capacitance will be recorded and based on that we can recognize that which phase is coming. Now the change in the capacitance will be the function of the distribution of the material present between these two plates.

So, what we need to do? We need to do the calibration first thing. So, that is the one major drawback of this technique that we need to do the calibration again like other invasive technique we have discussed in the velocity measurements. So, what we are doing? We are going to put the plate inside the flow we know that suppose it is a gas liquid flow or gas solid flow the gas has different permittivity or dielectric constant compared to the solids.

So, depending upon which phase is present whether gas is present or solid is present or the combination of gas and solid is present; the capacitance recorded will be different and the moment. So, based on that capacitance recorded you can calculate that what is the fraction inside or the solid concentration inside ok.

So, that is the basic way the technique work; the temporal resolution of this technique is very high because you are working on the electrical this current. So, the temporal resolution is very very high; the only problem with spatial distribution that may create a problem. Second thing it gives you a point measurements; so, it will give you the measurement where you will put these two plates.

Now, the size of the plate is definitely going to be big because you are putting two plates; these two plates will be inserted together with the electronics which will be the outside. So, it is the size of this plate type capacitor is big and therefore, the intrusive nature will be higher; the flow disturbance will be higher. So, that is the drawback of this and you can measure this the principle of measurement is very simple we are measuring the capacitance or change in the capacitance with the time and with that you can find it out how the volume fraction is changing with the time.

So, the time resolved solid concentration can be easily obtained and; that means, that the temporal resolution is very high. And our first wish list which I said earlier also that epsilon with the position with the time we want; we can find it out that how the epsilon is changing with the time that you can easily find.

Now with the position what you need to do? Because this is the point measurement or is a limited volume measurement; if you want to know that how the position epsilon is changing, a volume fraction is changing what you need to do you have to put several probes inside or the same probe you have to put at different location to get how the volume fraction at different location is changing with the time.

But the temporal resolution you will get very good the only problem is you need a calibration curve, you need to prepare a calibration curve between the change in the voltage with the solid concentration and that create a problem. So, what is the problem you are going to have? Because you have to suppose in the gas solid system, you want to find the solid concentration or solid fraction what you need to do? You have to do the calibration. Now it is not possible because you are using two plates that only gas are only solid will come inside the plate at a time.

So, what will happen? It will be combination of gas and solids. So, doing the calibration for only gas and only solid is relatively easier which we were doing in the optical fiber probe or hot wire anemometer while doing the experiment for the velocity measurement. Here the challenge is little bit bigger because you will have both the phases will be present at the same time, you need to do the calibration for different solid concentration. Now that is going to approach a major problem because how you will major the solid concentration ok.

So, to change the solid concentration in the gas solid you have to fluidize it and then once you fluidize then how you measure the solid concentration that itself is a bigger problem. So, what we do? In this case we do the calibration at extreme leads we do the calibration only with the gas; we do the calibration with the packed bed condition. Now once with the pad bed condition we know that packed bed volume fraction we can find it out depending upon how much amount of the solid we have poured in what is the height achieved in the column. So, you can find it out the volume of the reactor and if you know

the density of the solid you know the mass you have poured in you can find the volume of the solid and the ratio of this will give you the solid fraction ok.

So, you can find the epsilon of the solid and epsilon of the solid will be nothing, but the mass of solid into density of solid of solid divided by the total reactor volume. And suppose for the cylindrical column where the diameter is say D this reactor volume will be pi by 4 D square into h s where h s is the height of solid of solid in bed ok. So, you can find it out the solid fraction of a packed bed and for that you can measure it measure the capacitance ok.

So, our voltage recorded for that solid concentration. So, you can prepare a calibration curve and based on these two point calibration; you can calculate the capacitance this you can calculate the volume fraction or solid fraction inside. So, that is the one way of doing the capacitance probe, but the plate type capacitance has a major problem and the problem is that the this dimensions are too big. So, it disturbs the flow and the disturbance may be very big because your dimensions are big.

So, to overcome that a little type probe has been developed in which a small needle is being used which is being inserted in the flow like optical fiber probe; we put a small needle say more than optical fiber probe hot wire anemometer we put a small wire or a small needle inside the flow. So, that one phase is the middle becomes the one end of the capacitance and the body of the probe becomes the another end of the capacitance and you measure the capacitance between these two.

So, the needle once comes in contact with the solid the again the basic principle remains same that the needle, once it comes in contact with the solid the dielectric constant of the solid is different; compared to the gas you will record a change in the voltage because of the change in the capacitance ok. So, you can measure that and based on that you can find it out the volume fraction. So, that is the way capacitance probe is being used this is intrusive, but the major advantage is it is relatively cheaper and the time resolution is very good.

So, you can find that how the volume fraction is changing with the time. So, that part is very very good here and that is why the technique is still being used it is for measuring the solid concentration in the gas solid or liquid solids bed. So, that is the major advantage of this technique ok.

The only disadvantage is it is intrusive for optical fiber probe which is another method we have already discussed that it works on the transmission or backscattered depending upon which phase is there the refractive depending upon the refractive index of the phase and the reflection by that phase will be different. So, intensity recorded on the photomultiplier tube will be different and you can identify the phase and from there you can calculate that what is the phase fraction for that particular phase. And you can use that you have to again do the calibration to calculate the refractive index of the different phases.

So, that is the way you can use this capacitance probe and optical fiber probe, the drawback of the capacitance probe is that if suppose there is a moisture available or bed temperature is changing with the time; then your capacitance will also change because that the moisture and temperature affect the capacitance property or dielectric constants of that stage.

So, if you have that you this kind of accuracy will be lowered or it will be kind of hampered; neither it will provide a good accuracy with high temporal resolution, but the spatial resolution will be a problem the invasive nature will be still be a problem though you can sort out the invasive nature problem to a certain extent by using the needle type capacitance and that is why the needle type capacitance are more widely used compared to the plate type in current era.

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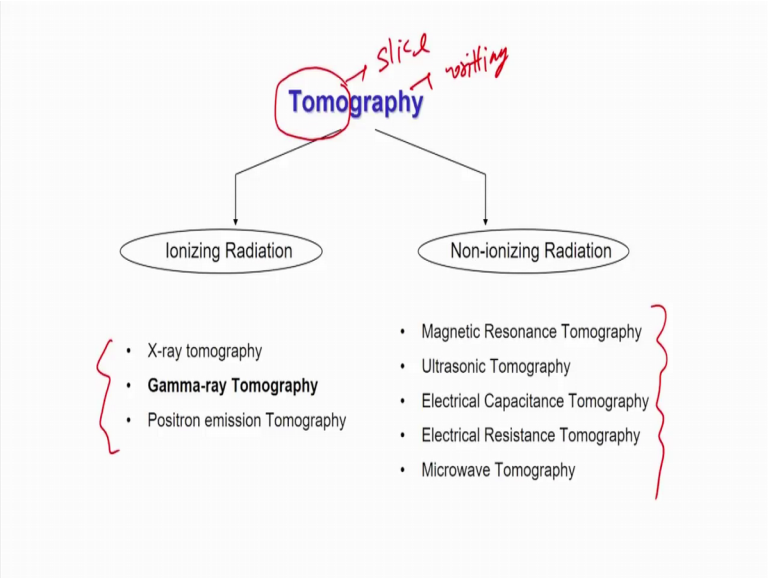

Now, next moving to the invasive technique non invasive technique as I said that non invasive technique is mainly based on the tomographic measurement; now what is tomography? Is tomography is a Greek word tomo means slice and graphy means writing. So, it means once you are writing in terms of the slice wise information that is called tomography.

Now, the tomography is being divided in two parts one is ionizing radiation another is non ionizing radiation. So, again this is not a complete list we are just using you are giving some list here some important technique here, but there are several other technique which is being used to measure the volume fraction by the non invasive methods. So, in organizing definitely the vase rays which can ionize the system is called ionizing radiation like X-rays, gamma ray positron these all comes under the ionizing.

The non ionizing means which does not ionize the system like magnetic resonance imaging, ultrasonic tomography, electrical capacitance tomography, electrical resistance tomography, microwave tomography etcetera. So, these all comes under the non ionizing radiation now again I am going to discuss only few of them which is widely used and based on their applicability and accuracy we will discuss some of the techniques here.

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Now, what I am going to discuss first is the electrical capacitance or impedance or resistance tomography; the idea remains same somewhere you measure the capacitance somewhere you measure the impedance, somewhere you measure the resistance

depending upon which depending on the phase and the level of accuracy or the mixture available which one will give you a good signal.

So, based on that we use the technique the basics remains same and the electrical capacitance tomography; the basic is pretty much same as of the capacitance probe. So, in the capacitance probe we were measuring the volume fraction by virtue of because of there is a difference dielectric constant of different material. And because there is a different dielectric constant of the different material, the voltage between the two rest electrons will change based on that what material is present between these two electrodes.

So, that is the same principle in electrical capacitance tomography we use; the only changes in capacitor probe you insert the probe inside here what we do we do not insert the probe inside we put the probe outside.

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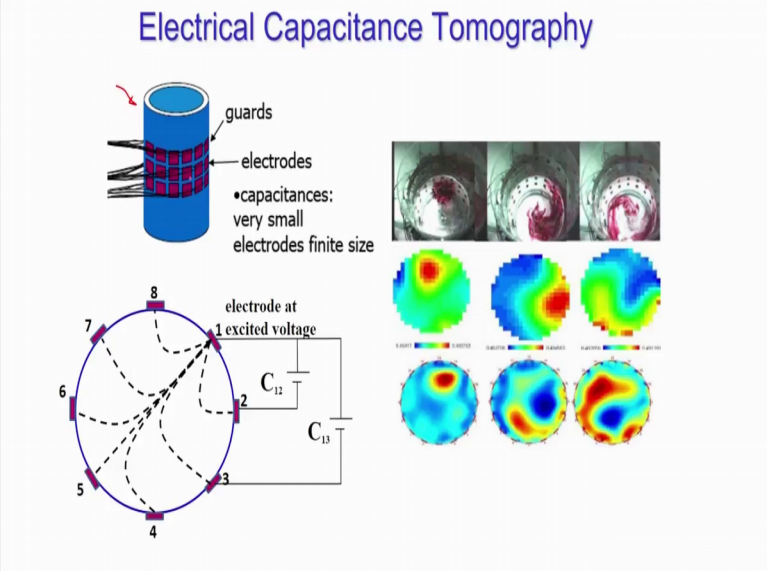

So, this looks like something this we put the probes outside these are the probes which is there some probes are the receiving probes some probes are the sensitive probe which is being sensitized kind of excited by a given a certain voltage.

So, what will happen? This probe suppose and there is some probe which is the guard probes of kind of a ground probes. Some electrodes supply the current and other electrodes receive it and based on that how much current will pass or how much voltage

will be there in that phase will depend on the capacitance between these two electrodes. And capacitance on these two electrodes between these two electrodes will be the function of the phase which is present inside. So, that is the basic principle we use in electrical capacitance tomography.

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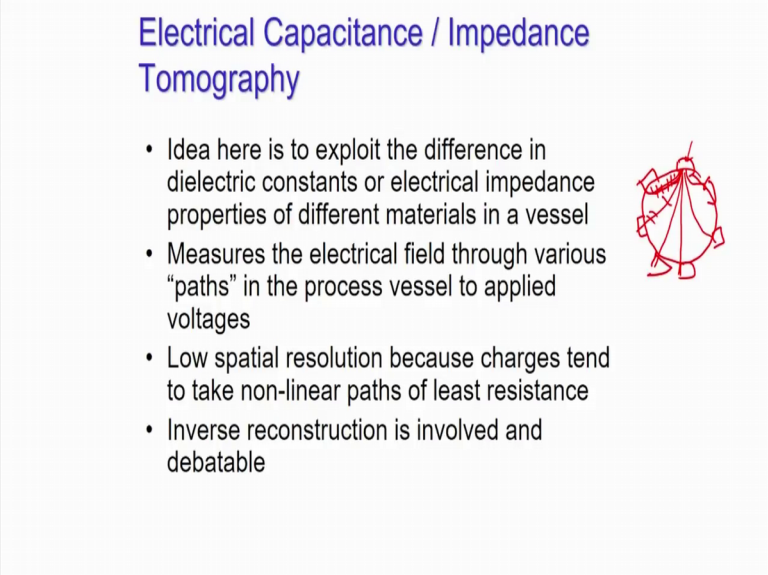

So, suppose this is my reactor. So, this is my column on the top view and I put several electrodes I put the several electrodes now if I put suppose if I excite this electrode all the electrodes let us assume has been kept at certain voltage or certain difference voltage. Now if I change a voltage on this if I excite it one electrode what will happen this electrode will see that what is the other electrodes will be receiving and because they have given that this capacitance will change. And that change in the capacitance between these two electrodes will depend on what is the material is the available in this line.

Similarly, what is the material available in this line. So, in that way you can find it out that what is the phase fraction dielectric constant value; you can find it out the diametric constant value is going to be the function of volume fraction or the phase present here ok. Again the temporal resolution is very good, but the spatial resolution have a problem; you will have a very low spatial resolution because of the non-linear parts it is followed.

So, it will not follow this linear path it will follow the non-linear path and therefore, the resistance depends on not only the material present is also depends on the path and therefore, the spatial resolution actually goes down.

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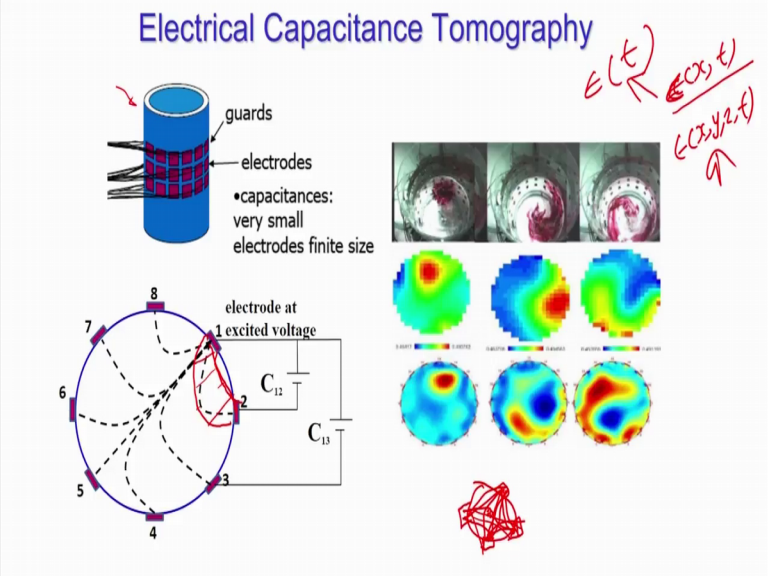

So, how it works? As I said you have suppose this is the system, you put the electrodes all around the periphery on the periphery of the system all around it. Now suppose you have 8 probe system, you have 8, you have taken 8 probe what we do we slowly start exciting the probes ok.

So, suppose we what we do suppose this is the electrode 1 these are the 8 electrode maintained at certain reference voltage now we excite the 1 electrode. Once you excite the 1 electrode by giving certain voltage excitation voltage what will happen the capacitance between these two say 1 and 2 will change.

Now, how the capacitance change you record in terms of the voltage change and what will be the function how the capacitance will change? That will depend that what are the phases present in this and this path cannot be linear it is not needed that it will be linear it will not needed that it will travel like this, it can be any path I have shown a tentative path here.

So, based on that this path will change and actually this is the mean path I have said it will say suppose goes like this something. So, it will depend on this path this path how much is there; what is the phase present in this? So, what will happen? You will record the C 1 2; similarly we record the C 1 3, C 1 4, C 1 5, C 1 6, 7 and 8. So, you record a kind of how the capacitance is changing and that change in the capacitance is actually the

function of dielectric constant which is the function of the phases present between these two electrodes.

Now, again we will excite the second one because I need the information in the slice wise I need pixel wise information. So, I will excite the second and then again I will do the same thing I will record that C 2 1 C 2 2 C 2 3 and so, on. So, that ways you will find that again the seven electrodes that what will be the dielectric constant between these two electrodes.

Similarly, we keep on doing it for all the 8 electrodes or 10 electrodes or 12 electrodes whichever you use in your system. And then for solving all these equations together we will get that what is the pixel wise distribution of the fraction. So, suppose this is the one you got let assume that this is the electrode ok. So, first electrode say given this information, the second electrode once you excited given this information the third electrode gives this information this is going at it in this way and the fourth again gives certain information.

So, what will happen if you will solve all this you will get that pixel wise information that what is the fraction here and because it is a non-linear path what will happen this resolution may not be very accurate. And that is what is being shown in this example there is a dye which is being injected in the liquid and we want to find it out that how it is mixing. So, you can see that the dye has been tracked and the fraction of the dye is being recorded and you can see here that this is the red colour shows that is a dye.

But the spatial resolution is not that good you can see that there is no sharp change here if you will see that after this there is a complete liquid, but here you are not seeing any sharp change there is a kind of first red goes to yellow then green and then goes to say blue. So, that is the way it is being a spreading and that mixing can be tracked here, but because its temporal resolution is very high you can see that how the mixing between the two phases is taking place, how the volume fraction is changing with the time that is can be made with a very high accuracy.

Ideally it can measure the epsilon that x and t in one go because you are covering the whole volume or kind of a zone of interest within that zone of interest it can give this information because you are covering the entire cross section not like a non intrusive

technique you are putting the probe inside and that is why it will just able to get the information at that location.

So, that is not true here you are covering the entire cross section and because you are covering the entire cross section you will get the epsilon as x and t, but the problem is your accuracy with the position is not very high the spatial resolution is not very high please. Remember once I say x is actually I mean x y z and t because all the position because it is going to be give you the 3 dimensional domain.

So, all these you will can major the temporal resolution will be very good spatial resolution will not be that good; so, that is the limitation of this technique. So, if you have to measure something which is changing with the time say in a gas liquid bubble column; if I want to find that the bubble fraction is changing with the time how it is changing with the time ECT can be you to find that the bubble fraction change within a particular volume or within a region of interest with the time that easily can be done.

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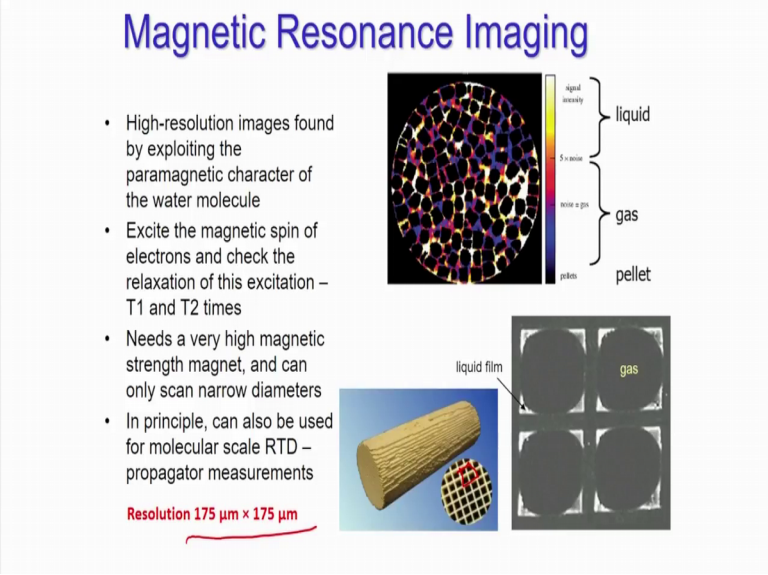

Now, next technique is again non ionizing which I am discussing is magnetic resonance imaging this is one of the most accurate technique available and one of the most accurate technique which can accurately measure the velocity as well as the phase fraction. Now, what we do here in this technique we use a very high magnetic field and this high magnetic field because of that you get a very high resolution image. And the basic principle is instead of now the capacitance different dielectric constants; we are

exploiting the paramagnetic character of different phases. Now different phases have different paramagnetic character, but we like water have a different parametric character based on that we actually; what we do with the magnetic field we excite the magnetic spins of the electron.

So, if you put a very high magnetic field we know that electrons which odd spin number will get excited and they will rotate their spin. Now what we do they excited electrons then what we do we do some relaxation and during the relaxation and excitation say T 1 and T 2 time this spins will again go back we measure that to get the velocity; different magnetic field or a kind of magnetic property a paramagnetic property of the fluid will all kind of phase we able to reconstruct the image here with the high accuracy. Because we know that there will be different magnetic field, we use the RF frequency for the relaxation and depending upon RF in a frequency you can find it out the velocities of the phase.

So, this is a typical MRI image; there is a detail if you want we can discuss, but kind of this course I do not want to go in detail I am just telling you that what you can do here. So, this is a typical diagram of a gas liquid solid bed which is a triple bed here actually you can see that the black colour is showing the solid; the blue colour is showing the gas, this yellow colour is showing there is the liquid. So, you can see that along the solid there is certain gas film is being formed and the liquid is on the outer side of that gas film.

So, this kind of imaging you can do the resolution goals in order of 175 micrometer to 175 micrometer or even better for the MRI. Similarly here there is a monolith channel and if you want to find it out that where my gas distribution is there how my liquid is flowing say in a gas liquid monolith channel you can find it out with the MRI that how the gas is flowing how the liquid is flowing?

So, this is the one section one square of this where the 4 holes is there. So, this is suppose this section and we are talking about these 4 holes and in this four 4 you can say that the white this yellow colour is the liquid film and the dark colour is the gas film. So, you can see that whole monolithic channel is actually failed for this condition with the gas and liquid is flowing as a small thinner cell around the gas bubble and that to be evenly at the corner it is not being covered properly.

So, you can have this kind of a detailed analysis which no other technique can do, but the major problem is this technique is you require a very high magnetic field. And because of that the use of this technique is limited and you cannot use a column this technique as of now you cannot use to scan a column of diameter more than 2 to 2.5 inch ok.

So, for a scanning two inch column you require around the magnetic field of 5 tesla ok. And that is why the use of this technique is being limited for the larger diameter system. So, again my wish list of having a technique which can do the measurement with the similar accuracy at a smaller scale and the larger scale will not be fulfilled though this technique is accurate this gives better velocity as well as volume fraction productions.

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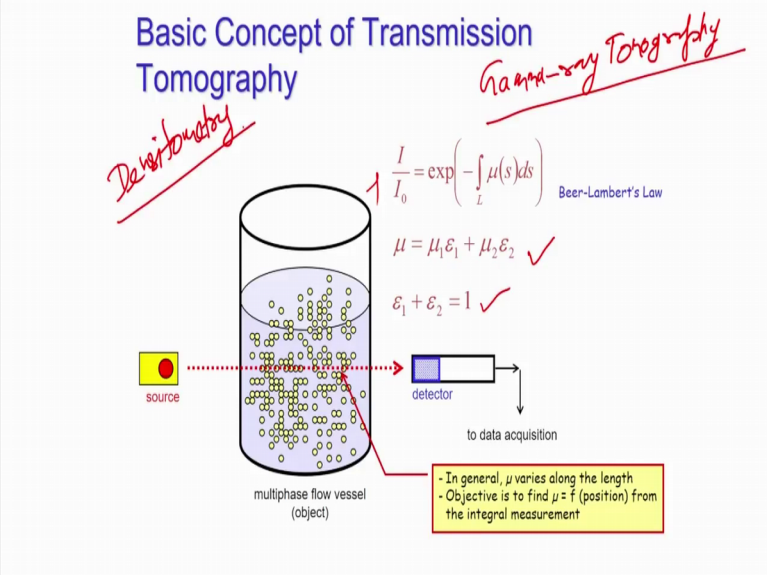

Then we move to the ionizing system and the ionizing system based on that gamma ray densitometry that works on the transmission tomography principle. So, what we are going to discuss is the gamma ray tomography or X-ray tomography. Now the gamma ray based principle of the gamma ray tomography is relatively simpler; what we do here is we take a source, we take a detector just the detector is similar to as of use in the RPT technique.

Now, in RPT what we do we put the source inside the reactor and we allow the source to move outside now here we work on the transmission principle. So, source and detector both are outside they are perfectly aligned on the moving carriage and the carriage has a

capacity should have a capacity to move in r theta and z direction so, that you can scan the entire column.

Now, what we do? We use the beer lamberts principle which is I equal to I naught e raised to the power minus mu l to calculate the volume fraction now we know that this mu l whatever you are measuring suppose this source it will be measured at a particular chord length of a particular line. And that is why this mu v do the line integral where ds is the distance between the source and detector or the chordal distance; because if the detector and source escaped into the atmosphere that attenuation is going to be negligible.

So, the attribution will be causing only because of the medium present here and that is being used here. So, what you can get you can get that the line integral value of the mu and that line integral value of the mu will be the function of both the phases. So, suppose there is a phase 1 and phase 2; the line integral value of this mu will be the function of a will be equal to the mu n which is the mass attenuation coefficient or attenuation coefficient of phase 1 multiply by the phase fraction plus mu 2 mass attenuation coefficient of phase 2 multiply by the volume fraction of the phase 2 at that line.

And we know that for two phase system the overall volume conservations should take place. So, the epsilon 1 plus epsilon 2 is going to be equal to 1; so, by using solving these two equation along with this you can get that what is the value of epsilon 1 and epsilon 2 along that line. So, this is the beer principle is being used in gamma ray tomography or X-ray tomography.

Now, what we are getting here? This we are getting a line integral and that is why this technique is called densitometry whatever we have discussed it is called densitometry which uses the line integral data which provided the line integral volume fraction data ok. So, that is the called densitometry which is also referred as a first generation tomography.

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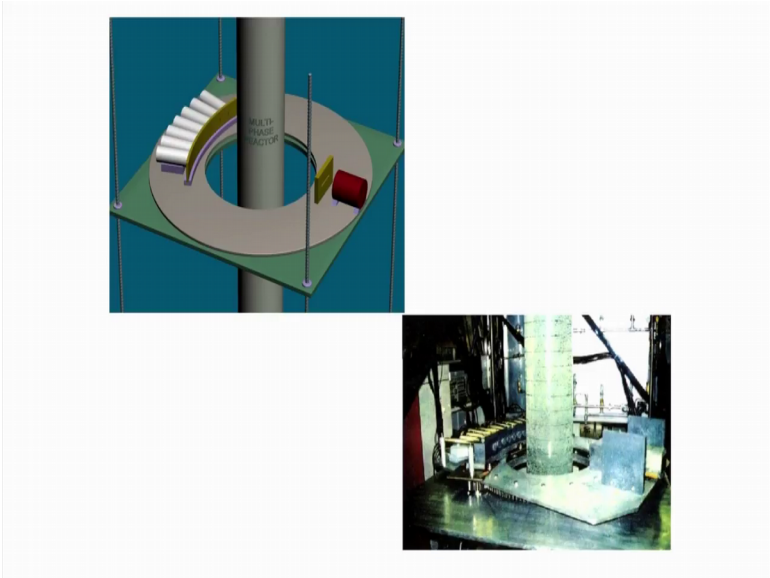

Now, if you want to have a pixel wise information or detailed information of the volume fraction distributed on the pixel wise; what we need to do? We need to acquire the data in a different way. So, how we can acquire the data? We can have two kind of a projection; one case we can use one detector one source several detectors and in other case we can use several source and several detectors.

So, this is two different projection is being used we will discuss about the projection, but these are the schematic and photograph of a typical computed tomography setup.

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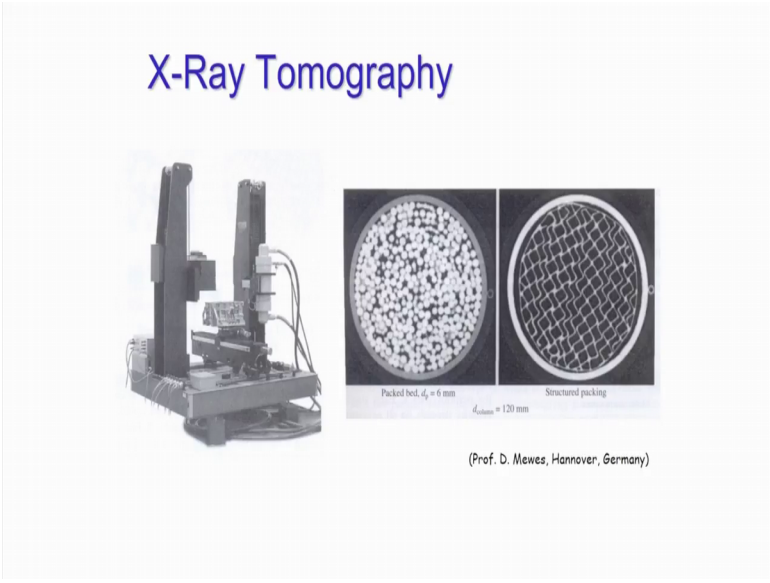

So, similar principle is being used as we discuss about the projection after some time, but similar principle is being used for the X-ray tomography also. In X-ray tomography what we do? Instead of using the gamma ray we use the X-ray source. So, again there is a X-ray source generator there is the detect the X-rays; they will be perfectly aligned you generate the X-ray based on the transmission principle the intensity of the X-rays will be recorded. And whatever will be attenuated density change will be recorded based on the attenuation that how much attenuation coefficient is there and that attenuation will be mainly because of the mixture present or the phase present within the system.

So, the basic principle remains same only thing is whatever I have discussed you will get the line integral and what we want is the integral or is the pixel wise information. So, to do that there is two type of projection measurement is being used; one is called is a parallel projection another one is called is the fan beam projection. So, in cross this parallel projection what happens you use several source and several detector.

So, like what we have done? We have used one source one detector then there should be a flexibility to move the x director in this direction the way it has shown by the arrow in this direction and then this whole thing should be able to move in the theta direction and z direction.

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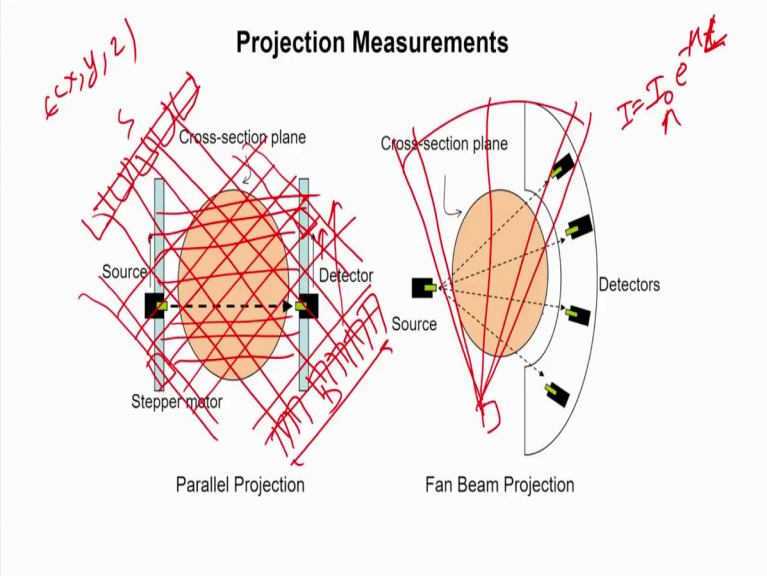

So, if you do that you can scan the whole column radially first you can scan the whole column with the different line average. So, you will get the different line average

suppose if you keep on moving here. Then if you move it here at the theta degree suppose the source goes at this location detector come at this location. And you again move it in this line if you move it again in this line say then what will happen? You will get different projection here and similarly if you will move it again on this line say; if you move further on this line source and detector ok. So, this is source this is detector you will again get a line.

So, if you keep on moving with the theta; you will get the different line projection and if you solve all these equations together by using the suitable reconstruction algorithm. I am not going to discuss those algorithm in detail, but for the more detail if you want you can discuss with us or you can see the literature any problem is there we can discuss it you can get the pixel wise information for that cross section.

Once the scanning at one cross section is done; we can do the same thing on the other height and we can do this repeat the same process to get epsilon with x y and z all these three, but which time you cannot get y because to get the xyz data you have to do the several integral several experiments or you have to move the motor like this. So, the time resolution of any ionizing technique or radiation based technique is generally lower where you have to scan it in this way compared to the ECT.

So, you get very good spatial resolution, but you do not get a time resolve volume fraction data. So, that is the limitation of gamma ray based tomography or X-ray base tomography data and why it is there because you have to perform you have to wait till the complete spin is not completed. And that will take significant time and because of that you cannot have a time resolve volume fraction measurements; so, you cannot do that.

The another way to reduce the number of experiment is that each line whatever I have said that each line should have one detector and one source. If this is detector line I will use that many number of detector and that many number of the cell so, that you can save certain time and to move the detector along the cordial length. So, along this direction you can save the time if I use several source several detector; I can save the time I do not need to move the detector in this direction in the this longitudinal direction.

What we can do we can just have this much and we can change the theta to scan the whole cross section, but still even if you do that what will happen you cannot have a time

resolved volume fraction data then time can be saved, but still you require certain time to move the detector and source around the cross section to get the pixel wise information. So, that is the drawback of this technique the temporal resolution cannot be done; in parallel beam projection if you use the projection the way I have told you that you take several source several detector what will happen? Your safety requirement will be very big because you will be now using many sources.

So, many sources means more activity you are dealing if you are doing very high activity you have to take the special permission your safety requirement will be very stringent ok. So, that is the drawback and because to overcome that the fan beam projection is being used in which what we do? We take a source we design the qualimeter in such a way that it generate a fan beam. Now, each this length of the beam one detector is being placed as we can measure the angle of this how what angle it will be emitting this gamma rays we can find that that where to put that detectors. So, each which one detector will be there and you can find it out that pixel information this line average information from the each detector.

Now, again you can move it detector and source say now the detector source will be see come here again you will get a fan beam here. So, again you will get a fan beam again you can measure that what is the attenuation; then again you can remove it and by doing that you will get to the same location you can get the pixel wise information; then you can move this carriage upward at a different height and again scan it. So, that is the way the projection this gamma ray tomography work, the only thing is principle is being used that I equal to I naught e raised to the power minus mu t or mu l what you need to do you have to first do the scan of the empty column.

And then you have to do the scan at the in situ condition to get the volume fraction distribution here and you can get a very good spatial resolution, but the temporal resolution will not be that well. So, that is the major limitation of this technique.

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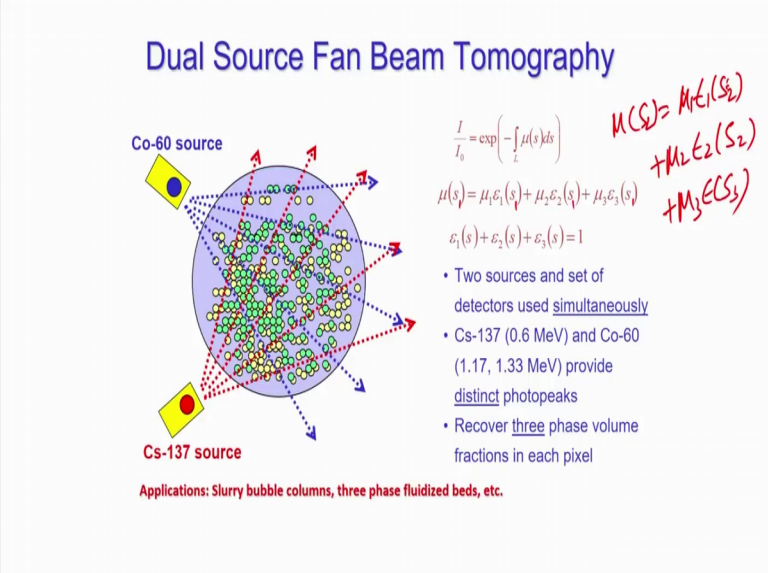

So, this if you want to have three phase bed suppose if you want to have a three phase fluidized bed or you have a slurry bubble column. And you want to measure the volume fraction by using the tomography what you can do instead of the single beam tomography you can have dwell beam tomography.

Now, what how does it give the advantage because in three phase you require three question; earlier you will having only two equation one equation was I equal to I naught into e raised to the power minus mu l now this is the line integral of this mu will be the function of all the three phases mu and epsilon 1 plus mu 2 epsilon 2 plus mu 3 epsilon 3 the second equation will be epsilon 1 plus epsilon 2 plus epsilon 3 is equal to 1.

Now, what you need? You have three variable two equation; now you need a third equation here. To get the third equation what we do? We perform the experiment with the different source. So, first say if I am using a CGM as a source another time I will use cobalt as a source. Now, how does it be advantageous because each source; the medium attenuation coefficient changes with also with the source energy and each source have a different energy.

So, the attenuation coefficient for the C or different sources will be different, it means what? You will get one more equation here and that equation this one more equation you will get that equation will be the power source two. So, you will get the same this will be I will be source 1, source 1, source 1, source 1 and then you will get the mu of source 2

will be mu and epsilon 1 of source 2 plus mu 2 epsilon 2 of source 2; 2 plus mu 3 epsilon 3 of source 3.

So, this will give you additional equation now that again you have now three equations, three variable you can easily solve it to get the volume fraction profile, but again a spatial resolution will be good temporal resolutions are not good ok. So, in gamma ray tomography or X-ray tomography; you can achieve good a spatial resolution, but bad temporal resolution, in ECT you can achieve good temporal resolution bad spatial resolution, MRI can fulfil both the job, but this is very costly.

And therefore, a combination of the technique is being proposed to use for measurement if you want to understand complete flow dynamics; if you want to understand the time resolve or spatial resolve both you need to have a combination of the technique used. Or you need to decide that which is the parameter which is more critical for your application for your system to be understood and based on that you can choose a suitable technique to measure the parameter ok.

But other than the MRI no one is going to give you the complete time resolved and space resolved volume fraction data or velocity data in the other technique wise.

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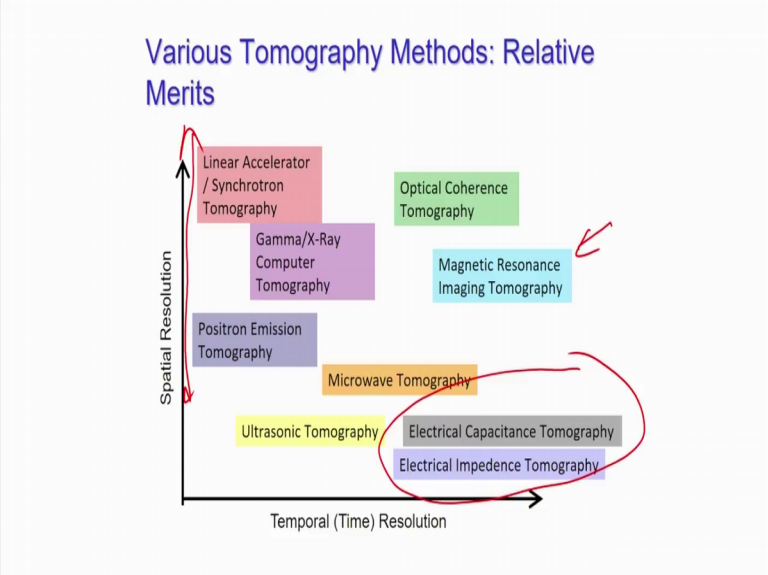

So, this is the kind of a conclusion for measurement techniques power and fractions. So, as I said that whatever the technique you have see that only one technique is here which

is magnetic resonance imaging, which has a good spatial resolution and good temporal resolution rest of the technique falls either in this line where the temporal resolution is poor spatial resolution is higher or in this line where the spatial resolution is poor and temporal resolution is higher.

A different technique I am not discuss them, but most of the time these techniques whatever we have discussed is being used in the industry this kind of they can be used for actually different type of system altogether. So, that is the idea applicability is more, but this is the graphs and again the problem is you have to decide what you want to measure in your system, which parameter is critical, where you want to kind of do the measurement and how what kind of a model you are using, what is the model prediction will be there? And based on that what kind of a data you require.

So, based on that you can take your judgment, you can choose the suitable measurement technique.

Thank you.