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

Lecture – 02
Invasive and Non- invasive Techniques

So, welcome back. So, last class whatever we have discussed is that about the basic take terminology, which we use in multi-phase flow and we will be also adding the same for the multi-phase flow measurement technique courses.

So, I have introduced deeply about what is volume fraction, number density, time averaged quantity, in sampled average quantity, ergodicity. So, this all things has been introduced and now we are going to use these terms repetitively in this course.

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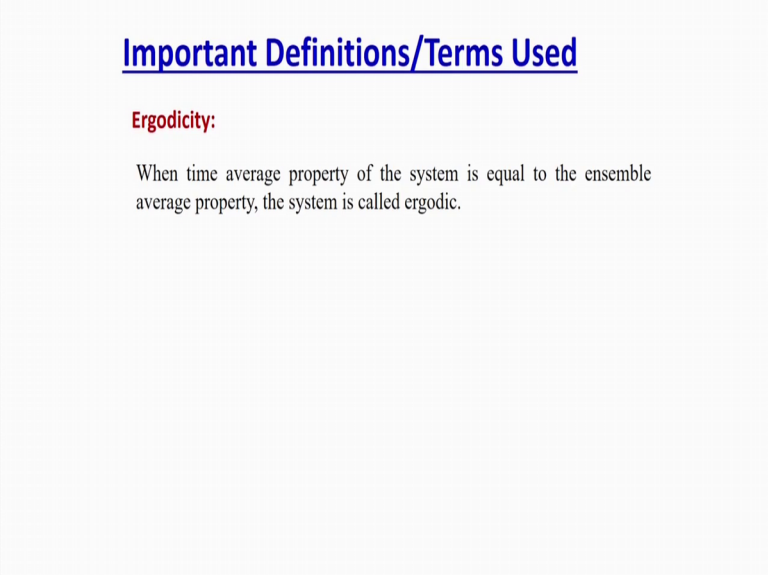

So, now, moving forward, so now whatever we have discussed it about the multi-phase techniques, multi-phase methods, and different techniques. Now I am going to formally introduce those different techniques, which are used in the multi-phase flow measurements.

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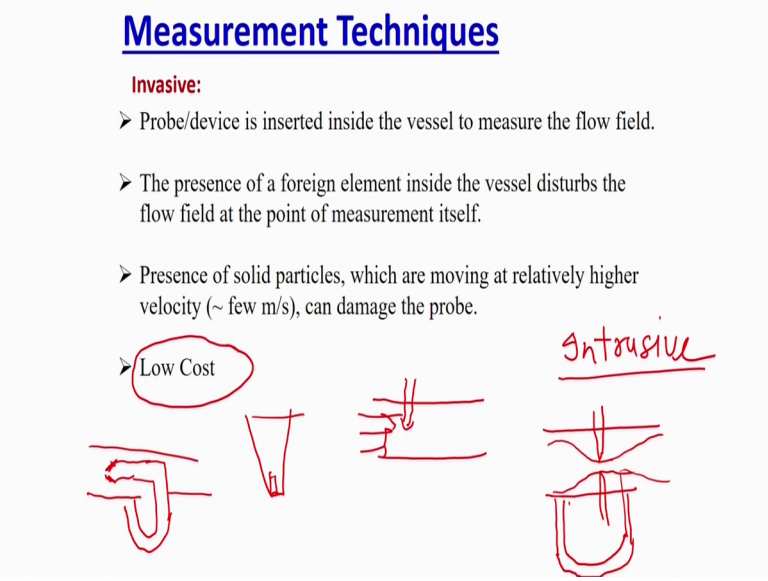

So, if I go with the formal introduction of that, actually the measurement techniques has been divided in 2 parts: 1 is invasive and 1 is non-invasive as I discussed during the introduction of the course. Now what is invasive techniques? So, invasive technique is a technique in which some probe or device is inserted inside the vessel for the measurement of the flow.

Now what does it mean suppose if I have to measure the temperature in any reactor. So, what we do we insert a thermocouple, if I want to measure the temperature of a fluid suppose there is a pipeline a fluid is flowing here inside and I want to measure the temperature of the fluid.

So, what is the way the best ways to inject a thermocouple inside? Now what this thermocouple is going to do it will measure the temperature. So, what you are doing actually we are inserting the thermocouple and that is why it is called invasive technique, but if suppose I want to measure the tech temperature, now there are certain new technique has been developed which are radiation based techniques or laser based techniques in which no device need to be inserted or photographic based techniques where you can find the temperature profiles.

So, those techniques are called noninvasive techniques. So, invasive techniques means you are inserting some probe or device inside the vessel and that is why the name is invasive some books or some philo also says that intrusive. So, both are same.

So, whether it is a invasive or intrusive, in which you have to intrude something inside. Now what does it means and what whether this technique is advantageous or disadvantageous? Now if we feel that if we are inserting something inside and you may have solved some problem in also in your undergraduates or in some graduate courses that boundary layer will start developing along the probe.

It means what if you develop any surface if you include any surface inside the flow will did disturb at the point of measurement itself. And that is the major drawback of these techniques it means if you have inserted something actually you are measuring that things, but you are also modifying the flow field.

So, once I if you modify the flow field definitely the relevant quantities or the quantities which you want to measure that is also bound to be modified. As we have already discussed that velocity in volume fractions solid distribution all those things are interdependent phenomena.

So, if you change one another is bound to change. So, that is the drawback major drawback of this technique that because you are intruding something it is going to change the flow field itself and that to be at the point of measurement. So, that is the major drawback, second drawback is suppose as we discuss different type of multi-phase flows reactors are there in many a class of multi-phase reactor solid particles are also present like gas solid fluidized bed, liquid solid fluidized bed or gas liquid, solid beds like this 3 phase little bit of slurry bubble column. Now in these cases if you intrude a probe inside then the presence of the solids may damage your probe over the time, because of the erosion.

And if the solid velocities are very high, like some of the fluidized bed case or solid holdup is very high like fluidized bed or in a packed bed kind of a situation or in a moving bed kind of a situation, the probe may also get damaged very fast.

So, in this actually limits the application of this kind of a technique and most of these techniques are widely used for the gas solve gas liquid flows, compared to the flows where the solids are being used. It does not mean that people have not used these techniques for the gas solid or liquid solid or 3 phase flows.

We will discuss the case studies and we will try to see that these techniques are also being used for these kind of applications, but most of the applications are limited to the gas liquid or liquid flows. So, this is about the technique the, but why if you ask the question to me that, why even if there is a drawback even if the flow field can change, even it cannot be used for the solid flow, why we need to study or why we need to use this technique. And the answer comes with the cost that this technique is cheap compared to whatever non- invasive technique.

We will discuss this technique is 2 to 3 times lower the cost. Even sometimes even more some of the techniques you may make in some 1000 rupees or 2000 rupees. So, that is the major advantage of this technique that you get an idea about the flow, at a very low rate a very low cost. And that is why the technique is a still very popular and even in single phase flow, if you go and see still we use invasive techniques.

Like what is if you see the single phase flow you want to measure the velocity field, what we use we use orifice meter. Now what does orifice meter do, this actually changes the area because you have included orifice inside or plate inside. So, because of that the measurement changes and you see some profile you measure the delta P around this to calculate the your you measure the delta p. So, you measure 1 delta P here, 1 delta P somewhere here and you can connect those 2 and with the measuring the delta P you can find the velocities.

So, this is also in a way intrusive technique because we have intruded a flange inside to reduce the dimensions or for the matter of the fact Rota meter also. So, if the rotameter what we do we intruder a small probe and depending upon the location of this probe which moves with the velocity wells the fluid is there depending on the velocity the height of the probe will change. So, depending upon that you can measure the flow rates.

So, these are also considered as intrusive technique this itself actually is a intrusive

technique, but widely used in the single phase flow. And the reason is we all know that the cost of rotameter or the cost of orifice meter is very very cheap, they are very cheap techniques. And that is the same thing we will use some of these techniques also we will try to see in the non-invasive in the invasive measurement for the multi-phase flow. Like the best example is Pitot tube. So, the pitot tube if you will see the cost wise it is nothing, but a small tube which is being actually connected with a manometer.

So, this is the pipeline I want to measure the velocity I will add a pitot tube and this will give me the point velocity. So, this is very cheap and widely used technique. So, though the flow velocity may change at the point of measurement itself, but still it is a very good thing to get an idea and to measure the velocity in single phase flow this is very accurate, but in multi-phase flow you will just get an idea, but still it is being used and why the measure concern is the cost, because it is very cheap and it gives the measurement very quickly with the local measurements.

So, that is also one of the major advantage of the invasive technique that you get the local measurements and that is very critical as we have already discussed in the last class that if your reaction is very fast or the phenomenon is very fast, then the local velocity field measurement is more critical compared to the mean velocity field measurement. And if you have anyway local velocity field measurement, you can do the in sampled average, you can do the time average and you can find out the average velocity field too. So, that is the another advantage of this techniques that you get the local field measurement.

So, this is all about the invasive technique. So, what is non in the other class of the technique is non-invasive technique, now what is non-invasive technique?

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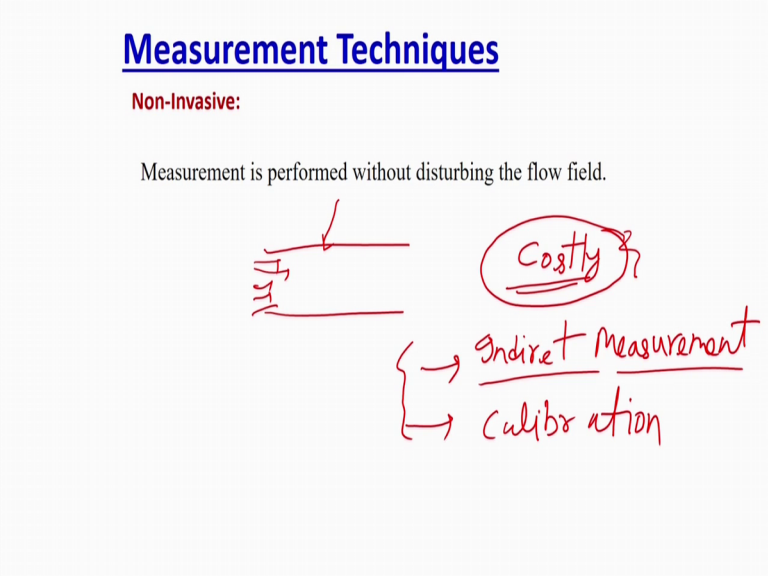

The technique which does not disturb the flow field is called non-invasive it means you are doing the measurement from outside of the system. So, if I take the same example that of pipe fluid is flowing and I want to measure the temperature of this pipe, there are laser based techniques available, which can actually you can fell some laser and depending upon the reflection you can find it out the temperature or you can have a camera where now the thermal cameras are available.

So, if you take the photograph of this film depending upon the thermal you can do the thermal imaging and by doing the thermal imaging you can see that what is the temperature distribution inside? So, in that case what you are doing you are not intruding anything inside of the system and that is why these things are called non-invasive. Now the advantage is this you are not disturbing the flow fluids.

So, whatever you are getting the measurement is very accurate you are not changing the measurement flow fluid of flow fluid including the measurements, but the major disadvantage of this technique is the cost. So, like a thermocouple or thermometer if I want to get I will get the thermometer or thermocouple say in 100 if you are going with the thermometer we will get in 100 to 200 rupees. If you are going for a thermocouple maximum we will get it in 2 to 3000 rupees, but if you want to get a thermal imaging camera that will be cost you in some lakhs of the rupees.

So, that is the major disadvantage of the non-invasive that it is very costly. So, I will say that it is very costly then the second basis that disadvantages that is do the indirect measurement. So, now, what do you mean by indirect measurement?

So, if I have to measure the temperature say with the thermal imaging camera what I am going to get is actually an image. Now the image need to be post processing, post process and to get that do the post process once we do it complete that, then only you will get the temperature or say in the laser way; if you are getting you will see the refraction and based on the refraction measurement you need to calibrate it and then you will get the temperature.

So, that is the major disadvantage of this technique that it gives the indirect measurement, now because it is indirect measurement of calibration is needed you need a calibration. Now this calibration is also needed in invasive technique depending upon what type of method you are using, but in non-invasive technique most of the non- invasive technique is almost must to do the calibration.

So, that you can find it out that what the quantities the indirect quantity, which you are measuring you can convert that indirect quantities to the relatives relevant quantities which you want to measure. So, that is actually also difficult and makes your life little bit tougher to implement these techniques in the flow system.

So, you need to do the calibration too. So, this is the major disadvantage also of this technique, but the measure limitation is still goes to the cost that it is very costly and that is why most of the time it is very difficult to afford this technique. So, that is the basic introduction of different techniques is being used invasive and non-invasive.

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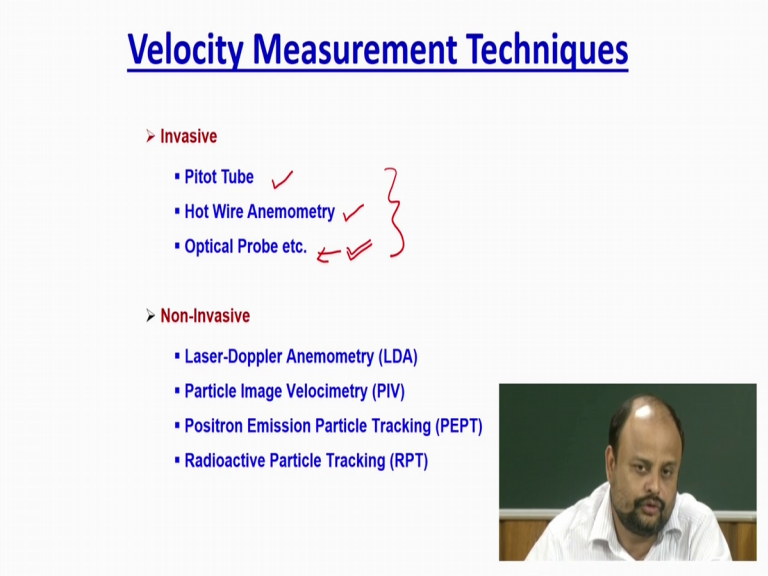

Now once we have said that we are going to divide the measurement techniques in 2 part; one is for the velocity measurement technique and one is for the volume fraction measurement technique.

So, once we think about the velocity measurement technique generally for in invasive the technique widely used is pitot tube, we already know about the pitot tube maybe everyone must have studied it in their undergraduate studies, but we will see that how you need to change the design of the pitot tube for multi-phase flow. Then the hot wire anemometry, I think again it might have been introduced in your electrical courses or in physics courses about the hot wire anemometry even in fluid mechanics courses.

So, this is widely used technique to measure the single phase flow velocity for (Refer Time: 00:00) the aerodynamics application, will also try to see that how to implement the hot wire anemometry technique in multi-phase flow. And then the third one is the optical fiber probe. So, optical fiber probe is relatively advanced technique and is being used to measure both velocity as well as volume fraction, in case of the gas liquid flow you can also measure the droplet size or bubble size bubble diameter, bubble quadrangle, all those things can also be measured even the bubble velocities.

So, this is the technique or will say that optical fiber probe it is widely used technique for the gas liquid and liquid system, people have also implemented the optical fiber probe technique in gas solid flows, but most of the time the solid fraction is very very small. So, you can use it for the solid fraction very low solid fractions say less than 5 to 10 percent and that is the typical case for circulating fluidized bed. So, in that case you can use the optical fiber probe, but invasive technique is generally divided over all in these 3 parts.

And we will try to discuss all these 3 parts individually we once we discuss those 3 parts we will also try to see the advantages and disadvantages of unusual techniques. Then for velocity measurement non-invasive technique the actually several non-invasive techniques are available, I am just writing the 4 popular techniques or widely used techniques, which is used in research as well as in industry some of the industry and by the scientist.

Now most these techniques are actually all indirect measurement techniques as I have also discussed earlier. So, major important the technique which is being used for non-invasive is laser doppler anemometry we will also call it LDA, Particle Image Velocimetry generally called as PIV, then Positron Emission Particle Tracking known as PEPT or PPT and then Radioactive Particle Tracking technique known also as RPT or copped some people also called it computed radioactive particle tracking technique.

So, that is called cop or radioactive particle tracking technique. So, we are going to mostly call it as RPT and we are going to elaborate this technique in more detail during this course, but you will also tell up on we also see the other techniques the working principle advantage and disadvantage.

So, these all are non-invasive technique now the name itself will suggest you that actually, you are not measuring the velocity, you are meeting some other quantity and then, you are converting it back to the velocity of measurement.

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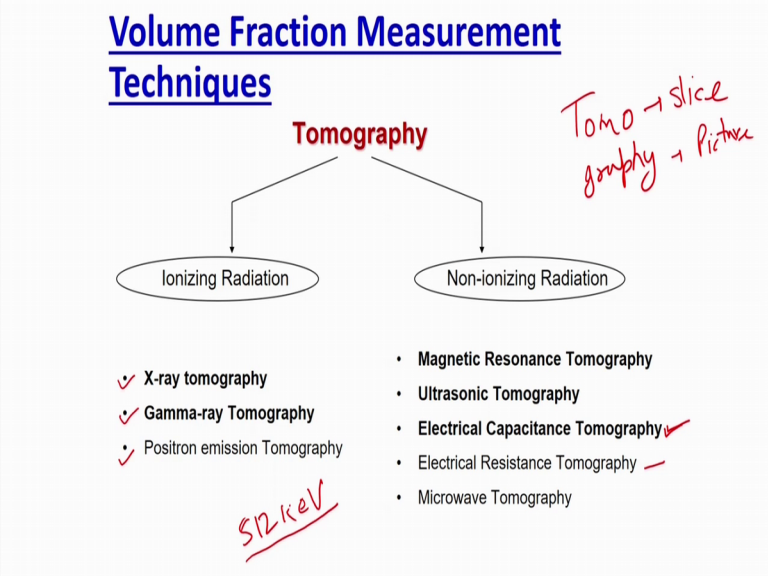

Now the second class of the technique is for the volume fraction measurement techniques for most of the volume fraction measurement techniques, other than the optical fiber probe is depends on actually tomography. Now what does tomography means tomography is made by a Greek word called Tomo and Grapy. So, Tomo means Slice and Graphy means Pictorial form or picture.

So, once you see any image in terms of the you slice a small slice and picture of is in terms of the small size this small slices or we can say pixel that is called tomographies. So, this tomography is actually being divided in the 2 parts one is ionizing radiation and second one is non-ionizing radiation.

As we know that ionizing radiation means we are using some of the radioactive things or radioactive material to ionize the field. And that technique actually ionizing radiation technique is being divided further in 3 different techniques one is called X-ray tomography Gamma-ray tomography and positron emission tomography.

Now the principle of X-ray tomography and gamma emission tomography is very close and that is why we during this course, we discuss about the gamma ray tomography, but the discussion equally hold for the X-ray tomography, the only difference is that the

gamma ray tomography. Even if you are not doing the experiment the radiation will be keep on emitting, because you are using a source which is gamma uses gamma active or it which emits the gamma rays.

So, even if you do the experiments or you do not do the experiment the radiation will always be there. So, you have to increase the safety measures and you have to keep the source if after the experiments in a led sealed box. So, that you can reduce the radiation that is a tomography you again use the radiation.

But, you can generate the ex tomo radiation whenever it is needed through the electrical currents. So, there are methods to generate that I am not going to discuss that method in detail will briefly try to cover that, but the good point is once you do not use the X-ray or when you do not do the experiments, you can switch off the system and in that case the X-ray will be produced.

So, inherently it is much safer compared to the gamma ray tomography, but they are certain limitation and which will discuss during the discussion of this tomography technique. Then the positron emission tomography it is same instead of the gamma ray using direct source of the gamma ray we are using positron and we know that once the positron inhelate with a electron it produced the gamma ray.

So, again the good point is the positron is not that the emission of the positron is not that dangerous, but once you go inhale it with the electron it will generate the gamma ray, but the energy of the system will be very very low.

And that is the advantage as well as disadvantage of the system. So, if my column diameter is very low I need low energy to penetrate the column, in that case the positron emission tomography can be used because it will give you less radiation, but if your column diameter is very high you need higher energy and in that time the application of the positron emission tomography is limited, because the positron emission tomography gives the energy of the gamma ray as 5.2 K e V.

So, this is fixed you cannot change it and that is why the application is also limited or the

diameter of the column is limited you can do it for a particular size of column, while in gamma ray or X-ray you can emit the energy of very high energy depending upon the source or depending upon the way you are generating the X-rays and in that case you can apply it for anywhere, but the safety will always be a concern.

Then comes to the non-ionizing technique now these techniques are very popular and used actually in the industries also, but the problem is the accuracy of these techniques and the cost of these techniques this techniques are very very costly.

So, non-ionizing technique the technique which is used no radiation is generally non ionizing techniques. So, like the first is magnetic resonance imaging or magnetic resonance tomography. Now MRT is a very very accurate technique and is widely used in the medical applications and it provides a data up to a micron level accuracy or the you can say the spatial resolution of this technique goes up to one micron or even low.

And that is the region that the technique is very popular in the scientific community, but the problem is the magnetic field and we will discuss that because you are want a magnetic field larger the system, larger the magnetic field, will be required and that is very difficult to produce or do the safe operation in that.

So, that is why the technique is accurate, but the application is actually limited. Then we also use ultrasonic tomography, now we know that ultrasonic waves can travel, but their travel distance will be low and the data will be hazy.

So, this tomography technique is also used mostly for the gas liquid or liquid flows, but the problem is only that the resolution of this technique is not very good. Then electrical capacitance tomography again this is a very widely used technique and the best part of the electrical capacitance tomography is that you are using the electrical currents and that is why your temporal resolution is very very fast.

So, if you want to catch that with the time how the things are changing you can easily use the electrical capacitance tomography to measure the phenomenon. So, that is the electrical capacitance tomography, now there is another electrical resonance tomography

also electrical impedance tomography. Now depending upon the property of the medium whether the capacitance resistance or impedance any of this property can be utilized to measure do the tomography analysis.

Now based on the application and the system we choose either we produce the residence, the resistance, capacitance or impedance which one this we should use that we choose based on the system, which is being used. Then the microwave tomography is also being popular and in which the microwave currents are being used and we know that the microwave current again will get attenuated if the system will be there, but the problem is in the microwave tomography you cannot use any metal particles or any metal wall.

So, you need to have a wall which you should be of the glass or the particles if you are using any it should be non-conductive it should not be a metallic surface, which can actually refract the microwave. So, this is the tomography technique for non-invasive measurement for invasive measurement, if you want to measure the volume fraction optical fiber probe is the best way to do that.

So, that is the whole classification of the measurement technique in terms of invasive and non-invasive, then you can divide those things in terms of the velocity measurement and volume fraction measurement and then there is another class of the technique which is called RTD, Residence Time Distribution studies.

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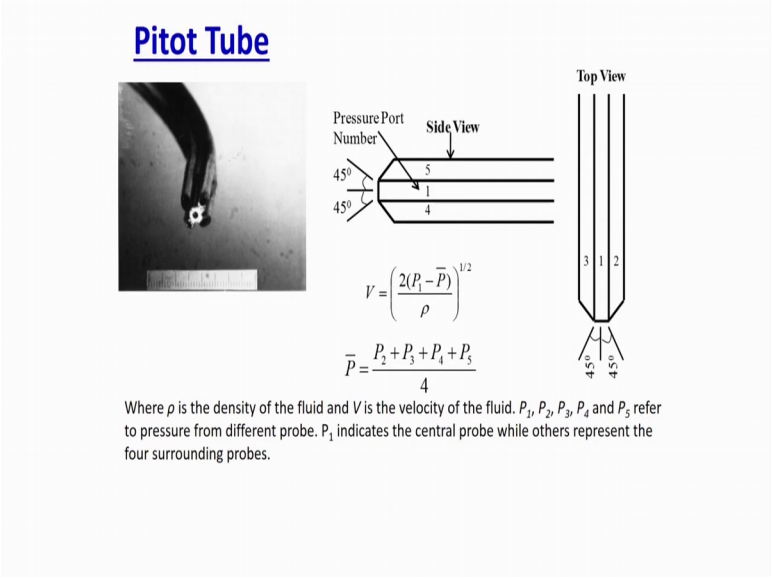

Now, we know that what is r td in RTD we injected tracer.

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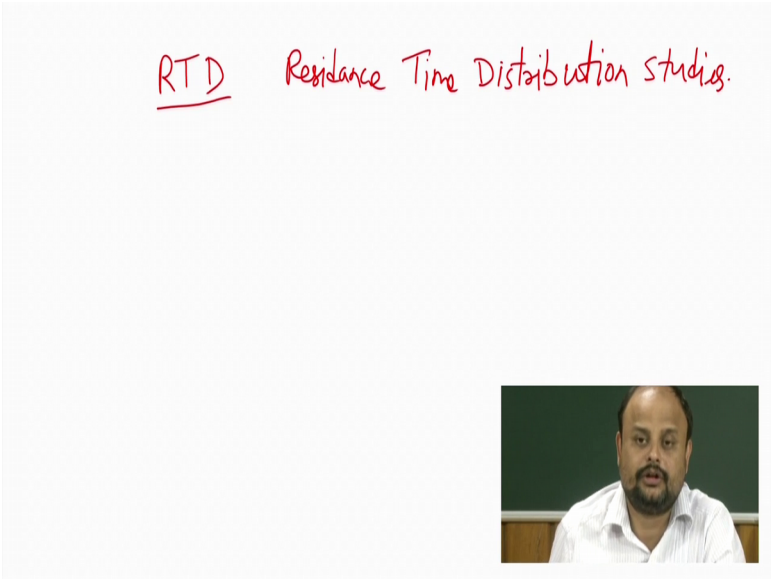

So, RTD is residence time distribution, now this is again a non-invasive technique it is a class of a non-invasive technique you can say depending upon again if what RTD method you are using how you imagine the RTD? See if you are using an RTD technique which is

based on the radiotracers it means you are using radioactive particles or liquid or gas as a tracer then it becomes a non-invasive technique.

If you are using some P h probe or conductivity probe to measure the RTD then it becomes invasive technique. So, anyway in RTD what we do as you all be knowing that what we inject we do? So, injection of some tracers the inner tracers whether it can be a mass tracer we can also take the radiation tracers or any other tresses, we inject that tracer and the image of the concentration of the tracer at the outlet.

Now again as I discussed that if you are missing the concentration by inserting sub probe inside the technique becomes the invasive, while if you are measuring the this concentration based on some other measurement like your measurement of the radiation then it is a non-invasive technique. So, it falls in between depending upon whatever you are using for the detection it becomes invasive or non-invasive, but the idea is to measure the concentration of the reactant or concentration of one species at the outlet.

So, that is called residence time distribution studies. Now going back to whatever we have started the velocity measurement, what we are going to now cover is the invasive technique and will majorly focus on the invasive about the velocity measurement. Now in the velocity measurement the first technique of widely used technique wall is the pitot tube. Now what is pitot tube.

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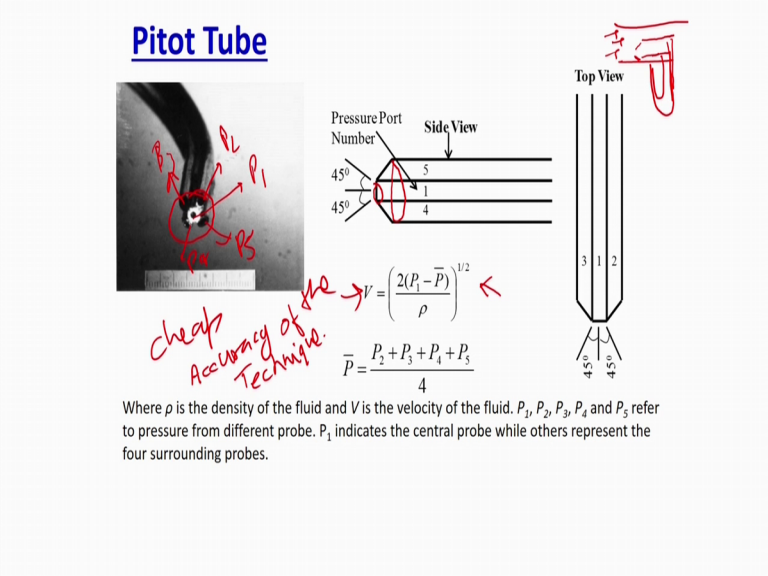

We all know that as I discussed that in pitot tube, it is just a pipe which is kind of put parallel to the flow in the opposite parallel opposite to the flow direction. So, suppose there is a pipe in which the fluid is flowing in this way in this direction, we will put a pitot tube it is in this direction and then this is connected to the manometer.

So, what we can do we can measure the pressure drop for this pitot tube and how it meters that the fluid which is coming in once it will go on the pitot tube hole, there will be stagnation and because of that the fluid velocity will reduce and because of that we will see a pressure drop a change in the pressure.

And that change in the pressure is being recorded and it can be collaborated with the basic bar by using basic Bernoulli equation or Navier stokes equations you can find a correlation that v is nothing, but 2 into delta P upon rho under root. So, you can use this formula and you can derive this formula from the Bernoulli equation or from the navier stokes equation and you can get that how to measure the velocities.

So, if you want to use the pitot tube you can measure the velocity if I measure the velocity at the stagnation pressure side to the sorry if I can measure the pressure at the stagnation pressure point or and one far from the a stagnation point. So, we can do that

now how this equipment is built. So, this is a typical photograph of the pitot tube.

So, you can see that there is a hole at the center and that is actually the main hole in which the stagnation pressure is being recorded and there are several holes made on the outer side now if you see that how these holes are made actually. So, you will see something like this. So, there is one hole this is suppose the pipe line there is one hole at the center of this pipeline and one hole at the outer side.

Now the inner side is connected actually with the manometer and the outer side of this is also connected with the manometer. So, what does they do or other leg of the manometer? So, what how the pressure measurement is done you measure the pressure of the P 1 and you differentiate it with the other pressure at the 4 point. Now why this 4 point is needed why these 4 holes are needed these holes are hole are needed to find the average static pressure across along the measurement point.

So, to do that what we do we have different holes say if I have 4 holes. So, this can be safe P 1 and so these are P 2 P 3 P 4 and P 5. So, total you have 5 holes P 1 is the central hole P 2 P 3 P 4 P 5 is the hole near the wall. Now what will be the average pressure average static pressure will be nothing, but the summation of P 2 P 3 P 4 and P 5.

So, what you can do, you can just simply add those pressures and divide it by the 4 you will get that average static pressure. Now that average the static pressure can be used in the formula which is being derived from the Bernoulli equation which says that z equal to nothing, but under root of 2 P 2 minus P 1 minus P bar upon rho. So, now, we know the P bar we can calculate the difference between the P 1 minus P bar or the value of the P 1 and then by doing that we can calculate the velocity.

So, we can easily calculate the velocity from this place. Now that is the major advantage of the pitot tube that it is very simple the velocity measurement is very easy, but the what the problem comes that once it comes to multi-phase flows. So, for single phase flow the problem is not that big it is easy it is widely used that is why in single phase flow to measure the velocity, but for multi-phase flow it is very difficult to use this method.

Now why it is difficult to use this method because suppose if I am trying to use the pitot tube in a gas solid flows, then what will happen the fall solid will go and actually they will choke all these holes whatever is mid met. And because of that you will see a huge error in the pressure rating and that is why the technique cannot be used in case of the solid if the solids are there. Similarly if there is a multi-phase say you have a gas you have a liquid both are flowing together. So, what will happen you will see the fluctuation?

So, the stagnation pressure if a liquid is coming and if a gas is actually being a stagnant it becomes different and that is why you will see lot of fluctuations in the flow if you are using the pitot tube. So, that is the region that the use of the pitot tube is mostly limited to the single phase flow application in the multi-phase flow also it is being used mostly in the aerodynamics or while the movement of the ship, where the multi-phase fraction or the fraction of the discreet phase is much lower compared to the is much lower.

So, in that case the pitot tube is being used the major advantage of the petot tube is very cheap technique, but the accuracy of the technique is not very high. So, it suffers from the accuracy. So, it suffers from the accuracy and that is the reason that though it is very cheap easily available can be easily used, it is not widely used in the multi phase flow reactors or multi phase flow process vessels to measure the velocity field.

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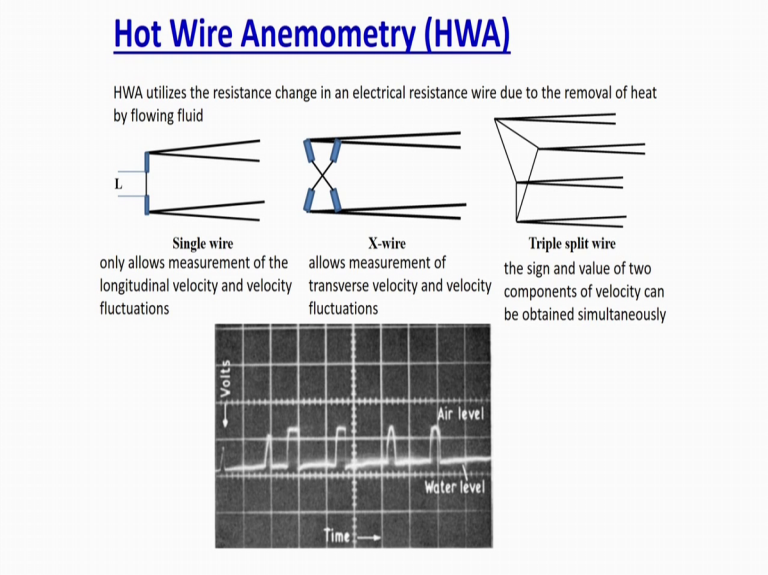

The another technique which is very famous and is also used till you can say the late

nineties to measure the velocity field in multi phase flow the name is called hot wire anemometry. Now hot wire anemometry is also used widely in a single phase flow measurement if you have say measure the velocity of the wind tunnel or something then the hot wire anemometry is widely used in the single phase flow.

So, the technique is actually being derived for the single phase flow and people have tried to use the technique same for the multi phase flow, but we see some problems even now to implement the hot wire anemometry technique in the multi phase flow. Now what is those problems we will discuss it.