Adiabatic Two-Phase Flow and Flow Boiling in Microchannel

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Lecture – 01
Brief Introduction to Multiphase Flow

Hello everybody, I welcome you all to the first lecture of adiabatic 2 phase flow and flow boiling in micro channels. Now what I feel is assuming that many of you will be new comers to the course.

Before I go into the details of the micro channels I would first like to give you a brief introduction regarding multi-phase flow. Once we understand what is multi-phase flow then we will try to see the indicate details of the uniqueness of multi-phase flow almost specifically 2 phase flow in micro channels.

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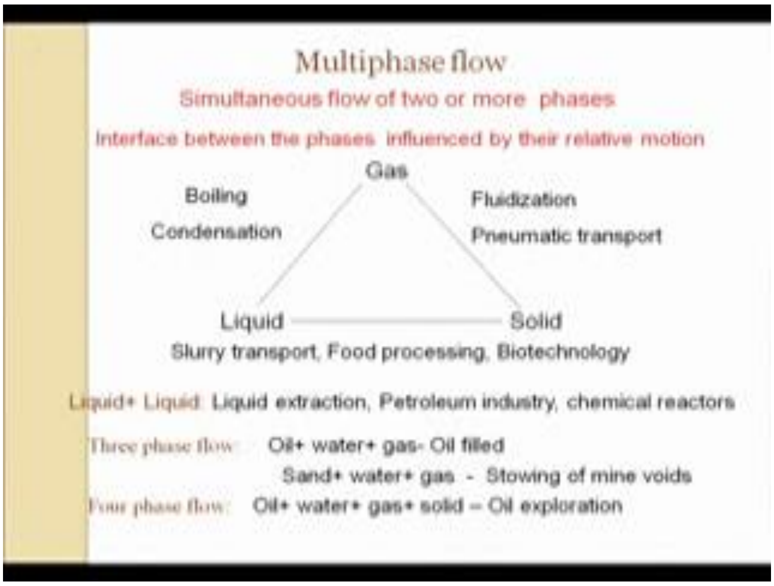

Now, in order to define multi-phase flow just the presence of the 2 phases, does not necessarily imply that is multi-phase flow for example, flow through fact rate is not multi-phase flow, but on the contrary flow in a (Refer Time: 01:05) is multi-phase flow.

Therefore, the way we define multi-phase flow is, if you can see here it is the simultaneous flow of 2 or more phases where, the interface between the phases is influenced by their relative motion. This particular phase regarding the interface is something very, very important because that differentiates single phase and multi-phase flows.

Now as we all know that we can have different types of even if you take the simplest type of multi-phase flows also, we can have different types, we can have gas liquid, we can have liquid solid and we can also have gas solid type of flows, we can also have liquid types of 2 phase flows as well.

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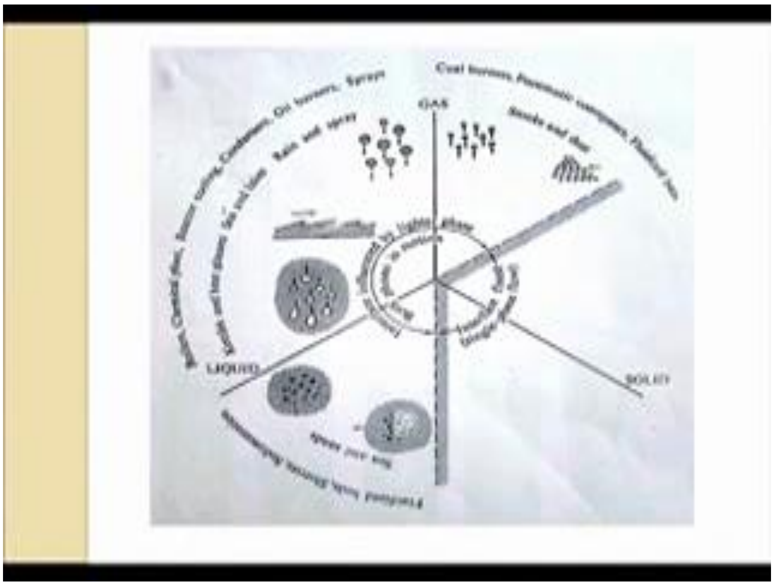

Just in continuation to what I was saying when we have a gas liquid flows the entire range is multi-phase starting from a large amount of liquid, very less amount of gas to a large amount of gas and a very less amount of liquid.

But on the other hand when we are dealing with gas solid and liquid solid flows, we find that when the solid load is quite high such that the interface becomes fixed it is single phase, while the solid loading is comparatively load the gas of the liquid loadings are high then under that condition we have 2 phase flows.

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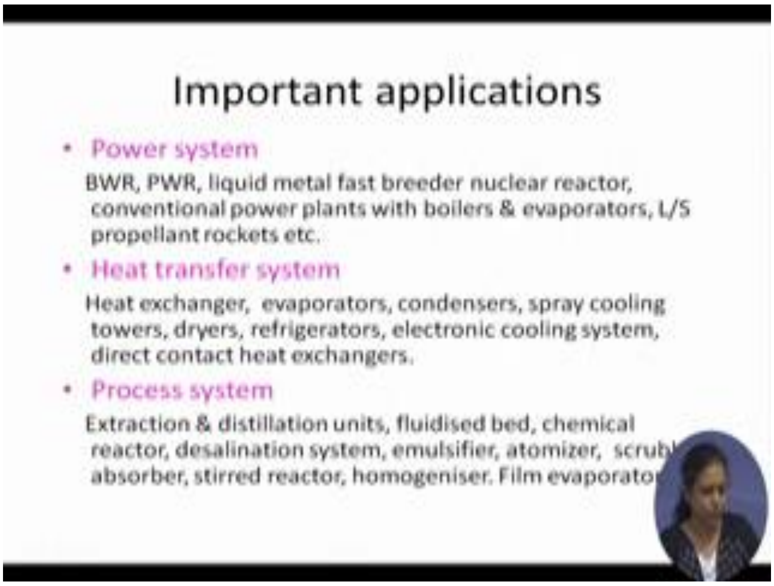

Well now, the multi-phase flow as got a large number of applications just dotted down the applications in power system heat exchanges, evaporators, condensers, where ever we have phase change or rather wherever we have 1 at least 1 phase which is changing its phase we have it in a large number of process systems.

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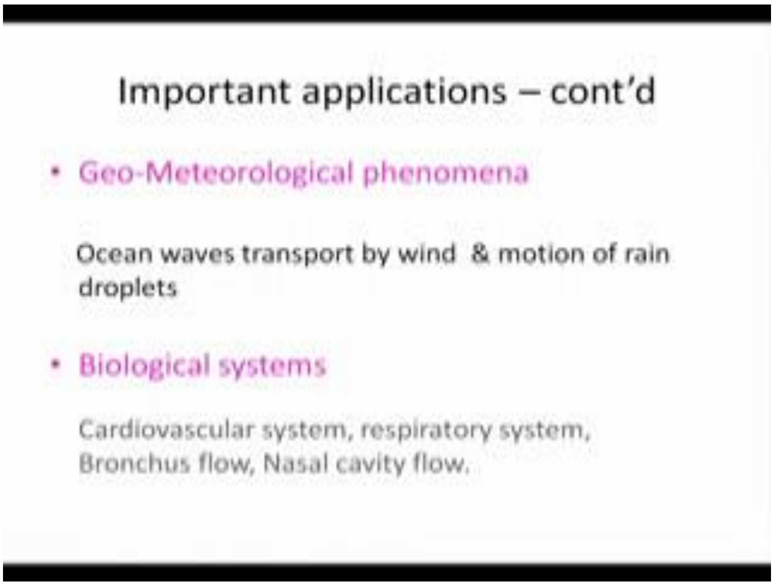

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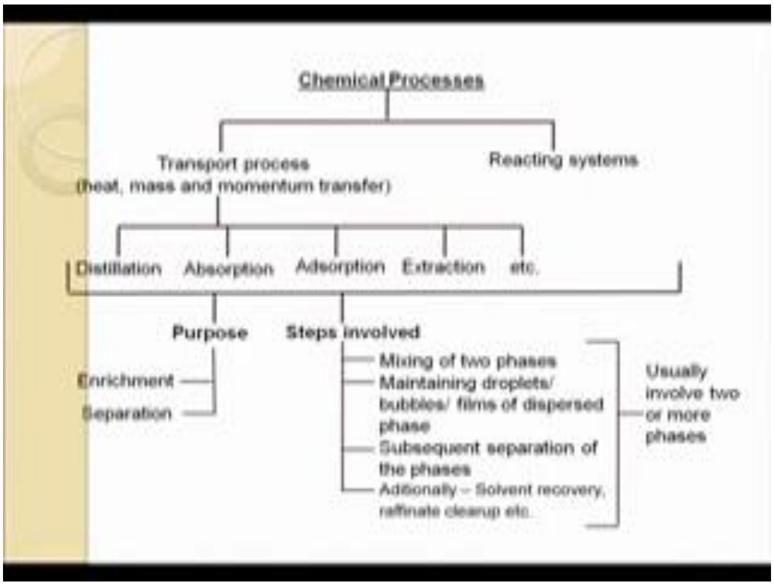

In fact, if you look at this particular slide, you will realize that when you are dealing with chemical process then in that we usually deal with processes with chemical reaction and without chemical reaction.

Now in the all processes which are already studied in your mass transfer and as well as kinetic subjects we find that usually the steps involved the mixed the 2 phases maintain 1 particular phase either in the form of droplet or bubble or film something on that such that the interfacial area is quite high and the maximum amount of transport, be it mass or the maximum amount of reaction then take place. And then finally, we separate the phases and they are also some other additional or some others subsidiary phases steps also involved. But in always things we find that there are 2 phases involved and for obvious reason we would always prefer a flow as compare to a bad system.

Therefore, it is very evident that for most of the situations, we come across multi-phase flows in fact, there are very few single phase flow applications in nature as well as in industries.

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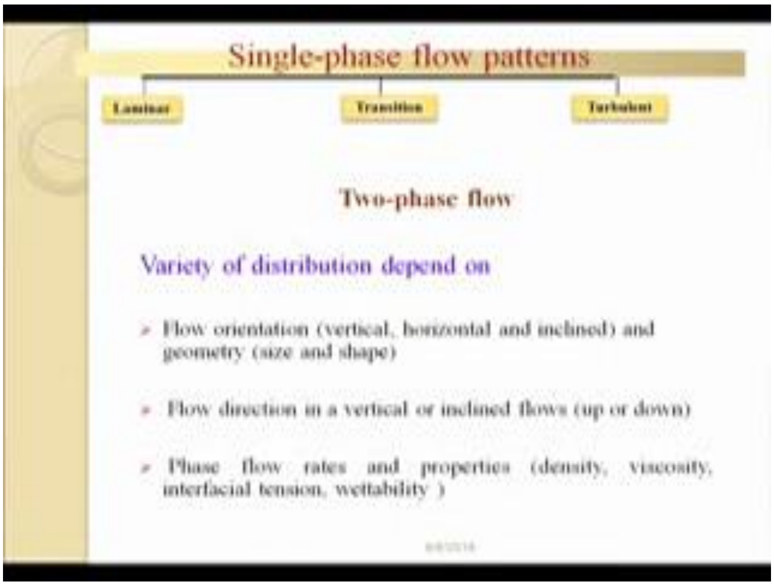

Now the thing which I was telling about the interface, well the interface is inference by the relative motion. This creates the uniqueness of multi-phase flows. Due to this what happens, if you are dealing with a single phase flow may be water flowing through a pipe the flow can either lamina or it can be turbulent.

But when you are dealing with 2 phase flows we find that the 2 phases, they can distribute in a wide varieties of ways.

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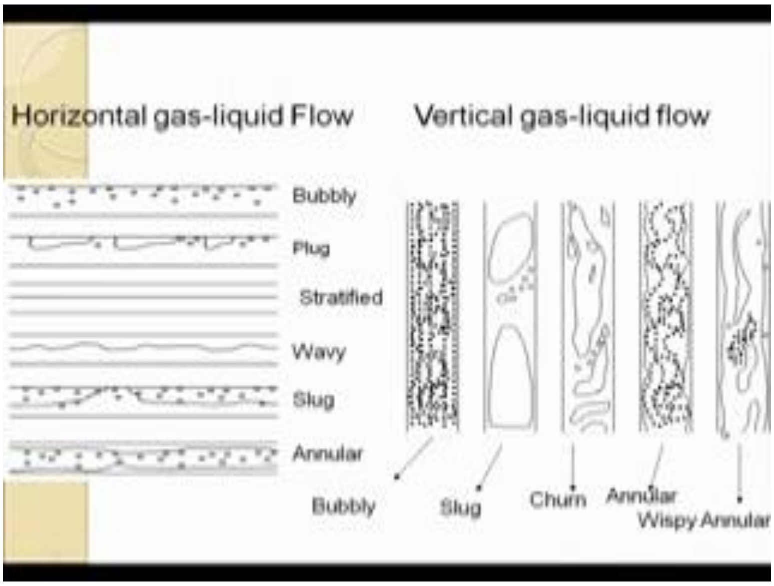

For example, suppose we look at the distribution, say gas liquid flow through a vertical pipe we find at 1 extreme what do we have if there is moderate or high liquid velocity and low gas velocity, gas is distributed as bubbles in the continuous liquid phase.

We go to the other extreme, there is a large amount of gas less amount of liquid here what do we have by intuition it might appear to you at well for a large liquid, small amount of gas the gas was dispersed as bubbles in the liquid phase.

When we go for a large gas low liquid it might be obvious that the liquid may be dispersed as droplets in the gas phase, but this does not happen, why, because it is the natural tendency of the liquid phase with the pipe wall.

Therefore, we find that there are a variety of distribution it is true and the distribution, it depends upon a large number of factors for example, it depends on whether the pipe it is vertical, horizontal, inclined, it also depends upon whether the flow in a vertical pipe is in up flow or down flow and just like single phase flows definitely the distributions depend on the phase flow rates and the physical properties of the 2 phases.

In single phase flow suppose I would like to find out the frictional pressure drop. It remains unchanged for the single phase, I flowing upward direction or in a down ward direction in the pipe. It does not depend the frictional component does not depend if the pipe is inclined or horizontal or vertical. But in this case we are going to find that all this in put parameters they mattered.

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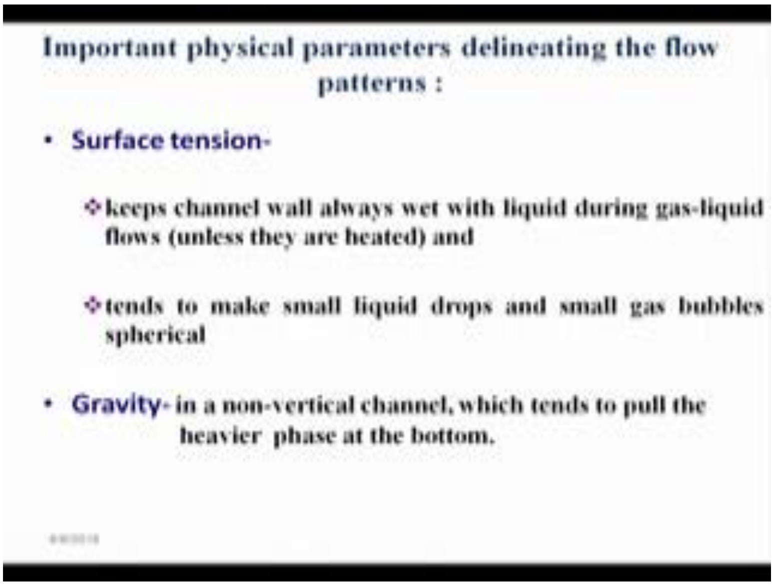

Therefore, it comes to once mind that definitely the 2 phases can be distribute themselves in no matter for toward ways and no means of predicting it, but fortunately there is a certain things switch also govern the distribution of the 2 phases. For example, if it is a gas liquid flow or vapor liquid flow the channel wall will always remain wetted with the liquid phase unless the channel is heated for adiabatic flow condition will always have the wall wetted by the liquid phase either if it is heated or if the wall is highly hydrophobic then of course, it is different otherwise the channel wall will be wetted with the liquid phase.

The other thing is, usually small gas bubbles or small liquid drops they tempt to be spherical and as the amount of liquid as the amount of gas increases, they take up some other different shapes.

The other thing is the effect of gravity whenever we have 2 phases they have different densities and whenever they have different densities its quite natural if it is a non-vertical system then the lighter phase flowing on towards the upper portion of the conduit and the heavier phase will be flowing in the lower portion of the conduit.

Accordingly, I would just like to discuss the flow patterns of the typical flow patterns which we encounter in a micro system when 2 phases are flowing. For the beginning let us consider a gas and liquid phase. The 2 the distribution are more less similar if it is a gas and liquid or a vapor liquid flow or in other words the distribution is more less similar for a 2 component, 2 phase flow or a single component 2 phase flow for gas liquid systems.

Just as I was discussing, initially when the liquid is in large proportion or rather from the liquid velocity is moderate more or less moderate to high and gas is at low flow rate is been introduced in it, quite naturally the gas will be flowing as bubbles because the liquid will have to wet the pipe wall and the liquid is in larger proportion.

Naturally it tends to share the gas phase due to the high liquid inertia the gas phase tends to gets shared the amount of sharing will depend upon or other the amount of liquid inertia that is present and this bubbles where, they are very small naturally they tend to take a spherical shape.

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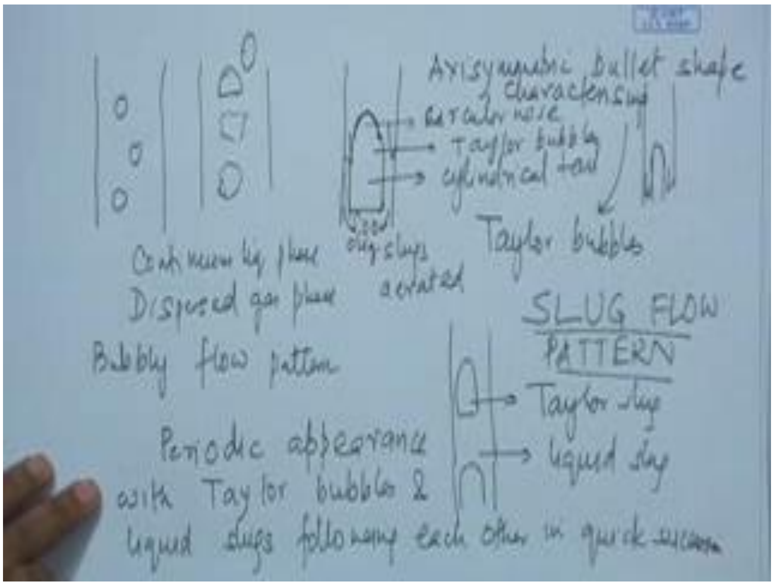

Therefore, if you observe what we find is that initially we find that spherical bubbles start flowing in the liquid phase and as we keep on increasing the gas velocity, naturally the bubbles it tends to along with it, they do not remain spherical anymore they tend to take some irregular or may be some sort of cap shape may be some sort of ellipsoidal shape.

They take a large number of shapes yet the distribution remains unaltered there is a continuous liquid phase and a dispersed gas phase accordingly no matter what the shape and size of frequency of the bubbles are this is known as the bubbly flow pattern.

Now, as we keep on increasing the gas velocity see what happens more and more amount of the this bubbles are found they start getting larger, their number also increases so, the qualis very fast and the start qualising they take a typical shape with a speri hemispherical or circular nose it is better a circular nose and a cylindrical tail.

Now these types of bubbles, they are very typical and quite a frequent occurrence I should say in gas liquid flows and these are commonly known as Taylor bubbles. In fact, if you would like to empty water from any particular bottle with a narrow neck we find during emptying, the gas bubbles starts entering or the gas fingering entering, as the gas finger starts entering the liquid grains from the side this is how liquid grains from any particular tube or a conduit or a bottle or whatever it is and in all those things we find that the gas assumes a typical shape with circular nose and a cylindrical tail and as this particular bubble starts increasing in size due to increased gas velocity, we find that the nose shapes remains unchanged the extra volume of air, it goes to increase the tail portion of the bubble.

Now, what happens as we increased the gas velocity from the bubbly flow pattern, the bubbles is start qualising and they start and then the bubble start getting elongated and finally, they assume the typical axis symmetric bullet shape characterizing Taylor bubbles.

Now movement such bubbles are found, naturally what happens the liquid is pushed at the sides, the liquid will naturally wet the pipe wall. Therefore, it flows along the sides in a downward motion and after flowing when it reaches tail of the Taylor bubble it comes in contact with the liquid portion which is there just below the Taylor bubble.

Now movement this downward flowing jet reaches the upwards flowing liquid here naturally a good amount of turbulence is created and due to this turbulence some amount of bubbles, they get sheared from the tail of the Taylor bubble and this makes the liquid slugs aerated.

Therefore, under this condition what do you find if you observe this particular slide you will find in this particular situation we find that the there is a Taylor bubble, there is a liquid slug, it can aerated or un-aerated and then there is again another Taylor bubble.

If you observe the any particular cross section of the pipe you will find that at one point a Taylor bubble is rising at the other point, the liquid slug is rising and again at another point the Taylor bubble is rising and this goes on this particular phenomena goes on.

At any particular cross section if you find, you will not find the mixed or well dispersed appearance of the bubbly flow pattern on the contrary, you will find a periodic appearance with Taylor bubbles and liquid slugs, following each other in quick succession and this particular phenomena this particular distribution it is known as the slug flow pattern and spending a little more time on this particular slug flow pattern will be understanding the reason of it as we proceed through our lecture.

Now, again from this slug flow pattern what we do we keep on increasing the gas velocity.

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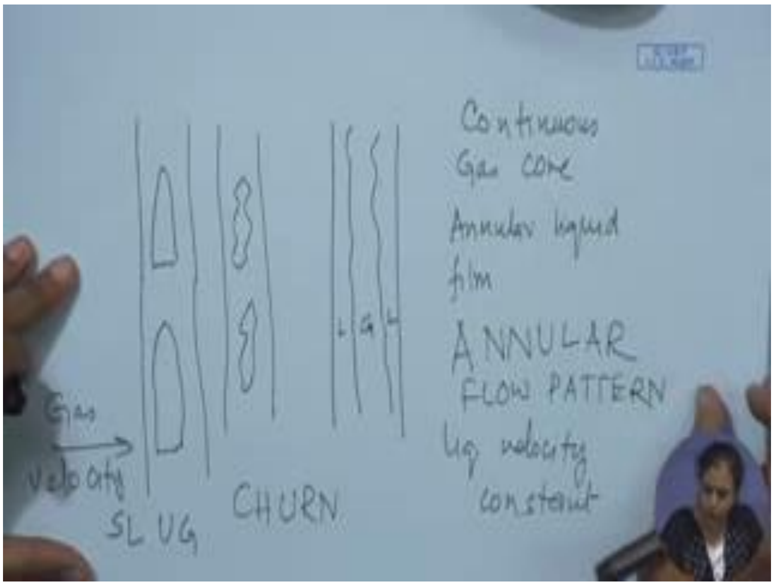

What happens initially, the tailor bubble this start becoming longer and longer and this start becoming longer as this start becoming longer they become unstable and due to the shearing action of the liquid a time comes when, this particular bubbles are no longer stable and they take up some irregular shape of some irregular junks which are randomly distributed in the liquid phase and the liquid we find that since the liquid it is wetting the pipe wall here it is coming down here and then it is meeting with the up flowing liquid there.

With everything the liquid, it exhibits or rather than whole 2 phase mixture it exhibits a random chaotic up and down motion, the whole flow passage, it appears as a totally mixed and it extremely random and a chaotic mixture and this particular distribution is known as the churned flow patterns.

And, again from this churn flow pattern, if you keep on increasing the gas velocity we find this irregular churns they keep on increasing on size if they keep the frequency increases and there is a totally chaotic random phenomena finally, all this gas churns they qualis with one another to form a continuous gas core pushing the liquid towards the wall.

Therefore, this was slug, from there we obtained the churn flow patterns and finally, from the churn, we are just increasing the gas velocity in this particular direction liquid velocity is constant, say for example, we are just changing one parameter to understand the influence of rather gas velocity on distribution we find that finally, we come to a situation when the gas phase forms a continuous core and the liquid forms an annular film.

This and this particular flow pattern with a continuous gas core and then annular liquid film between the gas core and the pipe wall, this typical flow pattern is known as annular flow pattern. As we further increase the gas velocity the interfacial wave start becoming more and more VV as it starts become more and more VV it tends to pick up.

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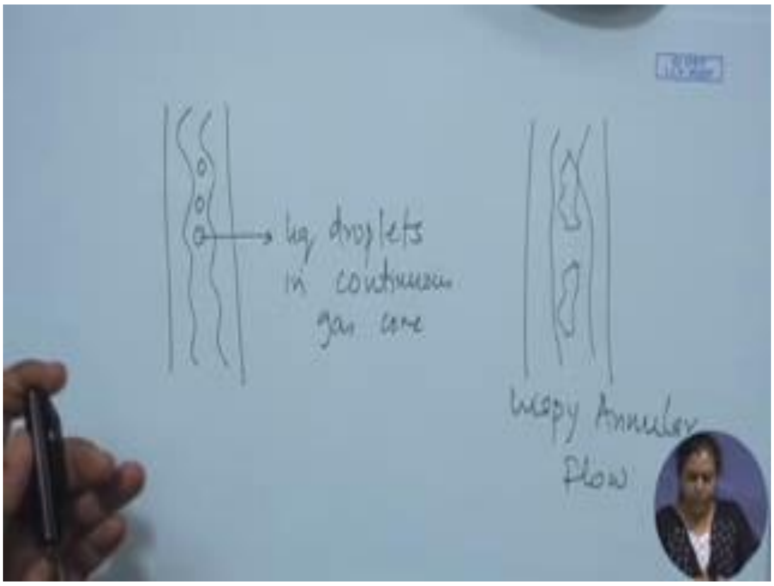

Some amount of liquid from the film and this particular liquid it gets dispersed as liquid droplets in the continuous gas core. And further if the gas rather the liquid velocity is increased more may be at some point is reached, where the liquid droplets they gradually qualis and they form wisp sort of things where we called it a wispy annular flow, but any how it is a annular flow.

Now if we see, what do you observe in a natural whatever I described it is exhibited in this particular presentation, we find that when we had a very small amount of gas the appearance was completely mixed and we find that under that condition if you continuously look at 1 particular cross section you will be see that every time you see the same particular distribution there is some particular liquid where some amount of gas bubbles are distributed keep on increasing the gas velocity you find that the homogenous distribution which you are observing so long is now no more.

Now assumes a periodic phenomena with intermittent appearance of first Taylor bubble and then a liquid slug and again a Taylor bubble and to liquid slug this particular way that follows and this particular phenomena it is very interesting I would like to say referring to my previous thing here what do we have we have a Taylor bubble region where the Taylor bubble and liquid film are flowing concurrent to each other then we have a liquid slug region which may be single phase liquid or an aerated liquid slug, but the whole mixture is going up.

Again we have a Taylor bubble region. So, in this Taylor bubble region it it it is sort of an annular arrangement, but mind it in annular flow both the film and the gas core are flowing upward in this particular case the Taylor bubble is flowing upwards the gas core is flowing downwards.

Here we have a completely periodic appearance and again from here we keep on increasing the gas velocity we again come across another chaotic appearance, but this appearance in no way this is also a mixed appearance this bubbly flow is a mixed appearance, but they are distinctly different if you perform experiments in the lab you will find that here you can find discrete bubbles dispersed in the continuous liquid phase the continuity of the liquid phase will be more or less evident.

While, in this particular case we will find that it is a totally turbulent random mixture which is going up and down and therefore, you really do not understand what is continuous and what is discontinuous phase here then as you go to annular flow you get a totally different a separated flow distribution where the gas and liquid are occupying completely different flow areas within the pipe cross section and they are interacting only at across a well defined interface.

Now, the same pipe you take and you just make it horizontal there are 2 things as I was telling. Firstly, there is gravity, what is gravity do it tends to separate the 2 phases? Naturally at no velocities like (Refer Time: 23:27) more important to as compare to inertia of the phases and therefore, due to the predominant effect of gravity you will find the 2 phases they flow in separate layers the gas phase on the top the liquid phase on the bottom.

You increase the velocity we find the interface becomes more and more wavy the 2 phases are in a separated flow pattern, but this separated flow pattern slightly different from the separated flow pattern you are encountered in the vertical case or the annular flow pattern.

And apart from this as we increase the phase velocities naturally inertia also sets in due to the importance of the liquid inertia there is a shearing effect and we have slug flow we have slug flow we have also have bubbly flow at the other extreme we have annular flow, but remember one thing for horizontal pipes all the flows are more are less asymmetric the liquid on the if it is bubbly flow the bubbles will be primarily concentrated on the upper region if it is annular flow the film will be thicker in the lower portion as compare to the upper portion. If it is slug flow the Taylor bubbles or the elongated plugs will be primarily concentrated towards the upper portion of the pipe.

Therefore, what we find is that mainly this particular situation the different flow pattern which are coming into picture and it is primarily due to the interaction between liquid inertia, your viscosity, the surface tension and gravity of the body force.

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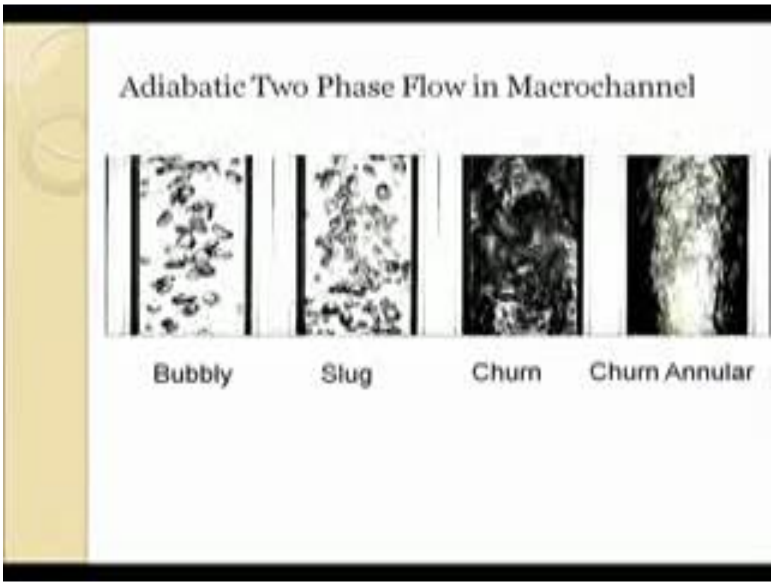

From an balance of this we get different particular flow patterns in this particular case and the video which has been taken in the gas dynamic slab of the mechanical engineering department of IIT, Kharagpur that shows the distribution in the bubbly flow its shows the elongated Taylor bubble and mostly and the aerated liquid slugs the most interesting feature is the churn and the churn annular flow patterns. If you observe this particular flow patterns, you will see the oscillating random chaotic motion which takes place in this particular situation.

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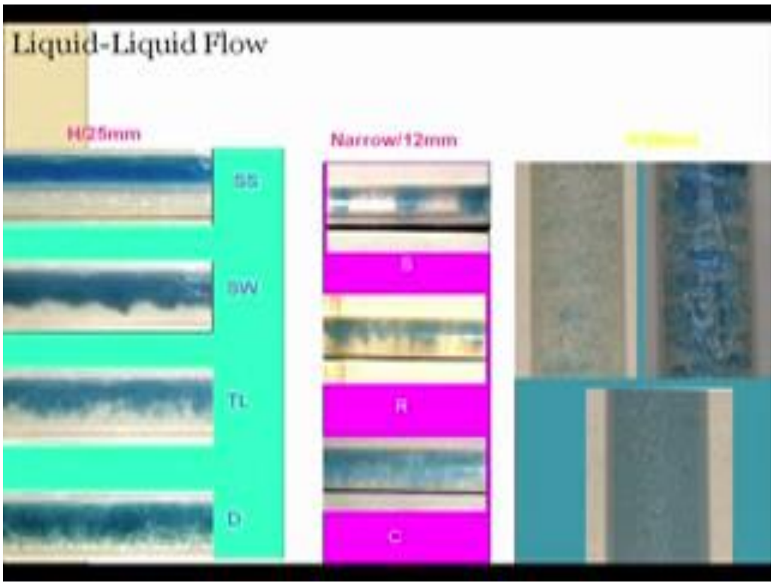

Now, instead of a liquid and a gas if we just introduce another liquid here then, in that case we find that the flow patterns change continuously we will be discussing it in our next lecture as we proceed with our introduction to multi-phase flow before we go to discussing the characteristics of the uniqueness of 2 phase flow in micro channels.