Two phase flow and heat transfer

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Lecture no: 02

Flow Regimes

Welcome to the second lecture of Two Phase Flow and heat transfer. So after the brief introduction in the first lecture we will be showing you over here what are the different flow regimes available? So at the end of this lecture you will be understanding what are the different flow regimes available for horizontal, vertical as well as phase change happening whenever. So what kind of different flow regimes we can see those we will be showing you in this lecture.

We will be also showing you maps, flow regime maps how it will be giving you the idea at different fluid, what flow regime maps will be give will be obtaining for horizontal and vertical those things will be outlining in this lecture. So let us quickly see different flow regimes in gas liquid Two Phase Flow because for the first few lectures will be only stressing on gas liquid Two Phase Flow.

So gas liquid Two Phase Flow different flow patterns or regimes are dependent on definitely channel size.

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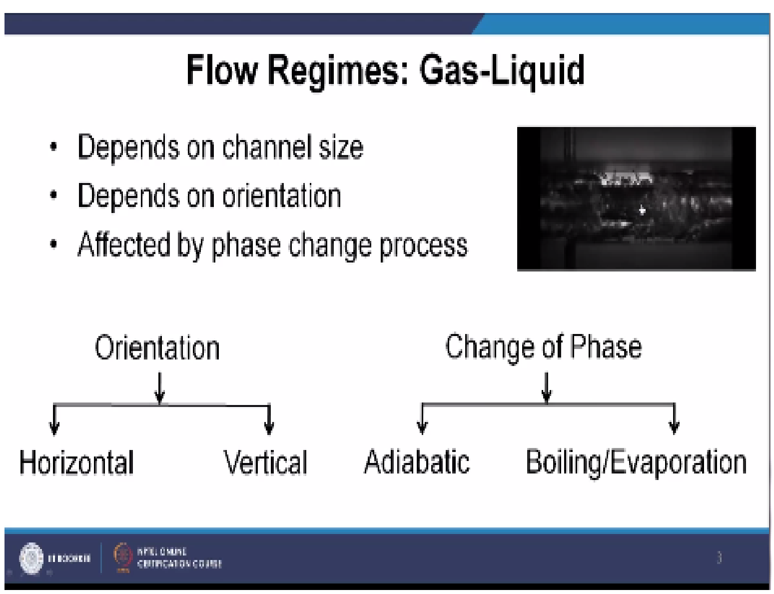

The orientation of the channel whether it is vertical or is it horizontal it will be affected by phase change processes. So if there is some sort of phase change process definitely this will be affected by phase change. Now in case of orientation, we know there will be horizontal and vertical position and in case of phase change we will be having adiabatic and or in case of presence of phase change we will be having boiling or evaporation.

Here I have shown you a typical video where we can find out lots of different interfacial structures. So starting from small bubble to a big churn of bubble also can be observed during the phase change process. So all these things we will be understanding in this lecture. So to begin with we have shown over here gas liquid Two Phase Flow in a vertical conduit.

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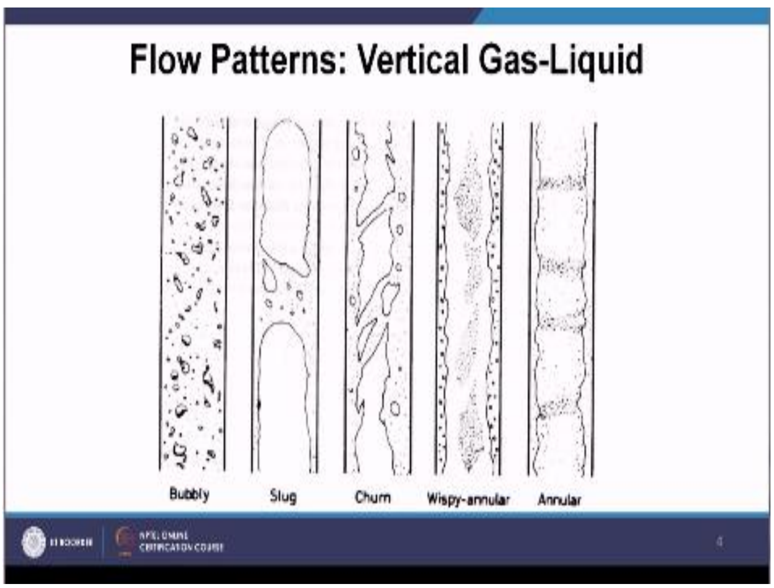

So see it is starts from very tiny dispersion of gaseous phase in the liquid one. This type of flow regime, we call as bubbly flow. So here separate identity of individual gaseous phases is not there. So you can find out a homogeneous mixture of gaseous phase in the liquid. So this is characterized by small bubbles.

Now when these bubbles are coming very close to each other, they will be merging and getting bigger in size and finally a typical configuration we can see inside a pipe like a long bubble like this. This actually called a slug bubble so here we have shown a complete slug bubble. So which is actually formed by amalgamation of multiple small sized bubbles in the bubbly flow and at the end of that we are having some satellite bubbles also.

So it is interesting to note that around the slug bubble we are having liquid film throughout this pipe. So we can find out this type of flow regime is actually a slug flow. Now whenever these slug flows are becoming very much merging with each other or they are very much (()) 03:27 you will finding out a churn flow like this.

So here you will be finding out lots of agitations and disturbances between the interfaces. So this is a typical example of churn flow. Now wherever these churns are actually merging with each other then you will be finding out that inside the core of that tube we are having gaseous phase, some gaseous phase in which droplets are being dispersed. And in the wall of the tube you can find out a film, inside the film also you will finding out lots of bubbles.

So this kind of flow pattern is called wispy annular flow. Now if you increase the liquid flow rate further you will be finding out that these bubbles are not coming into picture in the annular film you will be finding (()) 04:18 liquid annular film over there and in the core you will be finding out gas this is called 1 annular flow. Now the situation typically changes whenever we go for horizontal orientation from vertical. So you can find out here different flow regimes I have shown.

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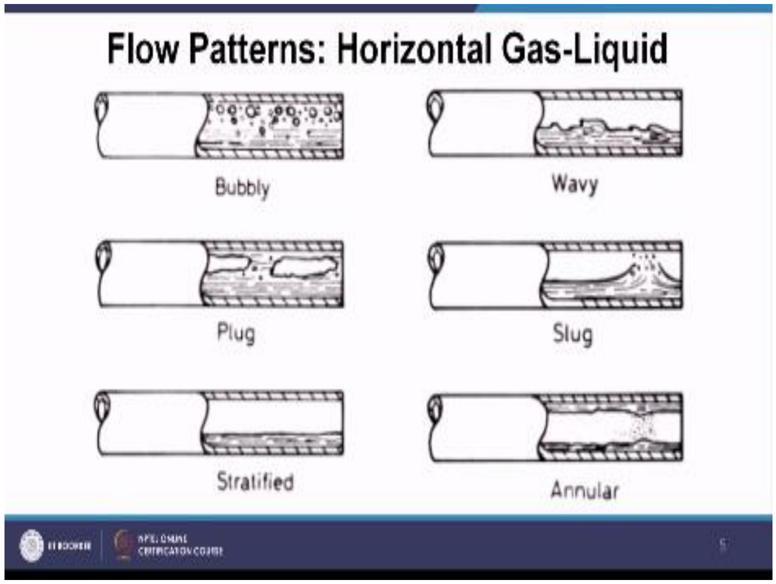

First one is as usual bubbly flow but it is interesting to note the bubbles are not well dispersed in the pipeline. Most of the time, the bubbles are sticking with the upper side of the channel okay. Same phenomenon applies whenever these bubbles actually merges and forms a plug flow over here. So plug flow is nothing but a big gaseous slug formed by merging of these bubbles. So you will be finding out the plug flow over here.

When these plugs are merging with each other, you will be finding out a stratified flow over here. It is interesting to note that in stratified flow you will be finding out the gaseous phases at the top and liquid phases at the bottom. Next whenever the liquid flow rate increases this smooth interface between the gas and liquid becomes wavy like this. So this is called a wavy flow pattern.

Next if these wave patterns are very high, so we will be finding out these waves are sometime touching with the wall so here this is the situation you can find out it is touching with the wall. So this kind of flow pattern is called slug pattern and finally whenever the gaseous flow rate increases, you will be finding out in the core we are having gaseous phase and in the wall we are having liquid film.

But interesting to note here is that at the upper side of the tube the film thickness will be lower compare to the lower side. So these are typical flow patterns for horizontal gas liquid flow starting from bubbly plug, stratified, wavy slug and annular which is totally different from the vertical one. Next let us see what different flow patterns are available wherever there is phase change associated.

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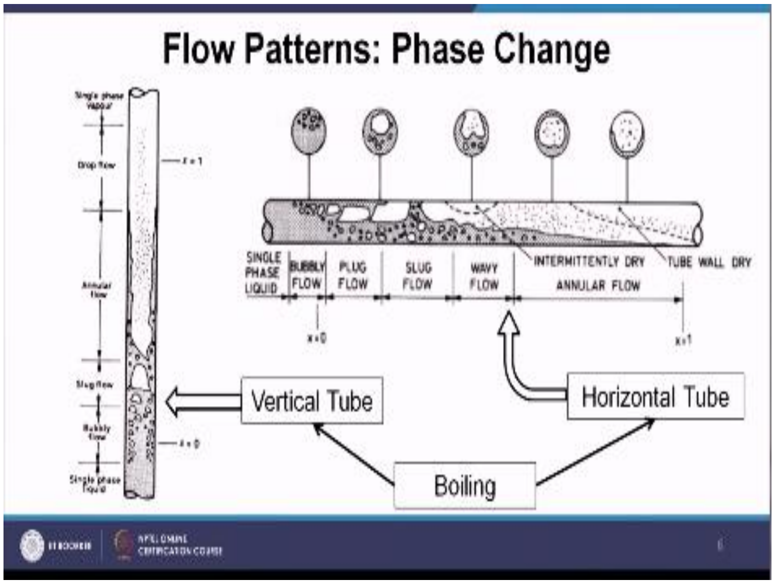

So you can find over here that we have shown 2 different situations vertical tube and this is a horizontal tube. You can find out we can, we are starting from singe phase liquid and we are giving heat around this tube. So, lots of bubbles are being generated at the pipe, pipe wall via nucleation. Those bubbles are getting bigger over here in size and finally forming a slug bubble which is resembling a slug flow.

And then finally the slug is being converted to annular flow over here you can see lots of droplets and in the periphery of the pipe you can see the liquid so this is actually annular flow. And finally you were getting over here droplet flow when this annular film is being dried up but the droplets of the liquid is continuing over here so this is a droplet flow only. So there is no film in the side in the annular periphery of the wall and then here in this zone you will be finding out single phase vapor.

So starting from single phase liquid to single phase vapor we go through bubbly flow, slug flow, annular flow and droplet flow simultaneously. In case of horizontal you will be finding out similar type of feature. So here we are having single phase liquid and in the side somewhere we will be having single phase gas so you can find out we start with the bubbly flow. But you see the difference between these bubbles and this bubbles, this bubbles are actually well dispersed in that pipeline but whereas this bubbles are actually attached to the upper side of the wall.

So you can find out same type of features, bubbles are merging and forming a big plug so this is plug flow and finally this plugs are forming slug so this is slug flow and then this slugs are actually generating some wavy interface. So this is actually wavy flow and finally we are getting the waves are dying down over here and the film is drying up so here and this is annular flow

Now typical things we can see comparison between horizontal and vertical here you see in case of annular flow both the walls are wet with the film. But here only the lower wall will be wet and higher wall will be actually associated with the gaseous phase and towards the end it will be converting to single phase gaseous flow. So this type of situation happens in case boiling or phase change.

Next let us try to understand each flow patterns individually. So here we will be first discussing about bubbly flow. So we will be starting with vertical configuration so bubbly flow in vertical channel so this actually disperse bubble in liquid phase.

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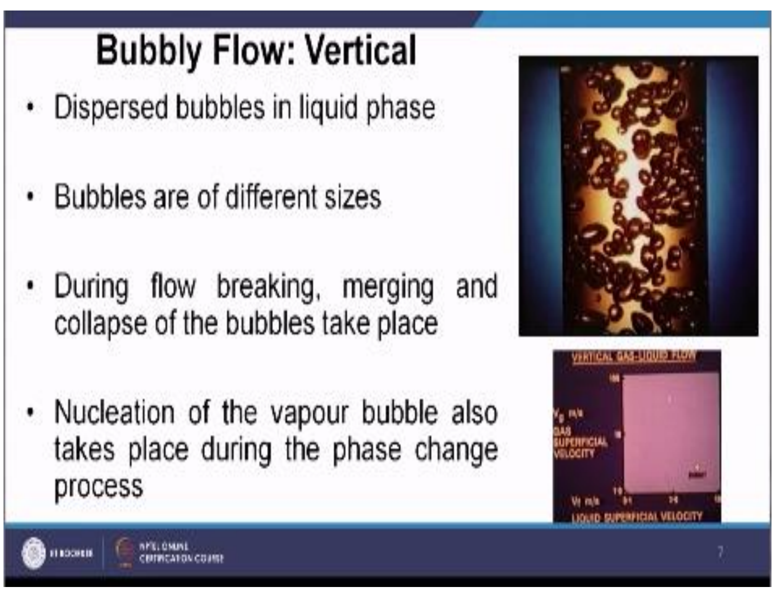

You can see this video, so lots of disperse bubbles you can see in the liquid phase. (Video Starts: 08:52) One important observation is that the bubbles are of different size okay and bubbles are causing breaking merging and collapse. So sizes are changing whenever it is moving upward. You can see nucleation of the vapor bubbles also takes place over here due to phase change. So, smallest size of bubbles will be generating in this phase. (Video Ends: 09:13)

So, bubbly flow is associated with breaking merging and nucleation. Here I have shown you that what flow velocities are required to obtain bubbly flow. See you can see this is a plot where in axis we have given liquids superficial velocity in ordinate to we have given the gas superficial velocity. Bubbly flow is actually obtained at a very high liquid superficial velocity and significantly low gaseous superficial velocity.

So this domain you can find out bubbly flow right. Next let us see another flow regime in case of vertical. So this is actually a slug flow. So next flow regime is slug flow.

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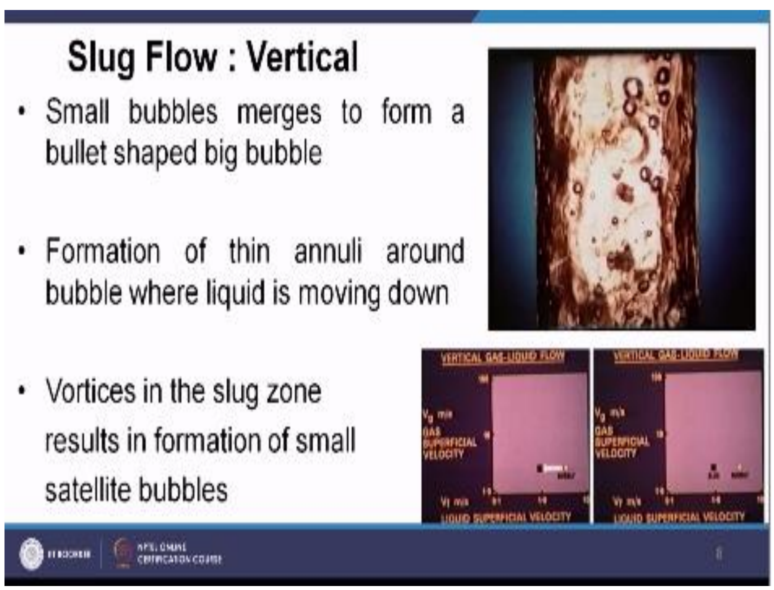

Here, we will be finding out small bubbles of bubbly flow those are merging and forming a big slug. (Video Starts: 10:01) Okay, so bullet shaped big bubble which is actually a slug bubble being formed over here. I will be showing you in the figure you can see this is a very big bullet shaped bubble followed satellite bubbles. So you will be having vortices in the slug zone which will result the formation of small satellite bubbles also right.

Here I have shown you that what flow rates will be important for conversion of bubbly flow to slug flow. So if you reduce the liquid superficial velocity by keeping the gaseous superficial velocity same then you will be obtaining in this type of flow regime where, we are having a big slug bubble okay followed by satellite bubbles. Right so this is the typical domain where we can get the slug flow. (Video Ends: 10:37)

Next let us try to see next flow regime which is called churn flow. In case of churn flow we will be finding out that it is actually intermediate flow regime between slug flow and annular flow, okay it is very chaotic in nature.

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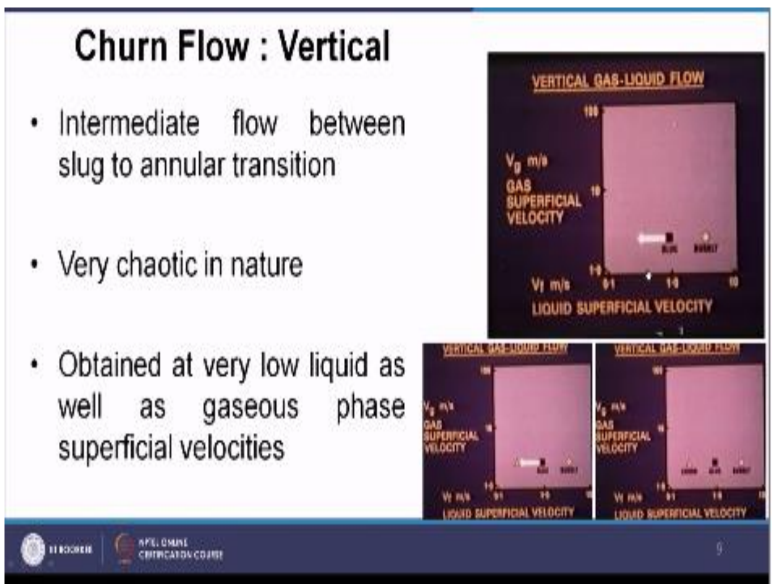

So you will be finding out over here that is very chaotic in nature you can see nothing, (Video Starts: 10:56) you can see clearly just like in the previous 2 figures. So if you zoom it then probably you will be getting it is very, very chaotic in nature lots of bubbles slug passing through interfaces not clearly visible okay. So this is actually obtained at very low liquid as well as gaseous phase superficial velocities.

So if you further reduce the liquid velocity you will be obtaining somewhere over here which is signifying this churn flow. So this is churn flow domain what we can find out in our flow regime map. (Video Ends: 11:27) Next let us see the next flow pattern which is actually 1 annular flow.

This is characterized by formation of liquid film around the tube so you can find out there is a film around the tube and at the core you are having gas.

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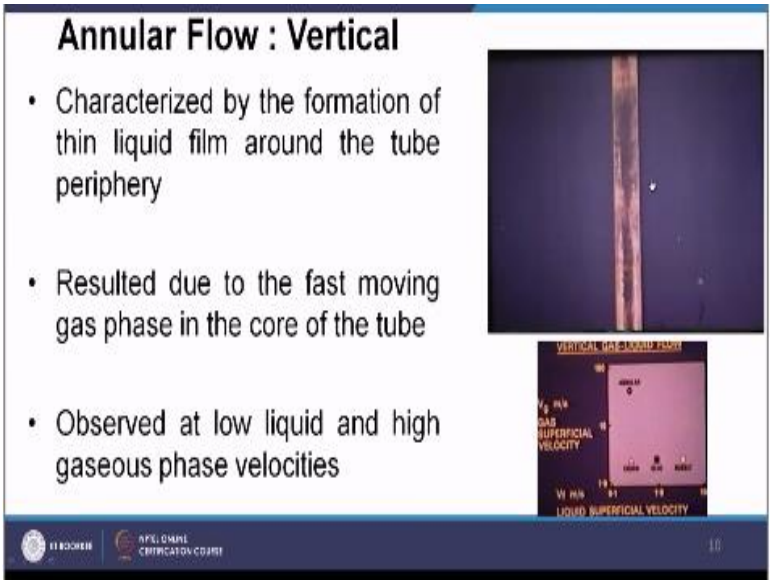

(Video Starts: 11:38) So this is a close view at high speed so you can find out here we are having film and the periphery, at the center we are having the gaseous phase. So this is resulted due to fast moving gas phase in the cross section also you can see this is the liquid film and in the core you are having gas phase only. Okay it is observed actually at low liquid and high gaseous phase.

So from here from churn flow keeping the liquid flow rate same if you increase the gaseous flow rate, you will be obtaining somewhere over here which is actually annular flow. So this annular flow is typically obtained in case of vertical channel at high gas superficial velocity and low liquid superficial velocity. (Video Ends: 12:20)

Next one, we will see is called wispy annular flow. So wispy annular flow in this video you can see lots of wisps you can find out.

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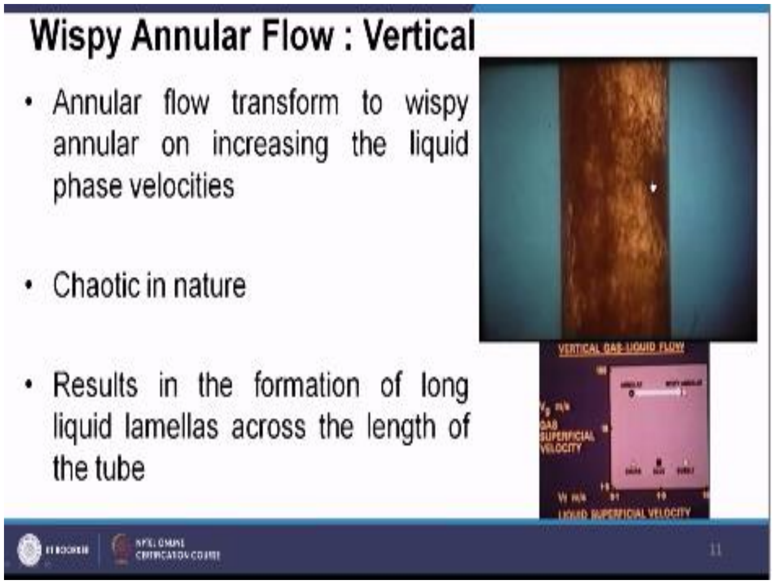

(Video Starts: 12:31) So this is actually transformation annular flow transformation to wispy annular flow transformation by increasing the liquid phase velocities. So if you increase the phase velocities from the annular flow pattern, you will obtaining 1 wispy annular flow. It is also very chaotic in nature okay just like as we have seen in the wisp flow. So similarly it is very chaotic in nature and it is resulting from high gas superficial velocity and high liquid superficial velocities. (Video Ends: 13:02)

So all these flow patterns we obtained in case of gas liquid vertical Two Phase Flow starting from bubbly, slug, churn, annular and wispy annular.

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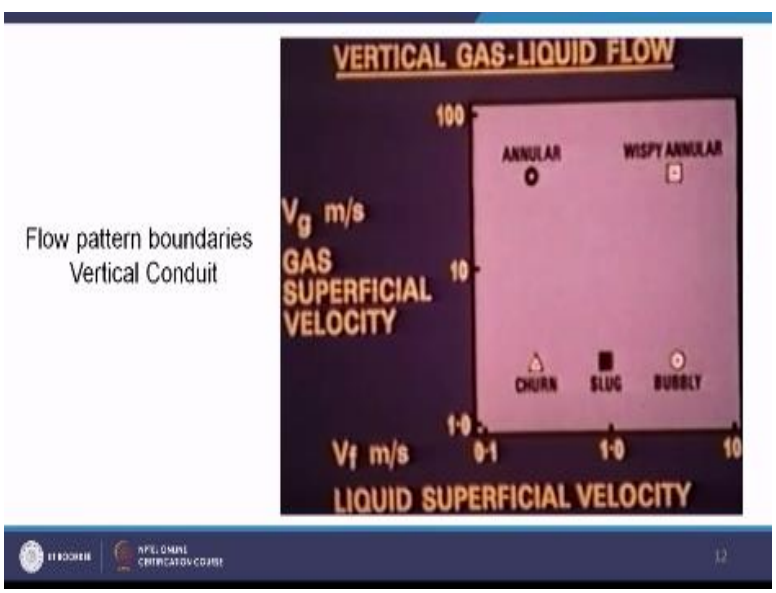

Now if you perform experiments of different superficial velocities of liquid and gas, you can generate this type of points in this plot and next we will be finding out lots of dotted points we have gathered.

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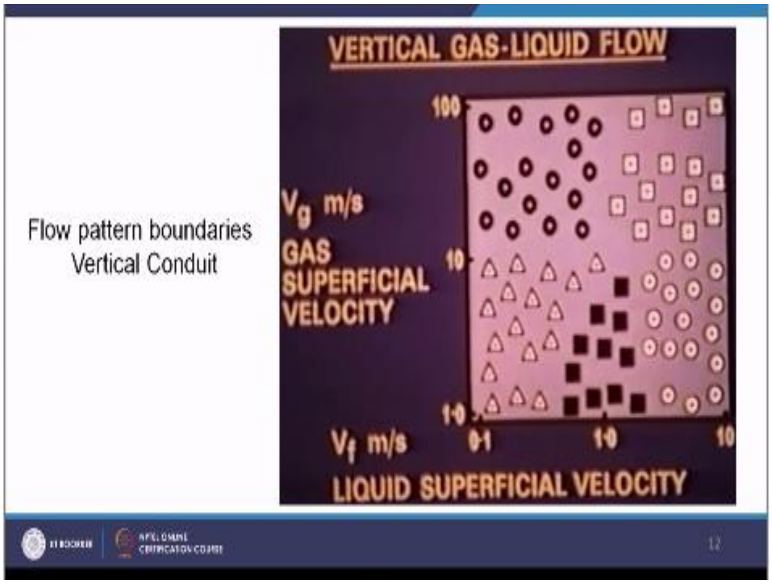

So we which are of different types, these are bubbly, these are slug, this is annular, this is wispy annular and this type of flow regime, this type of plot we actually called a flow pattern map. Now if you try to create the boundaries between these flow regimes you will be finding out a boundary like this. So this is actually domain where, we can get the bubbly flow.

This is a domain for slug flow; similarly churn flow, annular flow and wispy annular flow. So this type of flow regime maps are very, very important to know a priory that what type of flow pattern we will be obtaining. Next let us go for horizontal configuration. So, first in horizontal configuration we will be observing stratified smooth flow.

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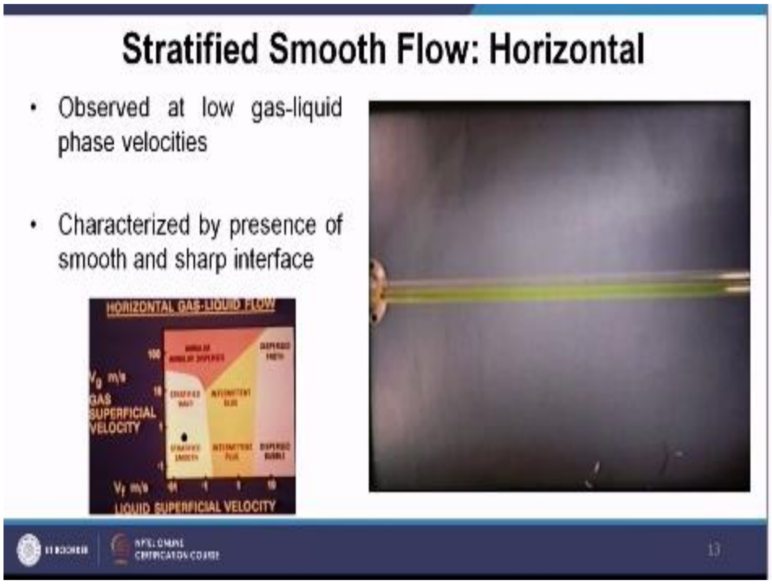

(Video Starts: 14:07) So here in this video you can find out we are having liquid over here and this is gases which are flowing stratified with a very smooth with the smooth interface for in the cross section you also find out. So this is actually characterized by presence of smooth and sharp interface, interface is sharp not diffused okay and this is observed at very low gas liquid phase velocities. So this is actually the domain where we are having stratified smooth very low liquid velocity as well as very low gas velocities right. (Video Ends: 14:35)

Now once we increase the gas superficial velocity we will be obtaining stratified wavy nature. (Video Starts: 14:43) So you can find out in this figure. So earlier the interface was smooth now it is forming from waves so in the close view also you can see lots of waves we can see okay. So this is actually having presence of 3d wave like structure and so it is actually 3d. So in the pipe cross section you can find out waviness.

So in the cross section you can find out this waviness okay. So this is steady waviness and as I have told earlier this is caused due to increased gas superficial velocity from the stratified smooth surface. What stratified smooth flow so this stratified wave flow pattern is lying over here. (Video Ends: 15:19)

Next let us see another flow pattern in horizontal which is called annular dispersed flow.

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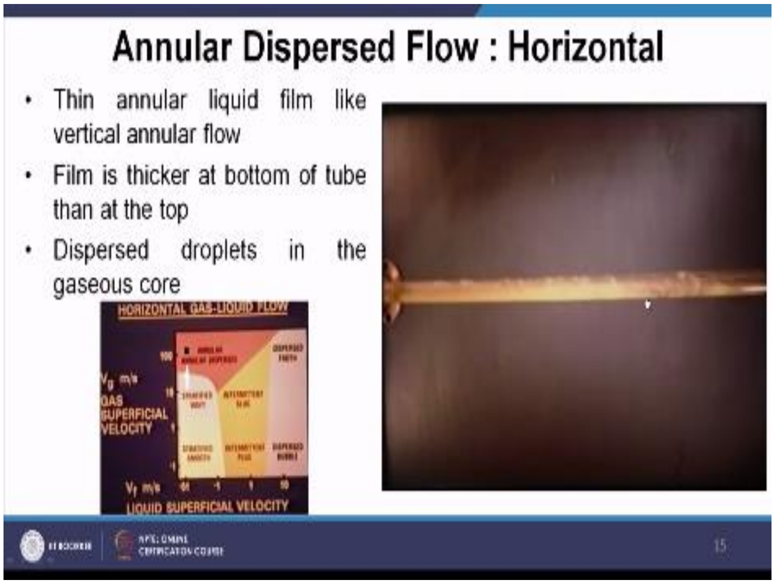

(Video Starts: 15:28) So in case of annular dispersed flow you can find out over here that thick annular liquid film is there okay. This is the film you can find out over like a vertical annular flow whatever we have seen in the previous slides okay and this film is thick at the bottom and thin at the top. So we can find out here we are having thick film and here we are having thin film.

So due to this horizontal nature you will be finding out film thickness is varying. We will be finding out here that lots of dispersion of bubbles liquid droplets in the core. So dispersed droplets in the gaseous core you can find out okay and this is obtained at further higher gas superficial velocity keeping the liquid superficial velocity same. So this is the typical annular dispersed flow regime (Video Ends: 16:16).

Next let us see the next flow pattern in horizontal which is called intermittent plug flow.
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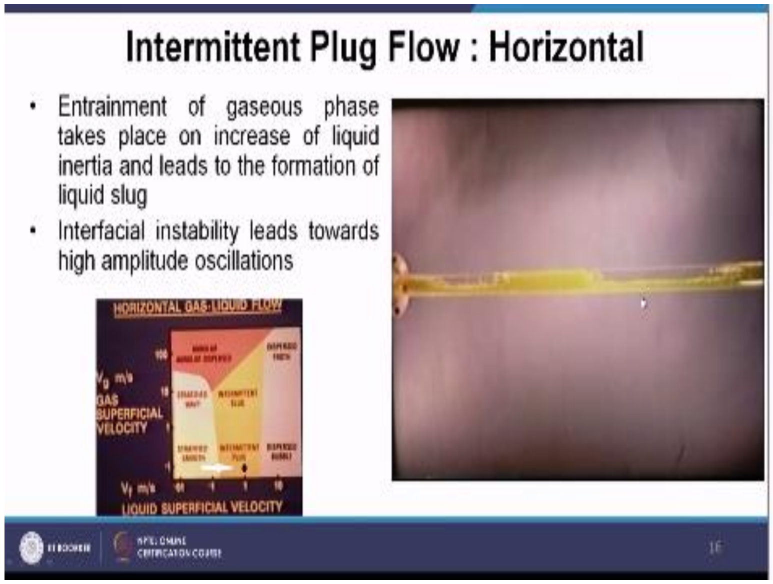

(Video Starts: 16:23) So you can find out over here in the pipe cross section that there is some sort of intermittent intermediate plug which is touching the upper portion of the tube. So here you can see this is gaseous phase and then the gaseous phase will be ending and liquid is coming in between as plug. So this is actually entrainment of gaseous phase which is increasing, which is causing due to increase of liquid phase velocity. So from stratified smooth if you increase the liquid phase velocity, you will be getting this intermittent plug right. (Video Ends: 16:55)

Let us see another one which is called disperse bubble flow.

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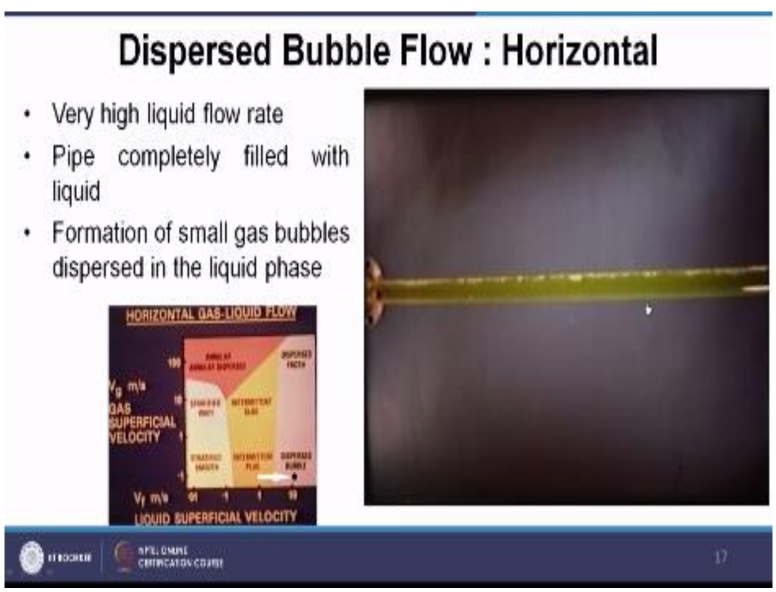

(Video Starts: 17:00) So if you increase the liquid superficial velocity further. So you will be finding out that pipe is completely filled with liquid okay here you can see completely filled with liquid okay. Formation of small gaseous bubbles were at the top somewhere over here you can find out the gaseous phase bubbles okay.

Bubbles are nowhere present in the lower portion of the tube but majority of the bubbles will be there at the top. So this is actually forming at higher liquid superficial velocity and very low superficial velocity (Video Ends: 17:32). Next let us see intermittent slug flow. This is also a typical flow regime for horizontal flow.

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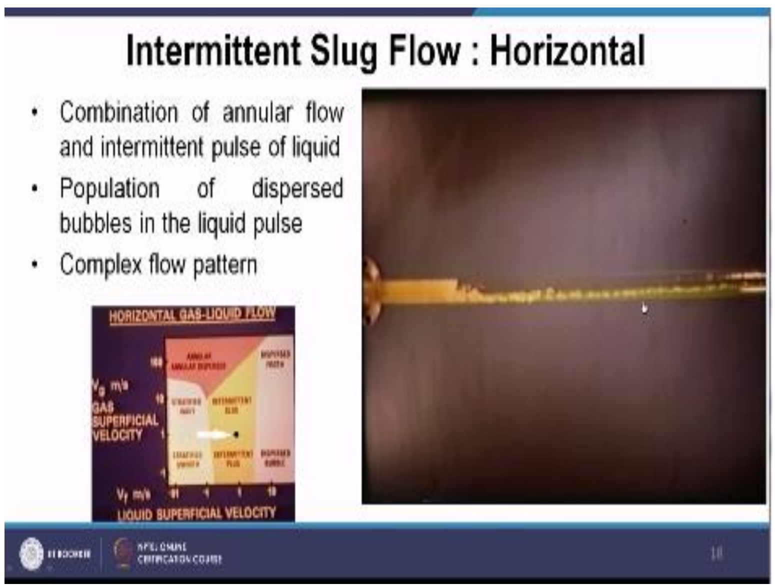

(Video Starts: 17:38) So, here what you will be finding out this is actually combination of annular flow and intermittent pulse of liquid. So we can find out first this is annular flow and then there is pulse of liquid with lots of bubbles entrapped inside this. So this is very complex pattern and this population of dispersed bubble in between these will be causing the flow pattern very, very interesting to see.

So this is actually obtain somewhere at the intermediate liquids superficial velocity and intermediate gas superficial velocity (Video Ends: 18:09). Next one let us see as dispersed froth flow. So this is also seen in horizontal regime. So you can find out over here that this occurs at very high gas and liquid superficial velocity.

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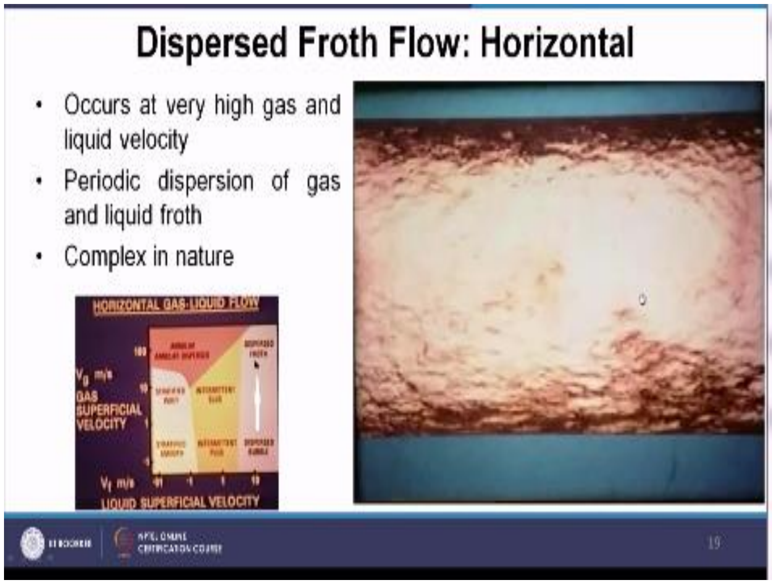

(Video Ends: 18:22) So from dispersed bubble flow if you increase the gas superficial velocity, you will be coming to this dispersed froth regime. So you can find out over here that we are having period of dispersion of gas and some liquid froth over here. In the cross section we can observe that one this is also very complex in nature studying this one requires lots of idea about the bubble dispersion as well as interfacial phenomenon (Video Ends: 18:48).

Next let us try to summarize the horizontal flow patterns as a regime.

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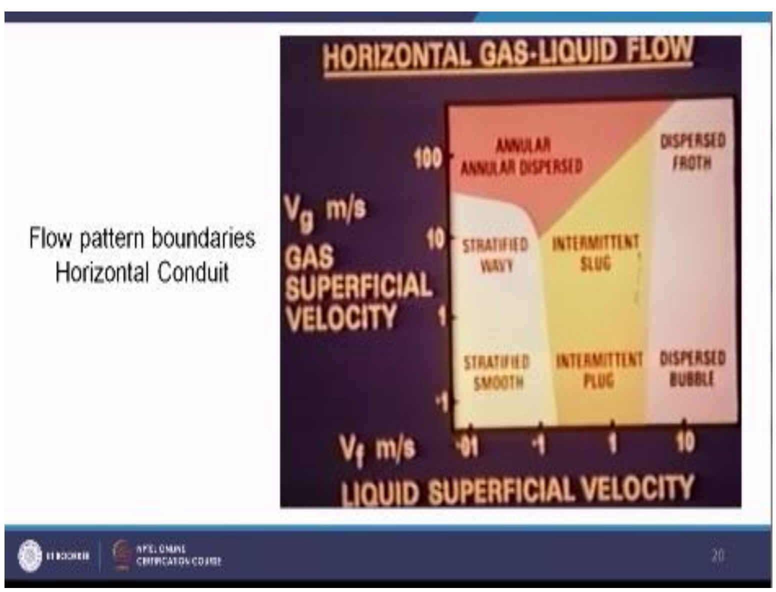

So you can find out over here in abscissa we are having liquid superficial velocity and in ordinate we are having gas superficial velocity and we will be starting from stratified smooth to intermittent plug and dispersed bubble. Once we increase the liquid superficial velocity keeping the gas superficial velocity same. On the other hand if you keep increasing the gas superficial velocity, you will be going through the stratified wavy and an annular dispersion flow starting from your stratified smooth flow.

At intermediate velocity ranges you will be finding out intermittent slug and finally at very high and gas, very high gas and liquid superficial velocities you will be finding out dispersed froth flow. Now there were some sort of flow regimes what we have shown for horizontal and vertical situations most of the flow regimens whatever I have shown you those are for water. Now if you are having some other type of fluid either we have to do experiments once again with that new fluid to find out the flow regime.

Or we have to create a flow regime which is irrespective of the fluid properties will be applicable for all the ah fluids. So here what we have shown 2 different flow pattern maps.

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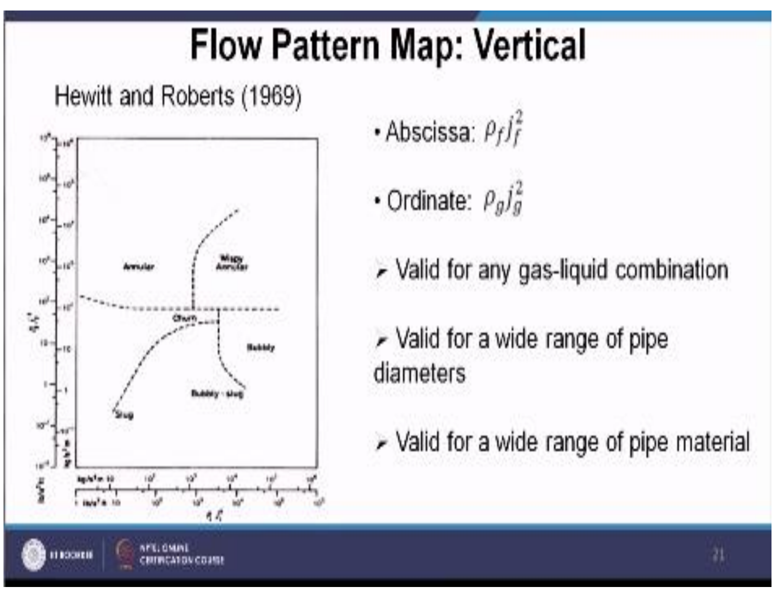

First one has been given by Hewitt and Roberts in 1969 this is applicable for vertical pipes. So here you can find out that this is a flow regime map consisting bubbly, slug, churn, annular and wispy annular whatever we have seen in our ah earlier cases. But here typically you see the abscissa and ordinate those are not superficial velocities but here abscissa we have given as a Rho f*jf square and ordinate is Rho g * jg square.

By incorporating the densities over here you can find out we are making this flow regimes actually universal to all the fluids. So for any fluid if you know the densities so you can find out the points specific points over here. And which flow pattern is obtaining that you can find out over here. So this is valid for any gas liquid combination. Similarly, we are having another map for horizontal. So here this map is developed by baker in 1954.

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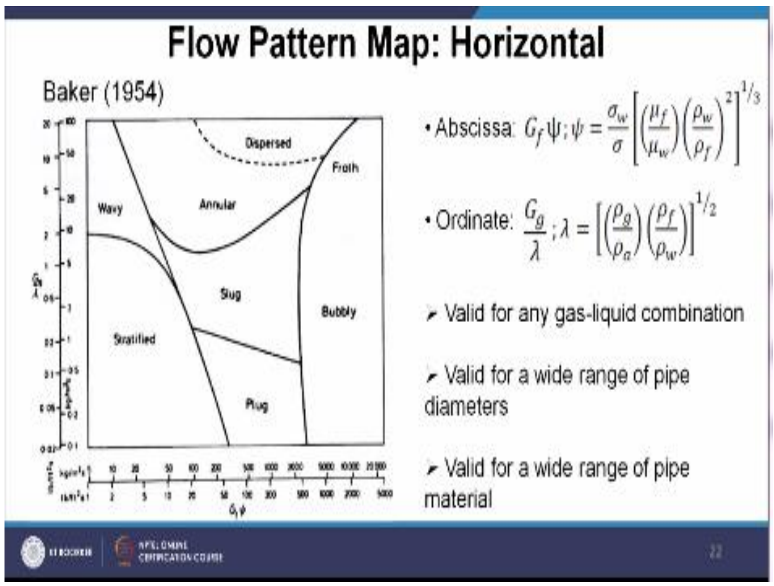

You can find out once again all those flow regimes. Whatever we have seen in horizontal stratified, wavy annular froth, bubbly, slug, plug all these flow patterns you can find out. This is also applicable for any horizontal gas liquid Two Phase Flow. So in the abscissa we have given gf *psi. So gf * psi is an abscissa and gj into by lamda is in the ordinate.

Now this lamda and psi those can be written in terms of the fluid properties so Rho g / Rho a that is actually the gases phase and af is density Rho f /Rho w this is actually liquid phase and water phase density. Similarly here psi is sigma w /sigma. Sigma is the interfacial velocity for the unknown combination and sigma w is the water air combinations surface tension.

Here mu f /mu w these are the viscosities of the unknown liquid and water here Rho w and Rho f these are the densities of water and liquid phase unknown liquid phase respectively. So this kind of flow pattern map can be use for any unknown flow. So to summarize this lecture what we have done introduced different flow patterns configurations.

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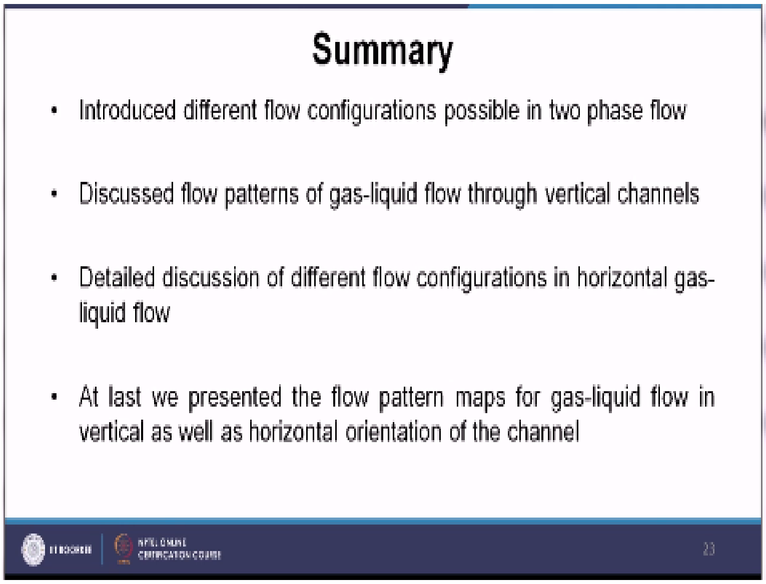

In case of vertical as well as horizontal and finally we have introduced the flow regime map for both the phases.

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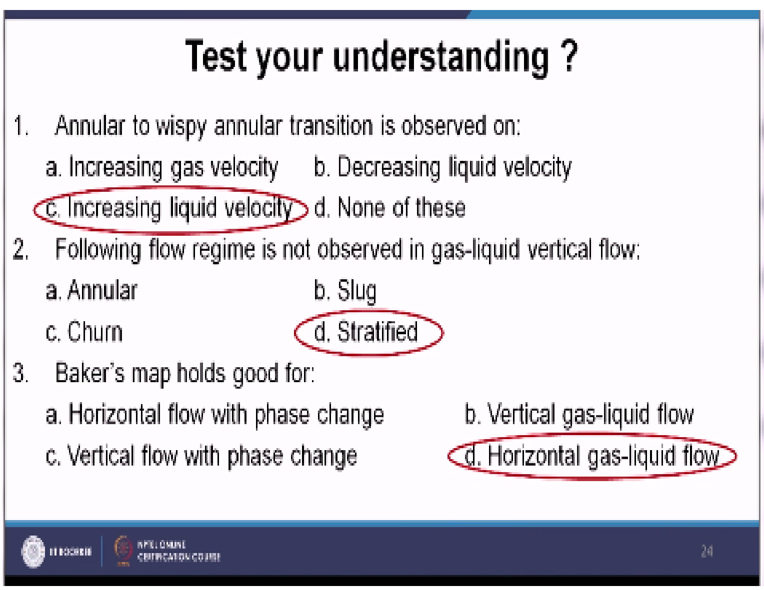

Next let us try to test you understanding what we have learned in this flow in this lecture. First one annular to wispy annular transition in observed on increasing gas velocity, decreasing liquid velocity increasing liquid velocity or none of these. So the answer is increasing liquid velocity I hope all of you have got the correct answer. Next following flow regime is not observed in gas liquid vertical flow. Answers are options are annular, slug, churn and stratified. Which one? Let us see the answer, stratified.

So stratified flow regime we have not obtain in case of vertical flow. Third one bakers map holds good for horizontal flow with phase change, vertical gas liquid flow, and vertical flow with phase change and horizontal gas liquid flow. What is the answer let us try to see the answer is horizontal gas liquid flow. So with this I will be ending this lecture. Thank you.