Multiphase Flow

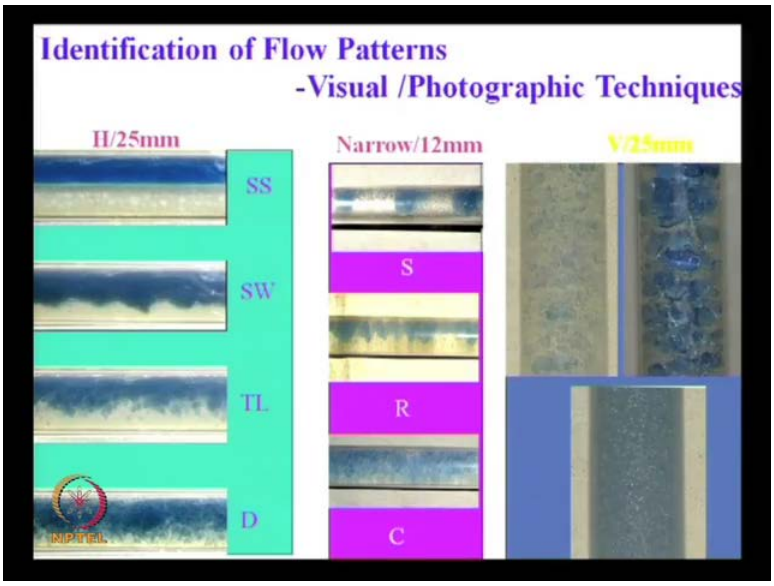
Prof. Gargi Das
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Module No. # 01
Lecture No. # 03
Estimation of Flow Patterns (Contd.)

.

Well a very good morning to all of you.

(Refer Slide Time: 00:27)



So, in the last class we were discussing about the estimation of flow patterns. Why it is so, very important for estimating flow patterns for what are the different flow patterns, which are encountered during in a vertical pipe, in a horizontal pipe of normal cross section; that means, greater than half inch or so. And then when the pipe is heated both in the vertical orientation, in the horizontal orientation we found out the differences in flow patterns.

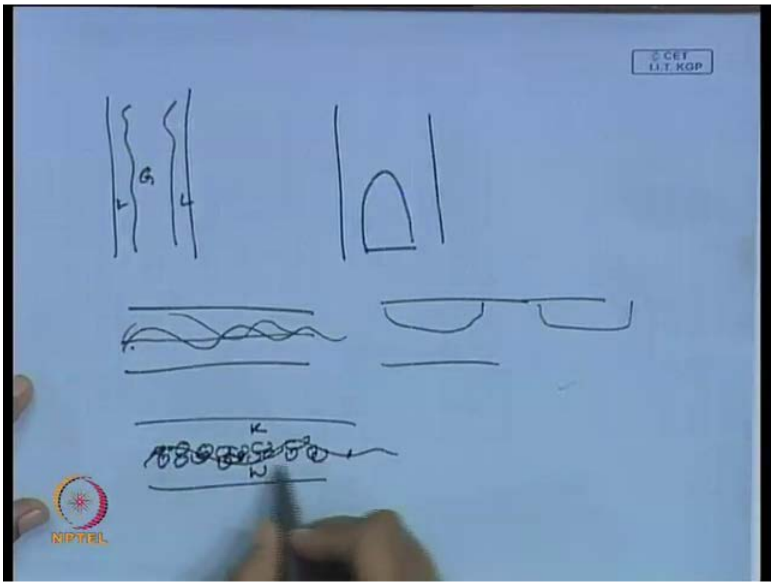
And then, we had just started discussing on the flow patterns which we encounter when instead of air, we introduce a second liquid it can be either kerosene, it can be toluene, it can be anything. So, that was the next thing that we were trying to discuss well. So, what what we have talked of was that initially what we found was that, just instead of air if we introduce a second liquid in this case we have done it with kerosene. And the whatever I will be showing you they have been done in the multiphase flow laboratory of the chemical engineering department of IIT Kharagpur.

And these photographs etcetera they have been taken in the experimental set ups which are there in that particular laboratory. Now, what we see is, there are certain differences which come in when instead of air we introduce a liquid, now what happens when you introduce a liquid.

First thing is surface tension is larger here, viscosity varies over a large range. In fact, we will see that if we have a low viscous oil and a high viscous oil, the flow patterns are remarkably different that also we have observed here. So, this whatever I am showing you today or at the moment it is for low viscous oils so, therefore, what we find is just because the surface tension becomes small sorry surface tension becomes large and viscosity varies over a wide range. So, therefore, the distributions at different as compared to the distributions which you observe for air water system are for vapor liquid, gas liquid systems.

Now, what are the immediate differences which we can see there is one more thing in gas liquid cases the gas phase was a compressible phase, but in this case in that way none of the phases are so, very compressible. So, therefore, we find there is certain differences which step in. The fourth difference is as I had already mentioned in the last class that either of the phases can wet the pipe wall. So, therefore, for air water or vapor liquid cases what we had when we had a very high gas and a very low liquid we had something like the annular flow pattern. Where there was a thin liquid coat sorry thin liquid film and a continuous gas coat.

(Refer Slide Time: 03:18)

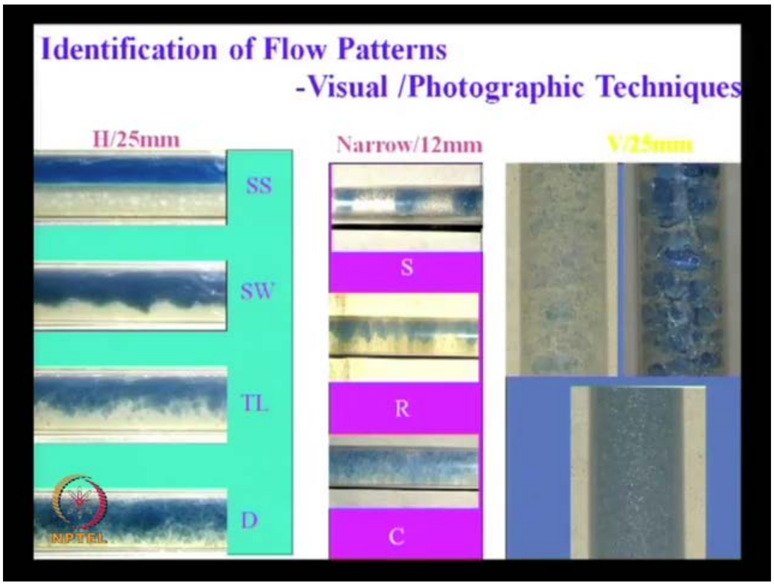


Beyond this we did not have anything, if we keep on increasing the gas flow rate keep on decreasing the liquid flow rate under unheated conditions we find that the liquid film it becomes thinner. And thinner the interphase becomes smoother the gas core becomes thicker, but never the less we find that there would be an existence of a annular flow pattern. And as we go for higher gas and lower liquid and the slip is very high we get a smoother interphase and therefore, we do not get anything beyond the annular flow pattern.

On the other hand we found out that for gas liquid sorry for liquid liquid cases either of the liquid can wet the pipe wall now surface wetting properties they are not very important as far as when we are dealing with quite large pipes. Where your surface energy is much less as compared to the inertial forces or the inertial energy, gravitational energy, etcetera. So, therefore, we found out that in this case depending on the relative proportion of the two liquids either of the phases can wet the pipe wall and either of the phases can remain dispersed in the second phase.

So, as we have shown there shown in this particular diagrams where we have shown kerosene water flow for low your low viscous oil water flows we find that at low kerosene high water we are distinctly having a continuous water phase with kerosene dispersed in it similar to the bubbly flow distribution which we had observed for air water cases.

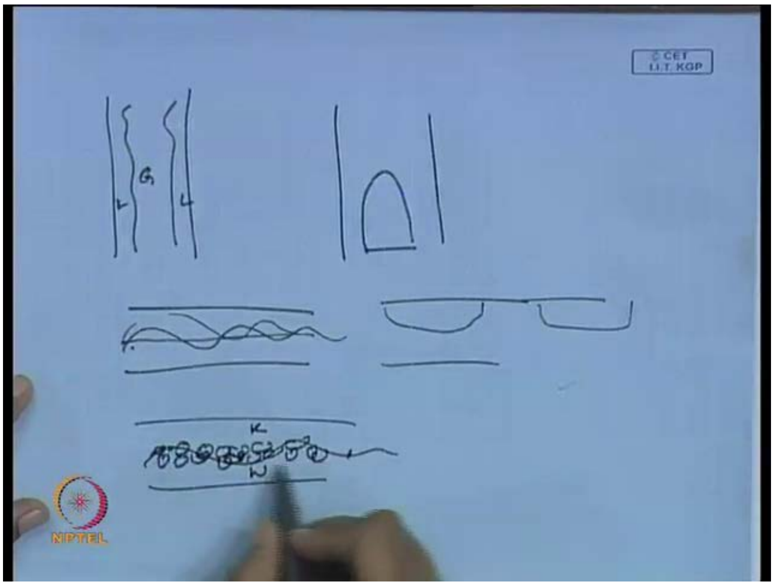
(Refer Slide Time: 00:27)



On the contrary when we go for a high kerosene and low water velocity we find that the entire cross section it becomes blue in color. And in that bluish cross section meaning that kerosene is a continuous phase and in that bluish cross section, we find out small droplets of water are dispersed here. So, therefore, this particular term phenomena the inverting from one continuous phase to the other as I have already told you in the last class this is phase inversion. This occurs for liquid liquid cases and never for gas liquid or for any other two phase flow situations.

The other thing just because of larger surface tension what we find for gas liquid cases what we had found out that initially we have bubbly flow, but if we keep on increasing the gas velocity then what happens a time comes when the gases they start coalescing start forming the Taylor bubbles and the slug flow pattern comes.

(Refer Slide Time: 03:18)



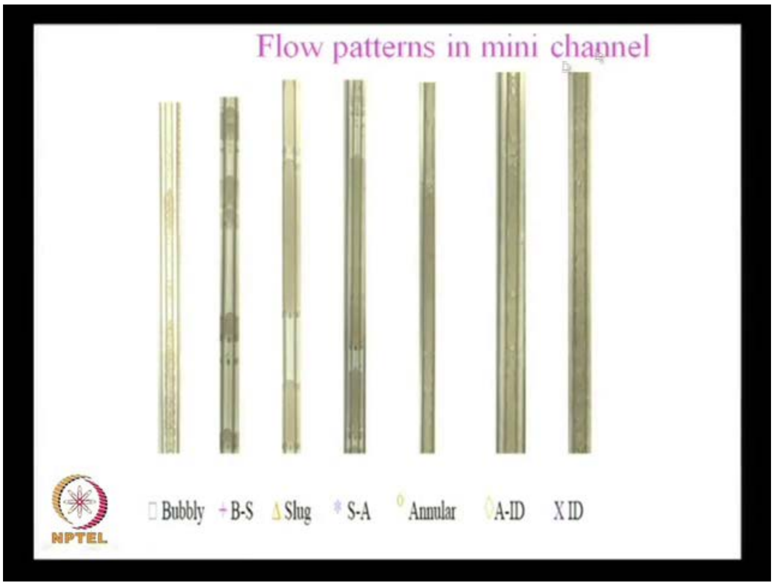
On the contrary in this particular case what happens is if we take a horizontal situation then what had happened there initially the interface was smooth for low phase velocities. Then, gradually a waviness sets in, then gradually the amplitude of the waves they start getting larger and larger and then finally, we were getting something of this sort, but in this case interestingly moment the interphase starts getting wavier what happens shearing occurs here. And due to the high surface tension the waves do not grow so much to form the slug flow pattern which we have we had observed for the air water cases.

On the contrary what you observe here we observe that this waves they break down and then gradually several droplets start to accumulate at the interphase between the kerosene layer and the water layer. Here we get a dense dispersion of droplets between these two layers and this particular layer this is this contains kerosene drops in water, water drops in kerosene. And this gives rise to the three layer flow pattern which we have shown in the third photograph in this particular case. Now, this three layer pattern which has a distinct kerosene layer on the top, a distinct water layer on the bottom. And some sort of a dispersed situation between the upper kerosene and the lower water layer which gives it a three layer appearance.

This was not evident or this does not occur for gas liquid cases this is the other difference that we have. So, generally for gas liquid cases under normal circumstances never for gas liquid cases we have bubbly slug (()) annual flow. In this case we have the bubbly flow pattern we have the inverted bubbly if you say or in other words oil in water flow bubbly flow pattern, water in oil bubbly flow pattern and then we have the three layer flow pattern. These things are the differences which we did not have there just by changing one phase by replacing the air phase with the another liquid phase low viscous liquid phase that too we find that these are the ranges of differences.

But interestingly we find as the pipe diameter reduces you can see from this particular slide for a horizontal pipe as the diameters reduce from the twenty five millimeters to twelve millimeters. A tendency of slugging occurs definitely the kerosene slugs they are not as well defined as the Taylor bubbles, but some sort of a tendency of slugging it starts to occur. This will be much more clear if we see another these things or already I have told you three layer flow pattern and things like that.

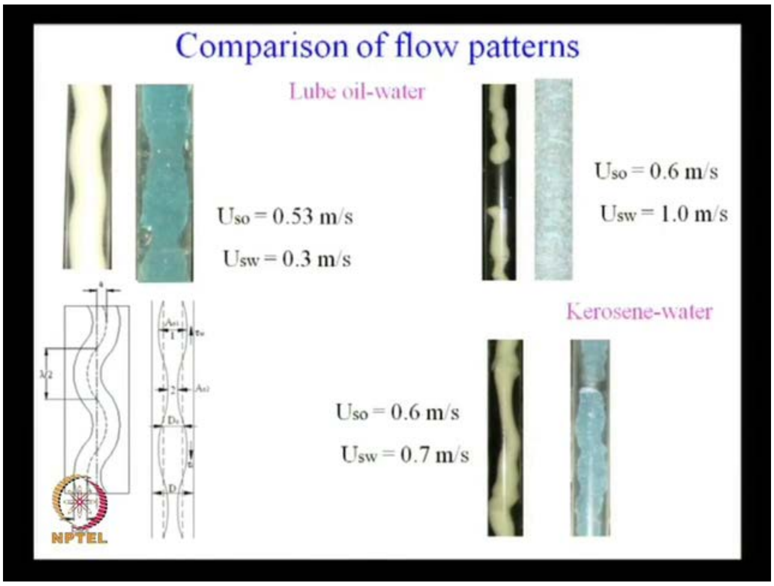
(Refer Slide Time: 09:03)



So, this is going to be much more clear if you see certain flow patterns for tolling water flow here you can very distinctly see slug flows Taylor bubbles just like the Taylor bubbles which we had observed for air water cases. So, therefore, we find that with miniaturization the differences between air water flow and liquid liquid flow gradually reduces. As we approach miniaturization since surface energy becomes more and more important. We find that initially just like air water flow, initially we had bubble flow here then gradually the bubble start getting larger and we get distinct slug flow sort of a situation and from slug flow.

As we keep on increasing the tolling flow rate gradually we do not come across churn flow pattern in this case this tolling Taylor bubbles they start coalescing and they form a distinct annular flow pattern. Where there is a tolling core and there is a water film between the tolling core and the pipe fall. If we keep on increasing the tolling velocity further then in that case what happens the entire then in the entire tube tolling becomes the continuous phase and some amount of water droplet start to accumulate here. So, therefore, we find that under normal circumstances in liquid liquid flows we do not have the slugging tendency, but as we go to the smaller pipe diameters then the differences between air water and liquid liquid flows they gradually reduce and we get we come across more similar flow patterns in the two cases.

(Refer Slide Time: 10:58)



So, this shows the effect of fluid physical properties or the fluid type on the flow distributions now instead of low viscous oil if we go for a high viscous oil, say lubricating oils or crude oil. Now, here I would like to tell you one particular situation initially people used to study low viscous organic liquids and water flows because that was for we were encountering in our practical applications. In petroleum industries also the lighter oil fractions were being explode and therefore, low viscous oil water flows were studied in great detail.

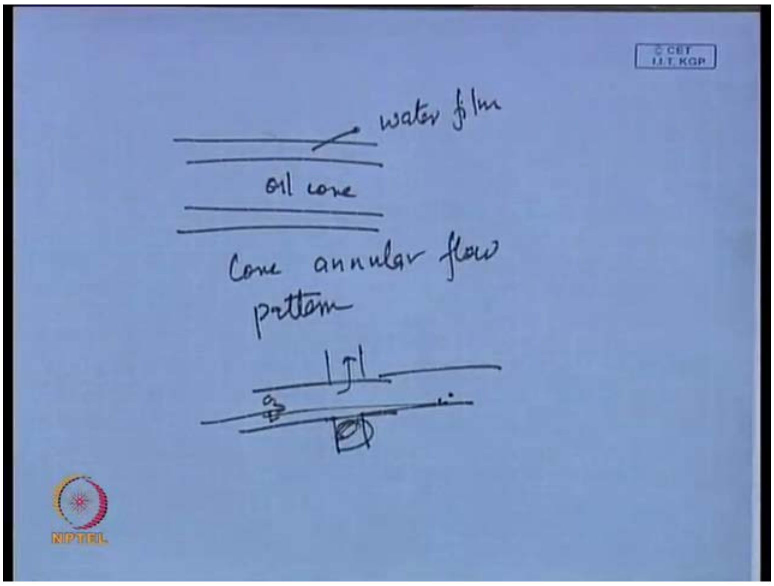
Now, gradually what is happening is the lighter oil reserves they are getting depleted is not it all the lighter oil reserves they are getting depleted we are going deeper and deeper.

And therefore, we have to explore and we have to recover the high viscous oils and the other thing what has happened is now the on shore oil fields are also getting depleted. So, we have to go for off shore cases, moment we go for off shore cases what is the problem transportation becomes a problem because from beneath the seas it has to be explode and then from there it has to be brought to the oil exploration units which are on the shore of the seas.

So, therefore, initially transportation was not such a very big challenge number one and number two we were satisfied with dealing with lighter oils. But now, what happens now due to these two factors the transportation of viscous oil has become a very big challenge, what happens whenever we want to transport high viscous oils we need a large amount of pumping power. And there have been several attempts to reduce the pumping power what people try to do they try to mix up some amount of lighter oil with the heavier oil so that it is viscosity goes down.

Another thing they try to do they try to heat the oil at regular intervals so that the viscosity goes down these things are not very feasible situation. Now, from two faced flow what we found out was that a very attractive solution can be proposed and In fact, and we are thinking of working we are to In fact, the discussions have also proceeded. And presently a work will be done with o n g c regarding the reduction of pumping power for transportation of high viscous oils.

(Refer Slide Time: 13:41)



What we have planned to do we have planned to find out or rather we have observed that there is something like the annular flow pattern is not it. For oil water cases we call it core annular flow pattern what happens under this circumstances just like the annular flow pattern there is a oil core here and there is a water film here this is known as the core annular flow pattern for liquid liquid cases. It is nothing, but the annular flow pattern that you have observed for the gas liquid cases.

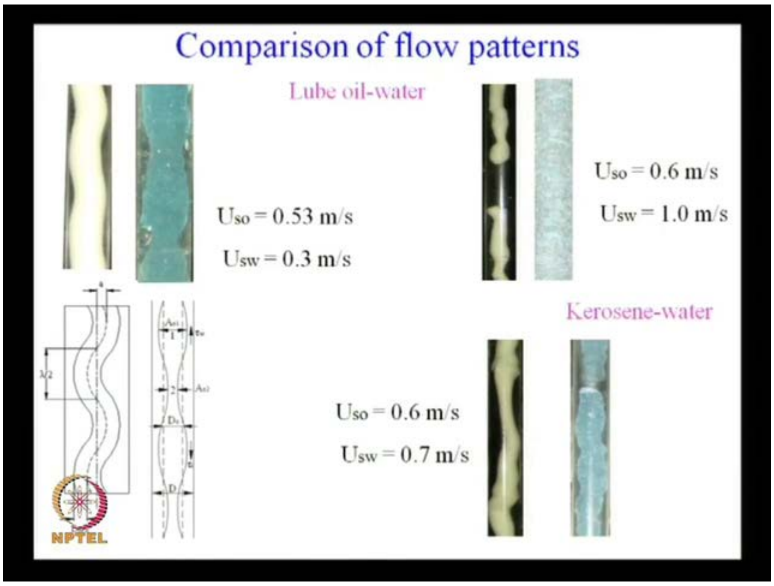
Now, in this particular case we find that if we inject a very small amount of water in such a way that it is the water only which wets the pipe wall and it separates or prevents the oil core from coming in contact with the pipe wall. Then what happens the frictional pressure gradient it arises due to the contact of water with the wall is it clear to you. Why is the pumping power so, high? It is so, high just because oil is viscous and therefore, there is a very large amount of wall share when oil has to be pumped. Now, suppose the oil is prevented from coming in contact with the wall. So, what happens the frictional pressure gradient it arises primarily because of the wall share between the water and the wall.

So, therefore, by this if we can maintain this particular flow pattern we are actually shown in our laboratory experiments that the pressure trough decreases so much that it is almost similar to the pressure drop which we will encounter if we pump o\nly water through this particular cross section. So, can we imagine the reduction in pressure drop. So, the pressure drop almost for this particular flow situation the pressure drop is almost similar to that particular pressure drop which we would encounter when only water flows through this particular pipe at the same mixture velocity. So, this results in a drastic reduction of pressure drop and this said leads to a drastic reduction of the pumping power required and therefore, this is a very attractive proposition as far as oil exploration is concerned.

So, therefore, this particular idea we had got from our studies of two faced flow only and interestingly you would also be interested to know that we find that the tendency of formation of the core annular flow pattern it increases with viscosity of the oil. That means, the more viscous the oil is the more it has a tendency to stay in the core annular flow pattern which is an extremely fortunate situation. So, therefore, as we go for a more and more viscous cases we find inverted disperse people have generally not found out for this high viscous cases. And core annular flow pattern occurs over a large range of flow velocities and apart from core annular flow pattern we have some sort of slugs elongated bubbles, but mostly the flow pattern is core for all pipe orientations.

So, therefore, we find that even when we are working with liquid liquid cases depending upon the liquid properties also the flow patterns vary.

(Refer Slide Time: 10:58)

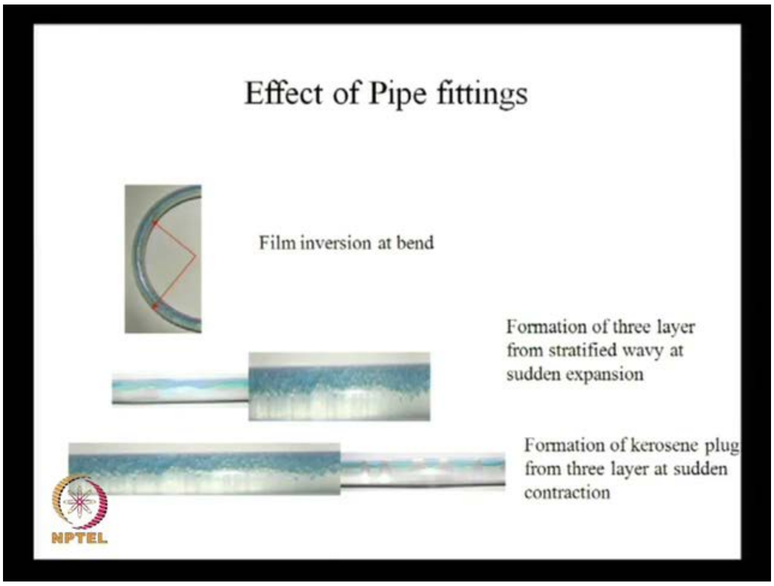


So, this is very important in this particular slide I have shown the comparison between lubricating oil water flows and kerosene oil water flows you can very well understand. That may be at high oil and comparatively lower water velocity there is a tendency of core annular flow for both the cases, but please note the difference in waviness for the two cases. In this particular case we are having an asymmetric wave whereas, in this particular case if we observe the waviness is definitely axis symmetric. Just because of the difference in the nature of the interfacial waves the the flow patterns which occur with decrease of oil or increase of water velocities they are drastically different for the lube oil water case and the kerosene water case.

You can see for the kerosene water case we have kerosene dispersed in water, but here we have a some sort of a slug flow where these particular lube oil slugs they are extremely sinuous tortuous sort of a thing and irregular a sinuous sort of a slug flow we have. So, therefore, you can see the differences in the distribution between lube oil water and kerosene water flows, under comparable or under identical flow velocity conditions.

Same pipe diameter they are for down flow situations you can notice the differences in flow patterns just by a change in the viscosity of the oil that we have used. After that

(Refer Slide Time: 18:44)



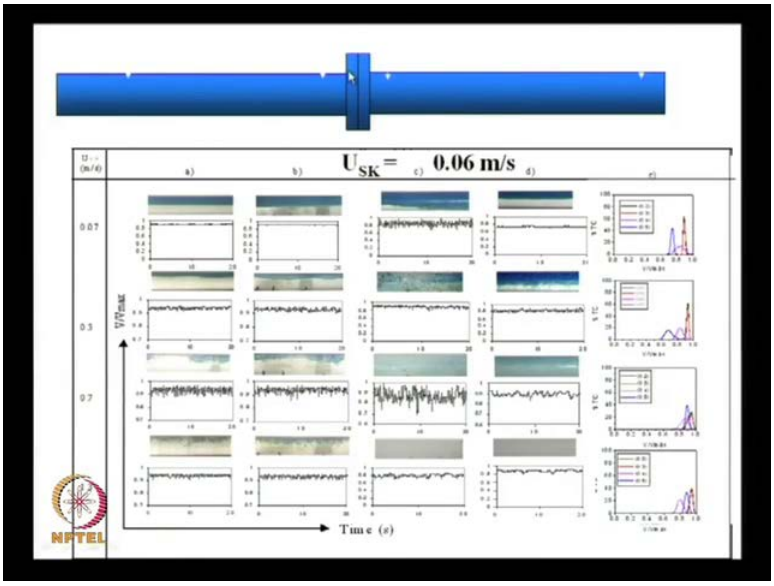
I would like to show you see whenever you are working or whenever something any particular thing is being transported pipe fittings are inevitable. you got to have t junctions you to have bends l bows contraction expansion these things have to happen. Now, when these things encounter for single face flow what we do we define an equivalent length and then we calculate the pressure drop accordingly. Is not it? Now, in this particular case we find even the distribution changes when we encounter such a situation. Why because, whenever there is there is some sort of particular pipe fitting it imparts some additional force, may be a centrifugal force or centripetal force. Something whenever some force is exerted that depends how much of the force will be manifested that depends upon the physical property of the particular film.

So, therefore, whenever there is sick/say say two particular fluids of different density then one tries to accelerate over the other this accelerating tendency. If it is enhanced by the presence of pipe fittings then naturally the distribution it tends to change. Is not it? For example, here I have shown you that kerosene water flow again when it is flowing through a bend what happens in the upstream section there was water here kerosene there by the time it covers the bend kerosene goes up water goes down. So, naturally there is some sort of a film inversion occurring if you I do not know how much clear it is that there is a some sort of a film inversion occurring from the lower portion water shifts to this particular portion.

And this is one particular thing which a bend brings upon. Then suppose we have contraction expansion this is very very evident. See suppose we encounter an expansion sudden expansion what we find initially the flow was distinctly stratified wavy small amount of waviness was there not much waviness, there was kerosene on the top water on the bottom now just after the expansion what we find it becomes a three layer or dispersed sort of a thing distinct droplets arise. And these droplets are more or less suspended between upper thin kerosene layer and a thick continuous water layer. In this case also we find another interesting thing initially in the upstream section there was a three layer flow pattern.

Now, as I have told you the tendency of formation of three layer flow pattern it decreases with pipe diameter. For larger diameter only it is important as we reduce the diameter the tendency of formation of the three layer pattern it decreases. So, what we find moment we encounter the contraction from the distinctly there layer or maybe the dispersed sort of a pattern we get distinct oil plugs under these conditions. So, this also gives you an idea of how the different types of pipe fittings they tend to affect the flow patterns.

(Refer Slide Time: 21:50).



This is another particular case which I would like to show a very interesting case when we were trying to study kerosene water flows through the orifice meter. Now, in this particular case if you observe say here what we found, you had started with a smooth stratified flow the orifice is located at this particular position. So, we had started with a smooth stratified flow just after the orifice what happened it become a it became a completely dispersed flow situation and more or less it ended up being a three layer flow pattern. So, from the distinctly stratified you obtained a three layer flow pattern. then again in this particular case it was sort of a plug sort of a situation or a dispersed sort of a situation, but where the plugs were concentrated only on the upper portion of the pipe.

From there instantly what we got we got a homogeneous dispersion of the two phases kerosene dispersed in the oil phase. So, therefore, we found what the orifice did in the low viscous oil water flows they served the two homogenize the mixture, they reduced the separation between the two mixtures. And every time we find what is happening if we start with stratified smooth we get a dispersed if we start with a plug we get a more or less uniform emulsion we start with dispersed flow get almost uniform emulsion. When we have a uniform emulsion it becomes whitish in color you must have observed emulsions.

They are so, well mixed the droplets are so, fine and they are so, well mixed with one another. That it cannot identify the difference between the two phases and it becomes the uniform a whitish a frothy appearance. So, here it is very clear that the two phases can be distinguished clearly, but in this case it becomes a whitish appearance where nothing can be distinguished. So, from these cases what I want to emphasize is that we know pipe fittings affected free flow behavior that you have seen in single phase flow as well, but in this particular case the influences much more pronounced. Because why because whatever pipe fittings are there they tend to influence the or rather they either try to homogenize the two flows the two phases or they tend to separate the two phases usually.

When we have a bend the bend has a tendency to means it enhances the separation of the two phases. If you have bubbly flow downstream up stream of the bend we get slug flow in the downstream portion. suppose we are having annular flow at the upstream of the bend annular flow with droplets what this bend does tends to separate the droplets from the gas core. So, it brings about a separation of the phases. So, therefore, what we find is that from all these things we find that even the using these different type of pipe fittings we can get some sort of a change in flow distribution which will be which might be desirable for us which might be undesirable for us as well.

If we want if we study these things well if we know these things well then probably we can use it to our advantage or else two phase flow will be exploiting us and we will be in a total in mess trying to control it. A very practical problem I will be telling you which had actually come to us from I o c l see the thing is I have talked about bends contraction expansion what is another inevitable pipe fitting which we encounter in industries T junction.

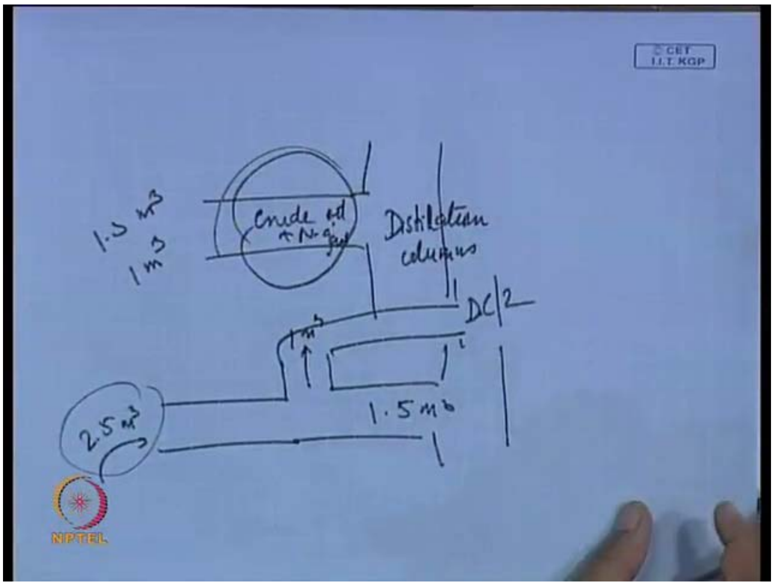
(Refer Slide Time: 13:41)

T junction is something very common now whenever we find whenever something flows through a T junction. Say horizontal junction also what happens? Suppose say gas liquid case is flowing now whenever it encounters a T junction I will draw it in this particular way it is a horizontal T junction what happens the gas will have a tendency to move in faster because of its lower inertia and the liquid will have a tendency to flow straight because of its higher inertia yes or no. So, therefore, we find a t junction it can be used as a partial separator also.

So, very frequently suppose we want to separate the two phases so, therefore, in order to reduce the load on the main separator what we can do we can just simply introduce it T junction upstream of the main separator. Some amount of separation will occur there so, therefore, the main separator it can be of a reduced low it can probably operate at a higher rating capacity. This is one advantage, the other thing is if you do not know that the t junction can separate the phases then probably what happens suppose you have a T junction say just downstream of a distillation column.

So, you have designed a distillation column according to a particular feed composition. Is it not? accordingly you have decided the number of plates you have designed the distillation column agreed. Now, there is just a T junction before in the T junction what happens partial separation occurs. So, the feed composition with which you have designed that feed composition does not enter the distillation column now. And what you find you find that your distillation column is not performing well, and you do not understand why it has happened at all? Is not it? So, therefore, you have to know these things. The practical problem which had come from I o c l was they were operating under particular circumstances.

(Refer Slide Time: 27:47)



Where in their distillation column, they were introducing a feed say crude oil and natural gas. This was being introduced in one of the distillation columns now due to some particular reason they had an enhanced supply of the raw material. Now, for this enhanced particular supply what they have to do either they have to increase the size of the distillation column. Is not it? Or in other words what they can do is suppose initially the entire feed rate was one meter cube. Now, it has become say one point five meter cube. So, now what they have thought of doing is initially one meter cube was coming.

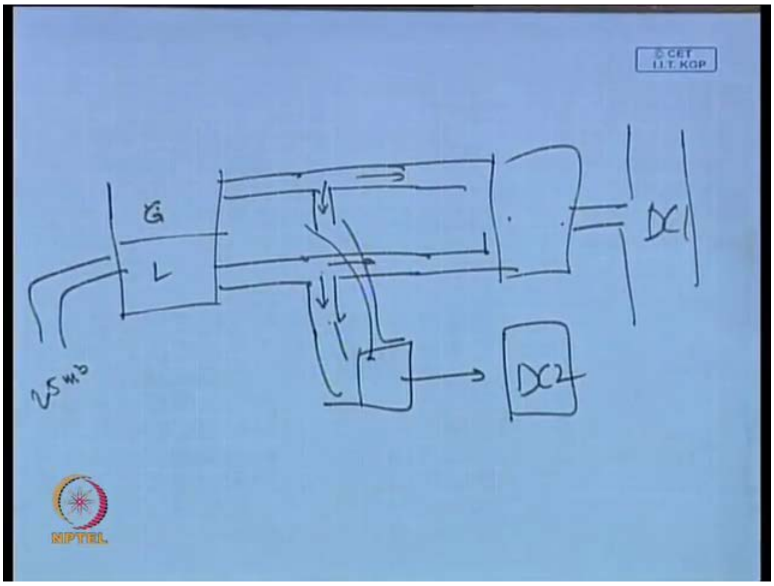
So, now what they thought is that let the entire two point five meter cube come we will design it in such a way that only one point five meter cube enters this particular distillation column and one meter cube will be diverted here and it is going to enter another distillation column say d c two. And therefore, or else what is the other thing that you can do you can simply dismantle this distillation column and you can big you can construct another huge distillation column capable of of handling this two point five meter cube of feed which you have now. So, naturally dismantling the whole thing constructing a new thing it is much more expensive.

So, what they thought no this is not a very good proposition we will simply bring the whole thing we will divert it at a T junction and then we will take them to two different distillation columns. In that case what is going to happen no d c one is already existing. So, distillation column two d c two will only have to be constructed and the pipe fittings they are quite cheap. So, therefore, with another d c two we can just perform the distillation of it is not going to be of much problem, but when they started doing this what they found out was the main was they found out that none of the columns were operating to their desired performance.

And they were getting very surprised because they thought maybe the design of d c two is not correct, but d c one was existing then also why was d c one was not giving the desired performance they were completely at a loss to understand this particular situation. So, they came here and they contacted one of our faculties to know what can be the probable reason of this what can be the probable reason that by just diverting the feed or just by dividing the feed we are putting the same quantity of the feed. Everything else is same we have not changed anything, but d c one is not operating properly. So, then we found out what was happening was that when they are using a t junction this acts as a partial separator.

So, therefore, more amount of liquid and less amount of gas is now being introduced to d c one it was designed for a higher amount of a gas and lower amount of liquid. So, therefore, now it is operating for a changed feed condition. And due to that particular reason that performance was not getting proper. So, therefore, what was the suggestion that we that we gave the suggestion that we gave was that we you cannot take the entire feed mixture and separate it.

(Refer Slide Time: 31:20)



In that particular way, what has to be done say suppose the feed is in this particular in one particular container we have say gas sorry its gas and liquid let us say. What we have to do we have to first bring the total see the two point five meter cube you have to first bring it to a separating any particular sort of a separator and separate the gas and the liquid. Then liquid we have to take out from there and this liquid have to be introduced or have to be diverted using a T junction according to the proportion that we require say suppose initially we required point seven five meter cube of liquid and point two five meter cube of liquid.

So, that we can do for the liquid separately similarly for the gas again let the gas be taken off separately then let they be diverted across the T junction then this particular gas and this particular liquid they have to be mixed up somewhere some fed they should be fed to the d c one. So, that the composition is maintained here is it clear or should I repeat this thing. It is clear, repeat what was the problem initially they were having a crude oil natural gas raw material mixture. And in that particular mixture they were feeding into a distillation column and the distillation column was performing a distillation.

This two phase mixture was feed now suddenly due to some reason they had an enhanced supply often they had an enhanced supply what to do that the column was not meant for such a high amount of the supply. Is not it? So, therefore, either a larger column had to be built to tackle this increased quantity of feed. Or what they thought no it is too expensive and time taking also if you have to build a new column. So, what they thought it is easier that well let the column exist we will introduce that amount of feed for which it is made. Say if it is made for one point five meter cube of feed now we are having two point five meter cube of feed. So, we will introduce one pint five meter cube of the feed into the distillation column and the remaining portion of the feed what we will do we will just introduce it into a second smaller column.

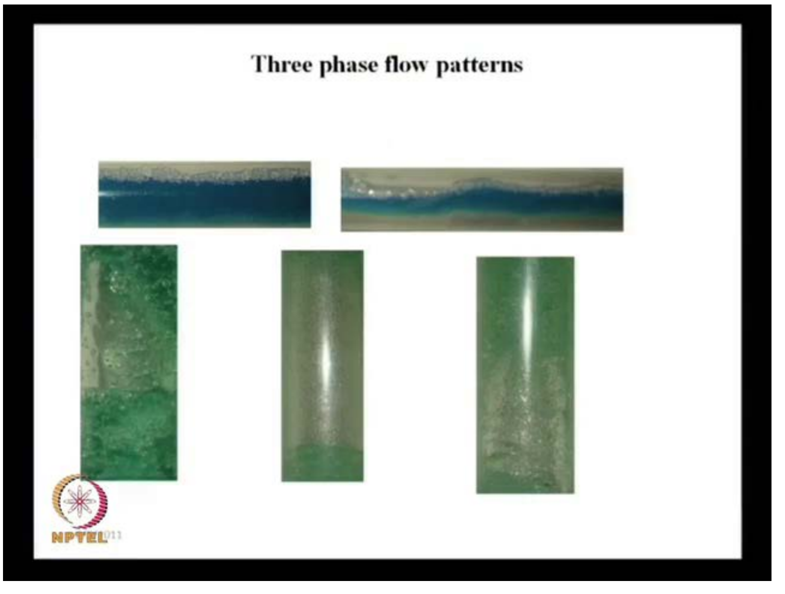
So, therefore, they are the things will be cheaper and we can perform distillation well now what they did. So, what they did the entire feed was coming there was a T junction they took out the required amount of feed which has to be fed in d c one the remaining feed went to d c two agreed what they did not understand or what they failed to understand was moment they are using a T junction it acts as a partial separator. When it acts as a partial separator it changes the composition of the feed for which a distillation column was designed got my point. So, therefore, when it changes the composition therefore, the distillation column started underperforming badly they because they were not being able to understand the reason because they did not know that T junctions act as partial separators.

So, therefore, they came to our institute for some suggestion. So, what we found out was that if the two phase mixture is subjected to a T junction then definitely the composition will change and definitely the distillation column will not perform properly. So, what has to be done does that mean then a separate column has to be made that is not at all a feasible solution. So, what we suggested is that whatever feed we have bring it and separate it into the gas phase and the liquid phase. Divert the liquid phase separately using a T junction as I have shown here.

Divert the gas phase separately through a T junction as I have shown here now phase, but then there will be one phase is flowing then the or rather the proportions can be varied at will there is no problem of composition changing is not it pure gas phase. Similarly, the liquid phase also the proportions can be varied by adjusting the diameters and things like that. So, therefore, by this process we could get the amount of gas and the amount of liquid for which d c one was designed right. So, now, these two were mixed and then they were introduced in d c one and the remaining proportion of gas and liquid they were again mixed here and in one particular container then they were introduced d c two.

So, now both the columns were getting the feed composition for which they are designed and they started performing well. So, unless we have an idea of two phase flow is not it is not possible for anybody to deal with these situations in a normal in a practical manner. So, this is one particular practical problem I thought I will share with you just to show you how pipe fittings can be advantageous to us as well as it can be extremely problematic if we do not know how the pipe fittings are affecting the two phase flow situations.

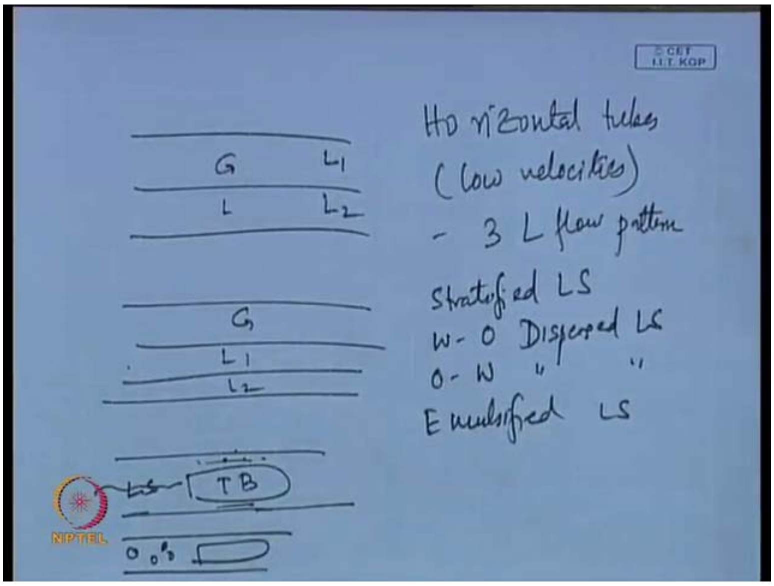
(Refer Slide Time: 36:56)



So, certain other things well the next things which I would just like I thought I will show you just to show you that how, the flow patterns evolved and how important it is for us to know the know the different flow patterns. We first found out the air water or vapor liquid it is more or less the same instead of water we tried to introduce oil we found out how it changes. We changed the property of the oil we found out how the flow pattern changes, the tendency of core annular becomes more and that is an extremely fortunate situation.

Now, in this oil water flow if we introduce a third phase say water then in that case what we get sorry we introduce the phase say air. So, now it becomes air kerosene water flow or air oil water flow, liquid liquid gas flows, for that particular situation what can we get how does the circumstances change under this condition we find that at very low flow rates horizontal pipe tendency of stratification will be there.

(Refer Slide Time: 37:59)



So, immediately what we get we will at first glance appears to us is initially we had a gas phase and a liquid phase or if it is liquid liquid we have l one l two this particular case at very low flow rates will be having g l one l two which has been shown in this particular case, but we find that whenever we increase the gas flow rate by a very small amount also there is a tendency of slugging and slug flows occur. The slug flow will be evident the photographs are not very good I believe from here you can see these are the Taylor bubbles which are there and this is the liquid slug. Here the liquid slug portion is shown much more evidently.

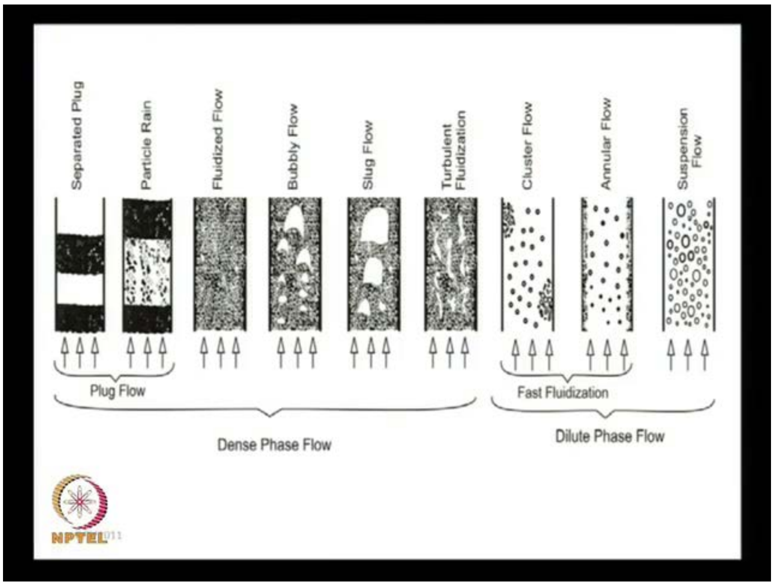
We find that usually there is a tendency of slugging and what we have usually for slightly higher air velocities for moderate air velocities also air tries to exist as Taylor bubbles. And in the liquid slug the distribution can be a number of types one is water continuous oil disperse, other is oil continuous water disperse and other is an emulsified flow pattern. Both for vertical as well as for horizontal we find these particular situations usually the range of slug flow increases here and the distribution in the liquid slug it can be oil dispersed in water, water dispersed in oil or stratified sorry or a emulsified situation.

For horizontal tubes what we have horizontal tubes for very low velocities(no voice 39:43 to 39:54) We have the three layer flow pattern as we increase the velocity we find that slug flows sets in we have something like huge slugs just like we have in gas liquid flows. And we a liquid slug in the Taylor bubble now this liquid slug it can either be stratified so, stratified liquid layer can be there stratified liquid slug it can have a droplet sort of a thing. So, we can have water in oil dispersed liquid slug, we can have oil in water dispersed liquid slug and we can have an emulsified liquid slug as well.

And interestingly in this case we also find that in the liquid film between the Taylor bubble and the pipe were also there can be some particular see its water film with oil droplets and. So,on. So, therefore, with the introduction of a third phase also we find that more or less the patterns are the same type it is usually slug flow it can be a three layer flow it can be a dispersed flow say when water is very high kerosene and air both are at low velocity, then we can have a completely dispersed flow also.

Or say kerosene is very high water and air are in very low proportions under that conditions we can have a dispersed flow pattern also, but under for a wide range we have a slug flow, but even for these known flow patterns also the distributions become slightly different by the introduction of the third phase why because if you have to analyze such flow patterns you have to consider the Taylor bubble is fine. But for the liquid slug if it is stratified then some stratified model has to some separated flow model has to be used if it is dispersed then some sort of a homogeneous model has to be used these models we will be discussing later.

(Refer Slide Time: 42:03)



Now, suppose these are some general flow patterns which we would like to discuss you should be knowing the different types of flow patterns which exist under the different conditions. So, this is about gas solid flow patterns. Now, where do we get gas solid flow patterns? Pneumatic conveying and fluidization these are the two applications where we come to encounter your gas solid sort of flows. Now, in under such conditions we get and usually the flows can broadly be classified into a dense phase and a dilute phase. You can very well understand difference between the two. Is not it dilute phase very less amount of solid larger amount of gas.

Dense phase larger amount of solid now the transition between the dense phase and the dilute phase it is usually it is defined by the choking velocity. Now, we have two types of choking velocities one is thus the different type of choking velocities that we have is one is the slugging type of choking velocity it is known as the accumulated choking and the other one it is known as the classical choking velocities. Now, within the dense flow regimes we have for the dense flow regimes you notice we have the slugging, the bubbly flow, the slug flow, the turbulent fluidization, the particle rain and the separated plug and this is almost like the plug flow pattern or the slug flow pattern in this particular case.

So, we have these types of flow for the dense phase situations now from the dense phase of we have to shift to the dilute phase the transition is usually governed by the choking velocity. Now, this transition occurs when the gas velocity is reduced at a fixed solid phase solid phase, then under that condition we find that we shift from the dilute phase to the dense phase. Is not it? And the solid loading is kept constant gradually the gas velocity is reduced. So, then we come from the we have transition from the dilute phase to the dense phase. Now, there can be two types of or we define two types of choking velocities one is the accumulated choking and the other is the classical choking velocity.

Now, accumulate choking velocity we get then the condition when the dilute flow becomes non slugging for example, from here to here when it the condition can the dilute flow becomes non slugging is called accumulated choking. And this is related to the accumulation of solid at the bottom of the pipe line. So, therefore, when it is the transition becomes or that the dilute flow becomes non slugging we have the accumulated chocking condition. And the conditions when the dilute flow becomes slugging flow from here we get a slugging flow then it is called the classical choking it is related to the formation of this gas slugs.

Now remember one thing both pneumatic conveying and fluidized systems they are designated for different tasks, but more or less they have got many similarities. For example, for both the systems we find in the dilute flow we have different phases like turbulent fluidization, fast fluidization, slugging fluidization, bubbling flow, fluidized flow. All these types of things both the systems they have and the dilute flow regimes they are characterized by suspension flow at high gas velocities and low solid loading. We have this suspension velocity we have this suspension flow we have.

Now, remember one thing although the fluidized beds as well as pneumatic conveying they have this same type of or rather they are used for different purposes more or less the same type of flow patterns they occur, but the thing is for fluidized bed we find that for pneumatic systems this particular suspension flow it is the desirable condition. We want to have suspension flow for pneumatic conveying and for fluidized aspect this particular regime occurs just as a bypass process. Then we want to empty the column when the inserted sample has a wide sized distribution only under that condition it occurs.

So, under certain depending on the application under certain situations we might want a flow regime or we might want to avoid a flow regime, but whatever exists they are more or less similar no matter what is application for which we use it. The other thing is when a white particle size distribution is where we find that the large particles they are fluidized at the lower part of the column and the fine powders they are carried over by the dilute flow regime. These are quite evident things, and when we reduce the gas velocity what happens the suspension flow it gets halted. And when the suspension flow gets halted, we find that some particle clusters they begin to they might appear.

And the flow regime which occurs after the appearance of particle clusters this is known as the fluidized flow. So, initially what happens when we reduce the gas velocity the suspension flow it gets halted particle clusters start appearing and just after this we get the fluidized flow regime or the flow regime is termed as the fluidization. The turbulent fluidized regime when do we get this turbulent fluidization regime when there is extreme particle turbulence without large discreet bubbles or balls.

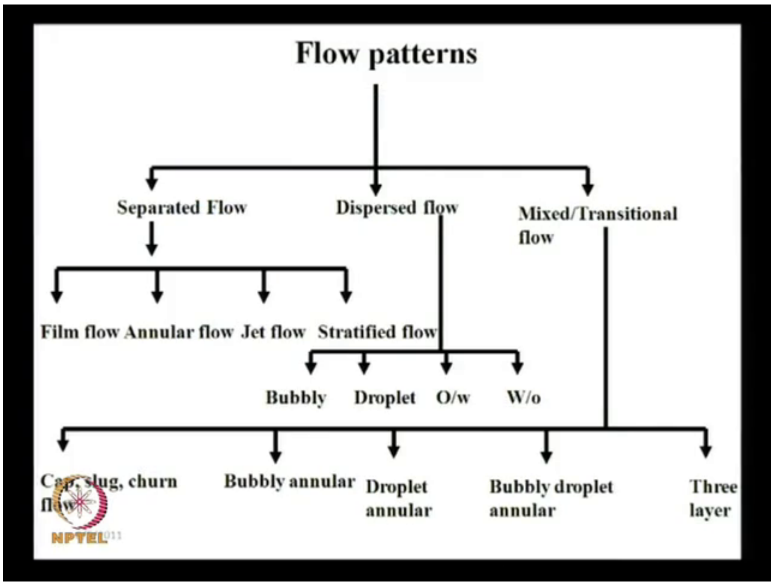
When there are large discreet bubbles or balls it is slug flow region and for turbulence fluidization regime there is extreme particle turbulence, but there are no discreet bubbles or balls. And this slugging flow region that is characterized by a particle dense phase transport it is facilitated by bubbles whose size is comparable to the pipe diameter. And the bubbling flow regime it is characterized by smaller bubbles. So, slug flows are characterized by larger bubbles. Bubbly flow regime is characterized by smaller bubbles in both the cases we transport it is facilitated by the air slugs or air plugs which are there.

Now, in pneumatic conveying we have two other flow regimes which we do not have for fluidized bed the first one is known as the plug flow regime in the plug flow regime what we have is they are characterized by particles which are transported as plugs and they are separated by air plugs. So, therefore, this particular situation we do not have for fluidization we have it for pneumatic conveying. Here we what do we find that there is a plug flow regime there are particles which are accumulated as plugs and they are separated by these particular air gaps. And sometimes what we find these particles they fall from one particular plug to the next then it forms something like the particle wing.

This occurs when the cohesion force between the particles is smaller than the particle width under this condition we get this. And worst scenario for designers for pneumatic conveying is blockage. Now, this particular flow condition which causes blockage that can also be considered as a kind of flow regime. So, these are the different flow regimes which we have for gas solid flow patterns. We will find that they are more or less similar to whatever we have studied for gas liquid flow patterns like we have bubbly flow here we have slug flow here and of course, we have a fluidized flow here which we usually there we used to call it as the dispersed flow pattern it is sort of that.

And in this particular case we find that since particles moment we have particles they are rigid a solid loading becomes important due to that we have the dense phase and dilute phase differentiation. We have something like the particle wing we have suspension flow we have fluidization and things like that.

(Refer Slide Time: 51:02)

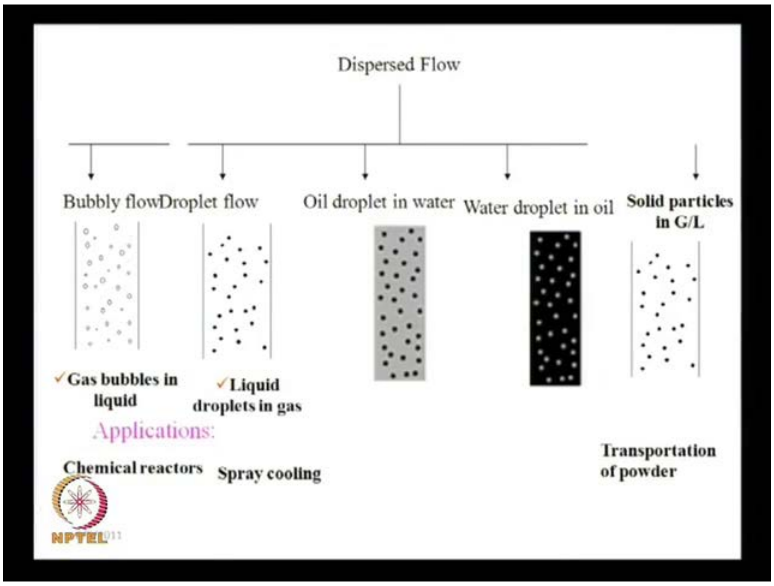


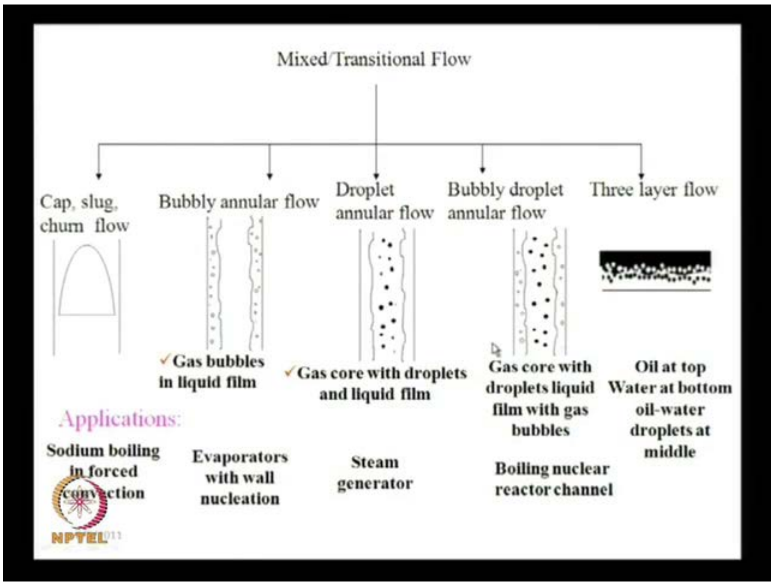
So, these were different types of flow patterns which we studied for gas liquid, liquid liquid, gas solid and such other cases. Now, among the wide range of flow patterns that we have studied till now it is quite evident that whatever we have studied. So, if we notice little critically we find that we can differentiate them into three types one has the separated flow pattern. What are the distributions which lie within the separated flow pattern it can be the stratified flow, the annular flow, film flow, jet flow, etcetera.

So, therefore, within separated flow patterns we have stratified annular and things like that the other extreme is completely mixed flows one is completely separated the other is completely mixed. Under this condition what we have we have the bubbly flow patterns, the droplet flow when it is liquid liquid or it can be mixed flow for heated cases liquid droplets in gas then we have oil in water, water in oil. All sorts of such dispersed are completely mixed flow patterns they fall within the dispersed flow pattern. And just like in single phase flow we have laminar we have turbulent and we have a transition here also we have a separated we have dispersed and a transition between the two.

And interestingly we will find that for most of the circumstances we operate in the transitional regime. Which comprises of this slug flow pattern of the three layer flow pattern and also when you study about the annular flow pattern you will find ideal annular. You hardly get it is either the droplet annular bubbly things like that where bubbles are dispersed in the oil in the liquid core or maybe droplets are dispersed in the gas core and So, on. So, therefore, ideally speaking unless you have very high phase velocities and very low phase velocities you hardly get completely separated or completely dispersed flow. Usually we encounter mixed flows and that is completely is the situation for two phase flow circumstances.

(Refer Slide Time: 53:12)





So, therefore, here I have just have such schematics just in summary the different schematics which show the dispersed flow patterns the transitional full flow patterns as well as the mixed and transitional flow patterns. So, that we can just in a nutshell you can have an idea regarding these now once you have learnt what can be the different flow distributions the next important thing is you know the distributions. But you also have to know under what conditions different distributions exists unless you can pinpoint that under this condition will be there under that condition that distribution will be there unless you know this thing it is no use learning the range of distribution which are available.

So, therefore, in the next class we will be dealing with how to represent the range of existence of the different patterns under different flow situations. And after that what I have decided is see we have talked a lot about flow patterns flow regimes etcetera. And how your conduit orientation your fluid type your pipe diameter all these things how they influence the distribution. Now, in the next class what I have decided is what I will do is we will take the simplest possible case of two phased flow. What is it a single gas bubble raising in a liquid simply a single gas or some particular air volume rising in a liquid.

And we will see that even for this particular circumstance also how the conduit characteristics how the fluid properties they affect the rise of the single elongated bubble. So, that it will give you an idea that when both the phases are moving then how complicated the situation can be. So, I conclude here more or less the more or less the flow patterns we have discussed we will be discussing the range of existence of the different flow patterns. And then we will be discussing simply the simplest case of two phase flow and how it is affected by the different circumstances and we will be continuing our discussion in this particular way thank you very much.