Multiphase Flow
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Module No. # 01
Lecture No. # 05
Definitions and Common Terminologies

Which were available and things like that. So, after learning all these things naturally the next thing which comes is to start the analysis of two phase flows, how to analyze two phase flows? Now, before we go for the analysis of two phase flows.

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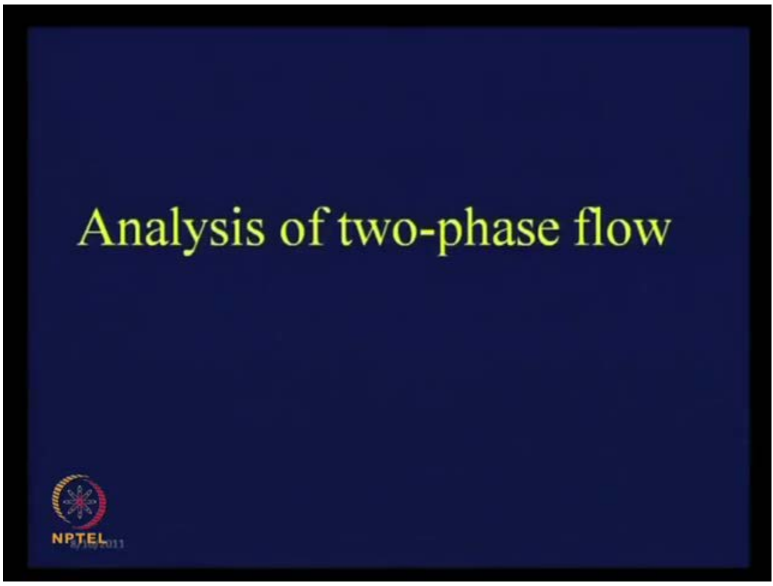

Analysis of two-phase flow

What I would like to first cover is to cover a set of nomenclatures some standard definitions and some standard, your some common terminologies those things I would like to cover. So, that because in this particular case what we find that in single phase flow situations we had one set of nomenclatures. Here, we not only have twice the number we have more than twice probably. Because we have the nomenclature say for example, mass flow rate in this particular case it is a mass flow rate of phase one mass flow rate of phase two total mass flow rate under certain circumstances, we also have the interfacial property.

So, therefore, we find that the total number of properties are more than twice and therefore, unless we define a definite set of nomenclatures and it is not just the nomenclatures which we have used in our single phase flows. We have certain things more also certain properties which were not certain parameters, which were not necessary for single phase flows, those parameters will also come into being. So, therefore, what I decided was that before we go for any sort of analysis it will be first prudent to cover up the set of notations and nomenclatures that we will be using throughout the class. So, that as we proceed you will not have confusions regarding which nomenclature to use how to use it etcetera etcetera.

Now, if any of you want to choose or want to use some other nomenclature some other notation say for example, I will be using u for velocity if you wish to use V, I do not have any problems, but in that case you have to specify that during your exams etcetera. Why I would like to use U, because I will be using specific volume for v for specific volume. So, therefore, just for and since we will be using so many properties, so many parameters. So, therefore, I would like to first specify the list of notations and nomenclatures, we would first discuss the nomenclatures which are common both for multiphase and two phase sorry single phase and two phase flow situations.

And then we will go for nomenclatures which will be used specifically for two phases or more than two phase flows or in other words two phase and multiphase flow situation. So, first we would like to specify all the nomenclatures, which are there and after that we would go for the different types of analysis which are used to be practiced. We find that more or less the analysis types will be the same, but naturally there will be slightly more involved in this particular case. Now, since we are having two phases so, the first thing to specify is, which phase is going to be one? And which phase is going to be two? That is the first thing and after that we will be specifing the other things.

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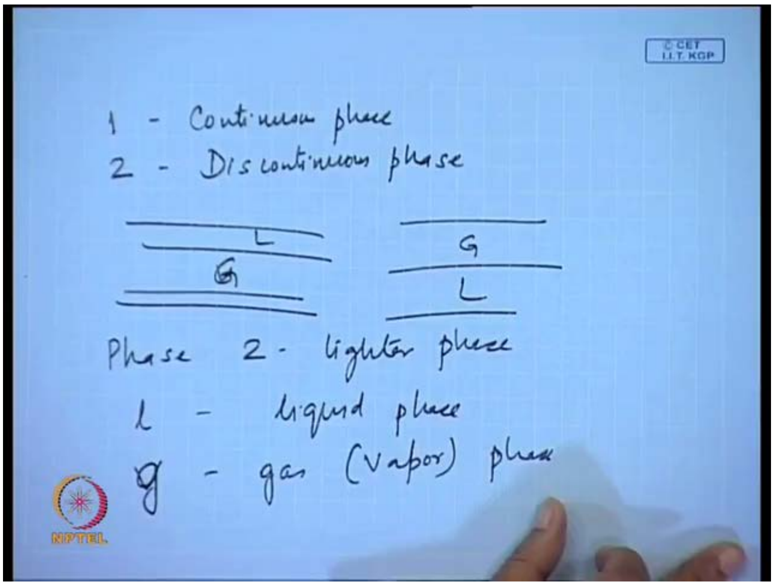

1 - Continuous phase
2 - Discontinuous phase

Phase 2 - lighter phase
l - liquid phase
g - gas (vapor) phase

Now, usually we find that; suppose we are having two phases say phase one and phase two then in that case normally we say that phase one is the continuous phase and phase two is the discontinuous phase. How do we define the continuous phase and the discontinuous phase? I had already given you the definition earlier a continuous phase is defined as one in which any two points can be joined by a line straight or curved, which passes though the same phase without crossing the interface. I would like to repeat it a continuous phase is defined as one in which any two points can be joined by a line straight or curved which passes through the same phase without crossing the interface.

And a discontinuous phase is one which cannot be joined by two parts or two points of which cannot be joined by a straight or a curved line. Now, it we can have circumstances when both phases are continuous. For example, in annular flow; if you remember I we had a vapor phase or a gas phase and a liquid phase, if we have stratified flow we find for these things both the phases are continuous. Now, when this is the situation then in that case usually we take phase two as the lighter phase.

So, therefore, this is usually the convention that for two phase flows phase two it is going to be the discontinuous phase when both phases are continuous then in that case phase two is going to be the lighter phase. Now, you will find in several books for what usually people do or the conventions are instead of one two under certain circumstances. We would also like to denote it as l v, where l refers to the liquid phase and v refers to the or rather sorry I would prefer g where g refers to the gas phase or the vapor phase.

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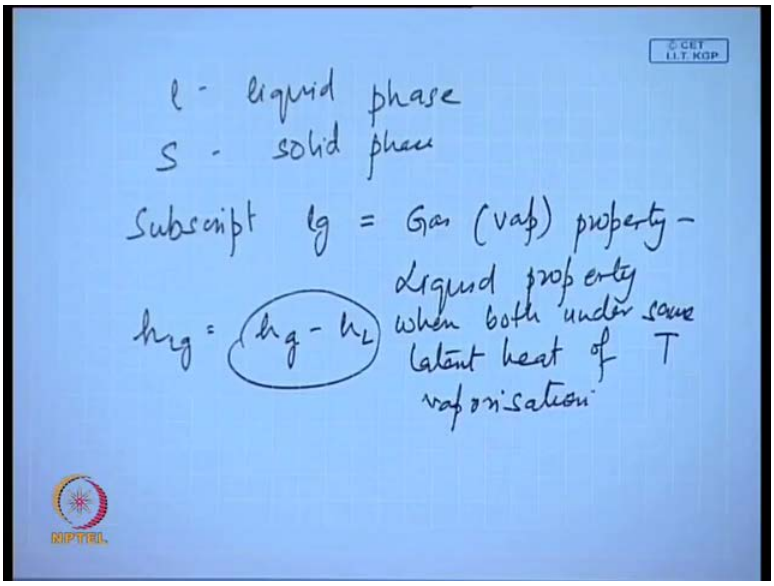

l - liquid phase

s - solid phase

Subscript lg = Gas (vap) property - Liquid property when both under same T

$h_{lg} = \boxed{h_g - h_L}$ latent heat of vaporisation

And we also have things like l g, where l refers to the liquid phase and your s refers to the solid phase. So, these conventions are also used under certain circumstances particularly when we are concerned with phase transform may be vaporization condensation etcetera. Under those circumstances instead of one two we might go for l g subscripts as well. But for our case usually I would like to prefer to use subscripts one and two according to the conventions which I have already mentioned. And also remember one more thing when we; when I use a subscript say l g, it refers to the difference between the gas and liquid properties that means, this refers to the gas or the vapor property.

You know most of the things, but then also I would like to repeat it just, so that we are cautious while using it. It is just a difference between the gas property and the liquid property for example, when we say h l g it is nothing, but it is h g minus h l. And therefore, this is nothing, but the latent heat of vaporization of this particular liquid. So, accordingly if we use as h l, it is the heat or the enthalpy content of the liquid phase h g enthalpy content of the vapor phase h l g. It is the latent heat of vaporization or the difference between the vapor phase and the liquid (( )) sorry it is the yeah the difference between the vapor property. And the liquid property when both under same temperature this is the thing which you are suppose to remember.

When both of them; are at the same specified condition usually it is the saturation both of them are in under the saturated conditions. Now, if we take up say single phase flow, what do we find? We find that was single phase flow, what is the single most important parameter, can you tell me? For single phase flow what is the single most important parameter which you measure whenever, you have to quantify single phase flow, volume flow rate or the mass flow rates that is the most important parameter. So, normally for mass flow rates still now you have used m dot and things like that.

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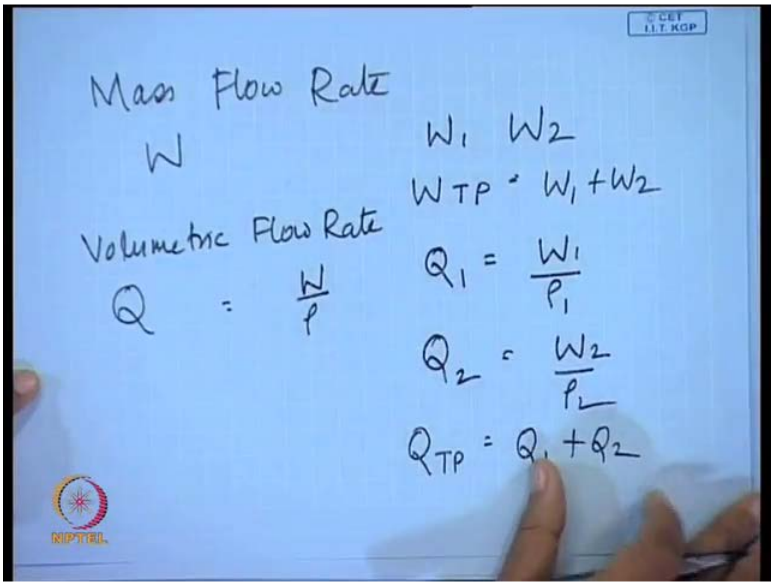

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Mass Flow Rate

W

Volumetric Flow Rate

$Q = \frac{W}{\rho}$

$W_1 \quad W_2$

$W_{TP} = W_1 + W_2$

$Q_1 = \frac{W_1}{\rho_1}$

$Q_2 = \frac{W_2}{\rho_2}$

$Q_{TP} = Q_1 + Q_2$

For this particular class I would like to use mass flow rate, this is w. So, for single phase cases if you take up this is going to be w. Accordingly here what we have we can have w 1 the mass flow rate of the of phase one which is usually for vapor liquid or gas liquid it is a liquid phase. There will be w 2 the mass flow rate of the vapor phase or the gas phase if it is a liquid vapor, if it is two liquid then this is the mass flow rate of the heavier liquid this is the mass flow rate of the lighter liquid agreed. Along with that we also have w 2 phase, you can also use w m if you wish, but I would prefer to use w 2 phase which is nothing, but equal to w 1 plus w 2 agreed from equation of continuity.

Next if we have the volume flow rate q, how do we define it? It is nothing, but w by rho is not it for two phase situations, what do we have? You are going to have a q 1 which is nothing, but w 1 by rho one we are going to have a q 2 nothing, but w 2 by rho two and you would also have a q 2 phase which is nothing, but q 1 plus q 2, is it not? Well. So, after this the next thing which we would have is certain things like say the density. We have already specified density while defining the volumetric flow rate, you can just write it down this is the mass flow rate and this one was the volumetric flow rate.

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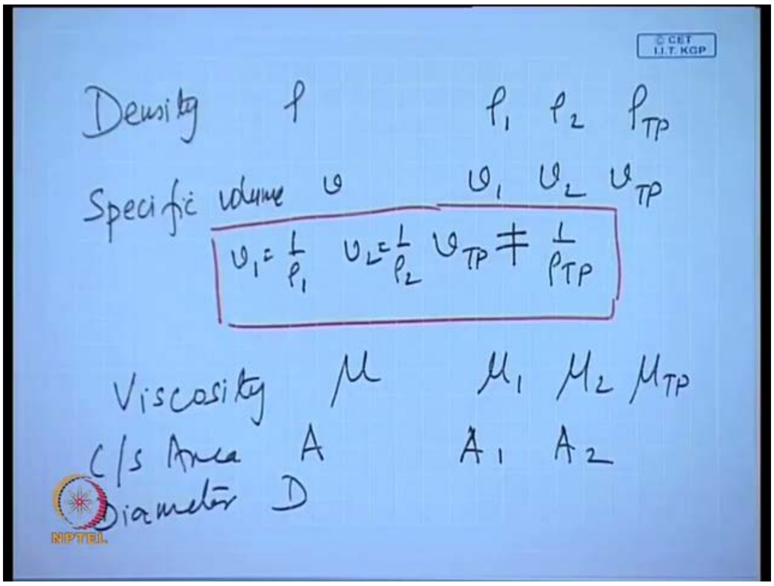

Density ρ ρ_1 ρ_2 ρ_{TP}

Specific volume v v_1 v_2 v_{TP}

$$\boxed{v_1 = \frac{1}{\rho_1} \quad v_2 = \frac{1}{\rho_2} \quad v_{TP} \neq \frac{1}{\rho_{TP}}}$$

Viscosity μ μ_1 μ_2 μ_{TP}

C/s Area A A_1 A_2

Diameter D

Next is, if we have the density in this case, it is rho here we have rho one we have rho two and we also have a mixture density rho t p. How we will be defining it, that you already know and we will be discussing it later next we have a specific volume. I have a slide for this as well. So, I will be showing you the slide after I complete this and v t p. And remember one thing which we have already discussed that v 1 equals to 1 by rho 1 v 2 equals to 1 by rho 2 and v t p is not equal to 1 by rho t p. Please remember this particular; this is something very very important, we have already discussed it I think in the introduction class, is it not?

After that certain other properties say for examples, we have viscosity in this particular case. So, viscosity you know it is simply mu, in this particular case we have mu 1 mu 2 and we have mu t p. We are considering two phases they are flowing either co-currently or counter currently up flow down flow, whatever it is through any particular pipe. So, for that particular pipe the cross sectional area of the pipe is going to be A. Now for single phase flow if you know A it is sufficient, you can just measure the diameter of the pipe and diameter is say capital d. Please try to stick to these nomenclatures, because may be the capital would be referring to one particular notation or one particular parameter may be the small later will be referring to some other particular parameter it can happen.

So, therefore, the; for single phase flow if you just measure the diameter of the pipe, the length of the pipe you find out the cross section. It is sufficient in this particular case in addition to the total cross sectional area, it will be important for you to know, how much of the cross sectional area is occupied by phase one? How much of it is occupied by phase two? So, accordingly we have A 1 here we have A 2 here. So, naturally a equals to A one plus A two, well after that after the cross sectional area we have.

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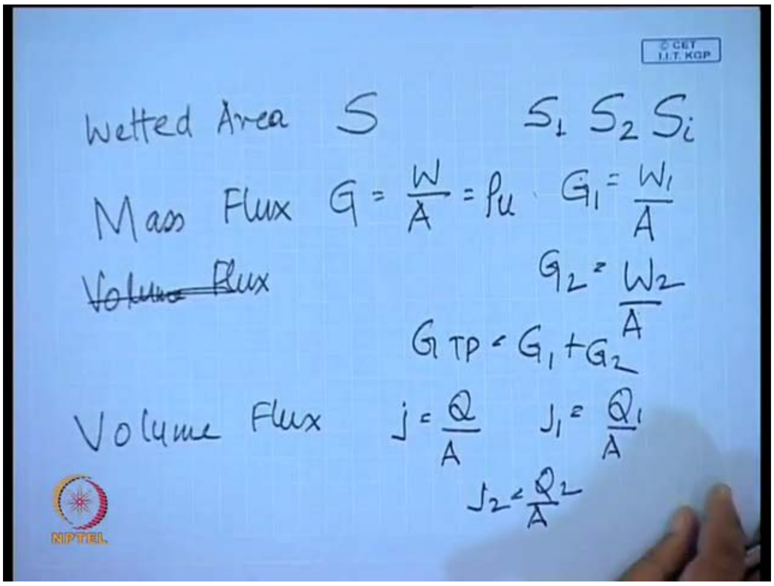

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Wetted Area S S_1 S_2 S_i

Mass Flux $G = \frac{W}{A} = \rho u$ $G_1 = \frac{W_1}{A}$

~~Volume Flux~~ $G_2 = \frac{W_2}{A}$

$G_{TP} = G_1 + G_2$

Volume Flux $j = \frac{Q}{A}$ $J_1 = \frac{Q_1}{A}$

$J_2 = \frac{Q_2}{A}$

The wetted area or the wetted perimeter as you say. Usually, you can denote it as p, but I prefer to denote it as S. In this particular case for two phase flow situations we will have an S 1, S 1 denotes the area in which phase one is in contact with the wall. We would have S 2 the area in which phase two is in contact with the wall in addition we are going to have an S I the interfacial area as well. Certain other things are also important which you did not use much for your single phase flows, but in this particular case we will be using them more or less quite frequently, one of them is the mass flux the other is going to be the volume flux.

Can you tell me, how do we define mass flux, how do we define any flux for that matter per unite area? So, mass flux means, mass flow rate per unit area the total amount of mass which is flowing per unit time per unit area. So, therefore, mass flux we denote it by capital g nothing, but w by A, what is w, in terms of velocity? If you write then this is going to be rho into u into A by A. So, therefore, g equals to rho u, is it not? This relationship is also quite important, we are going to use it quite frequently. In this particular case what do we have, we are going to have G 1 which is nothing, but, w 1 by A.

Mind it they are all per unit cross sectional area not the per unit actual area which has been occupied G 2 it is the w 2 by a and finally, we have G t p which is G 1 plus G 2, is it not? Similarly, we have something known as the volume flux, we will not use it very frequently, but we will be using it, this is defined as small j which is nothing, but volume flux means, it is volumetric flow rate per unit area, is it not? Accordingly here, we will be having Q 1 by A j 2 it is Q 2 by A.

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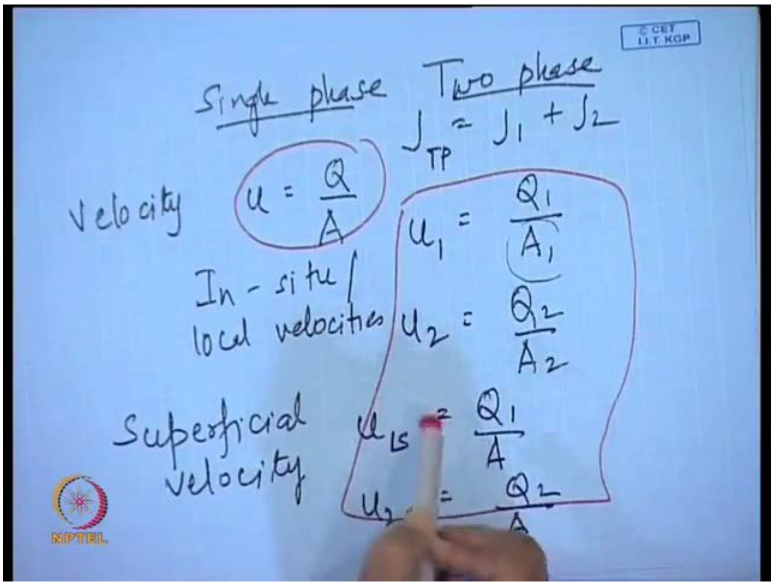

Single phase

Two phase

$J_{TP} = J_1 + J_2$

Velocity $u = \frac{Q}{A}$

In-situ / local velocities

$u_1 = \frac{Q_1}{A_1}$

$u_2 = \frac{Q_2}{A_2}$

Superficial velocity

$u_{LS} = \frac{Q_1}{A}$

$u_2 = \frac{Q_2}{A}$

And then we will be having j, which is equal to j 1 plus j 2, agreed all of you. So, this we are going to have next we come to the velocity, how do you define velocity tell me? Velocity u, it is equal to displacement point of time was in mechanical in fluid how are you define velocity, what is the velocity of flow? It is the volumetric flow rate per unit . So, therefore, it is equal to q by a agreed for single phase it is equal to q by a, what about two phase? See whatever, I am teaching for two phase the same thing is going to apply for three phase or other situations as well only the number of properties will be more here it was j equals to j 1 plus j 2 they will be having j 1 plus j 2 plus j 3.

Interfacial instead of one interface, you will be having two interfaces may be j it is j t p very true. So, therefore, here we have velocity equals to Q by A, in this particular case what we can have; see remember one thing we are having two parameters q 1 q 2 we are having total cross sectional area a. And we are having a one the actual cross sectional area occupied by phase one, is it not? So, if you talk about the actual velocity then u 1 which the velocity of u 1 this should be Q 1 by A 1, is it not? The volumetric flow rate of phase one divided by the cross sectional area occupied by phase one.

Similarly, we can have u 2 Q 2 by A 2 now remember one thing it is very difficult to measure this a one a two it is not very easy, because how much amount of as I had discussed in the last class, how much amount of cross sectional area will be occupied by phase one, how much of it will be occupied by phase two that depends upon the interfacial distribution their density, their other physical properties and so on and so forth. So, therefore, remember one thing in single phase flow velocity was a measurable parameter. We could measure, what we had to do? We had to just use any particular flow meter to find out the volumetric flow rate we knew the cross sectional area of the pipe.

So, therefore, velocity was an input parameter we always use to refer that see water is flowing at one meter per second or two meters per second. In fact, reynolds number is also defined on the basis of velocity, it is not on the basis of flow rate. But in this particular case if we find that the velocity it is no longer a measurable parameter at all. But we are very much used to mentioning the flow characteristic of any particular fluid in terms of its velocity. So, therefore, instead or apart from these local velocities which we say these local velocities u 1 and u 2 the velocities which happen inside the pipe depending upon how much of the area has been occupied. Apart from this, we also have two other definitions of velocities.

These are known as the in-situ or the local velocities, apart from this we define something known as the superficial velocity which again is a measurable parameter. So, that when we talk of the velocity say air and water are flowing we always mention as the superficial velocity of air is say one meter per second, the superficial velocity of water it is say 0.5 meters per second where we define the superficial velocities as Q 1 by A and this will be equal to Q 2 by A. So, therefore, you can very well observe see just by increasing one particular phase in the flow passage, what did we land up to? We landed up to four definitions of velocity, in place of the single definition which we had for single phase flows.

So, this will just give you an idea why I was so, very particular about mentioning all the nomenclatures and things like that even though most of the nomenclatures we have already used. Because the number of parameters is increasing, so many folds. So, unless we have a definite nomenclature after some time when we go for the analysis we will find you are completely lost in nomenclatures itself. So, you are not very confident that this particular term will be referred or rather will will u refers to velocity, small v refers to your specific volume capital v refers to the volume of the bubble. If you are not very categorical about all these things, very frequently you will find that nomenclature itself becomes a problem in the analysis of multiphase flows.

So, therefore, from this itself we can get an idea, where we find that instead of a single velocity in single phase flows, we have come across four different velocities definition of velocities in two phase flows. We have two local velocities for the two phases we have two superficial velocities. We define the superficial velocities as the velocity which the fluid would have had it flowed alone in the pipe. So, if only water or say if only phase one would have flowed alone in the pipe then the velocity which it would have was U 1 s. But now, which what velocity it has it has the velocity of u 1.

Similarly, if only phase two would have flowed alone in the pipe, the velocity which would it would have was u 2 s. Now, since fluid one is also flowing along with it it cannot occupy the entire cross sectional area. So, what velocity it has, it now has the velocity u 2. So, therefore, remember we have additional definitions of velocities in this particular case. Now, apart from this see whenever, we have any particular flow of anything say water alcohol whatever it is, first thing we would like to measure is its flow rate. Depending upon the flow meter available we either measure usually, we measure the volumetric flow rate, there are mass flow meters, which you can measure the mass flow rate as well.

And then while it is flowing through the pipe, this is the input to the pipe. Now, while it is flowing through the pipe, what we are interested? We are interested to find out the pressure drop, depending on the pressure drop we will decide which palm to use and things like that. So, the first hydrodynamic parameter which is very important is pressure drop, in this case also pressure drop should be the most important parameter. But we find usually pressure drop and pressure gradient, there are two things. Now, can you define or can you tell me, what is the pressure drop? Usually as engineers, we are interested in the pressure drop. And there is another thing which is known as the pressure gradient which is the weight of pressure change with the axial distance. So, therefore, these are the two terms, we will be defining these two terms after we define a few more terms, which are unique to two phase flow situations. Now, what are they?

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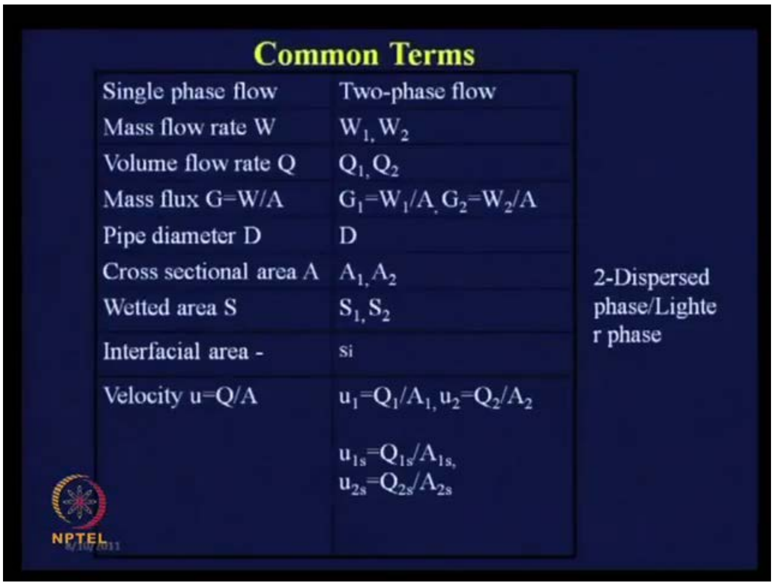

Common Terms

Single phase flow	Two-phase flow
Mass flow rate W	$W_{1,}W_2$
Volume flow rate Q	$Q_{1,}Q_2$
Mass flux G=W/A	$G_1=W_1/A_, G_2=W_2/A$
Pipe diameter D	D
Cross sectional area A	$A_{1,}A_2$
Wetted area S	$S_{1,}S_2$
Interfacial area -	si
Velocity u=Q/A	$u_1=Q_1/A_{1,}u_2=Q_2/A_2$ $u_{1s}=Q_{1s}/A_{1s,}$ $u_{2s}=Q_{2s}/A_{2s}$

2-Dispersed phase/Lighte r phase

So, till now whatever terms I have defined, if you see in this particular slide it is available, whatever terms please note this interfacial area it should be capital s I, it is wrongly denoted here as small s I, this should be capital s I in this particular case. So, these are the common terms which we have already finished defining till now. Now, apart from this, we find there are certain other important terms, which have to be defined. For example, see when it was single phase flow; what was the single most important parameter? It was the flow rate, mass flow rate or the volume flow rate.

Along with mass or volume flow rate, we need to know the volumetric composition of the two phases which are flowing in the pipe, just knowing their volume flow rates are sufficient. Because we know that moment, we introduce them in the pipe they do not flow in the volumetric flow rates in which they have been introduced. Why, because they have got different properties, they have got different densities. So, the lighter phase tends to slip past the heavier one, as a result of which the in-situ composition is different from the inlet composition, the; this I had already mentioned in the introduction part also.

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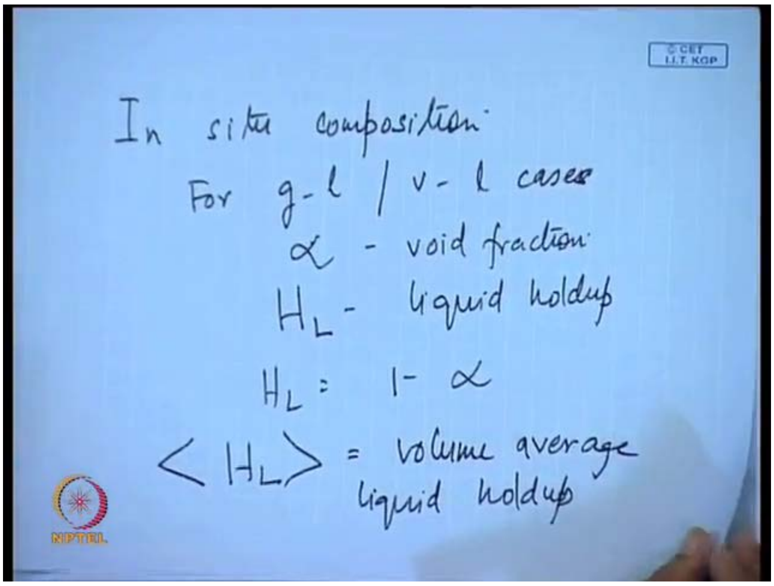

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In situ composition:

For g-l / v-l cases

α - void fraction

H_L - liquid holdup

$H_L = 1 - \alpha$

$\langle H_L \rangle$ = volume average liquid holdup

So, therefore, we need to have two particular parameters to define the composition. One of them is going to be the in-situ composition which is nothing; if we take it up as for gas liquid cases then or vapor liquid or gas liquid or vapor liquid cases. It is nothing, but the void fraction which we denote as alpha and we all; this is the void fraction. And there is one more thing, which we defined which is known as H l which is known as the liquid holder. Where H l is nothing, but it is 1 minus alpha, is it not? Very frequently, we would prefer to rather, we would prefer to use liquid hold up instead of void fraction to specify the composition of the two phases.

Why because, suppose we have a gas a liquid solid flow, we can use h l to specify the liquid hold up. If we have a liquid liquid flow we can use h l to specify the hold up or the composition or the fraction of the heavier liquid there. So, liquid hold up is a much more versatile situation and we find that usually, we have several cases where liquid is in a larger proportion as compare to the gas. Then, under that circumstances it is more accurate to measure the liquid fraction in the pipe as compare to the gas fraction. So, therefore, we find that liquid hold up is much more useful as compare to the void fraction.

All though, till now wherever you have used any sport of gas liquid mixture in absorption in all sorts of mass contacting devices and such other applications you were more acquainted with void fraction. But in two phase flow very frequently you would prefer to use the liquid hold up instead of the void fraction. So, it is usually the volume (( )) or the faction of the total volume occupied by the heavier phase. So, therefore, usually what we do for this particular cases. So, we specify it as h l and we define h l as; now remember one thing this h l or this alpha it may not be constant throughout the entire channel. It may not even remain constant with time, as well they can be fluctuations with time, there can be fluctuations with your distance as well.

So, usually we define H l as a in this particular way where this refers to the volume average liquid hold up. This is known as the volume average liquid hold up we usually define

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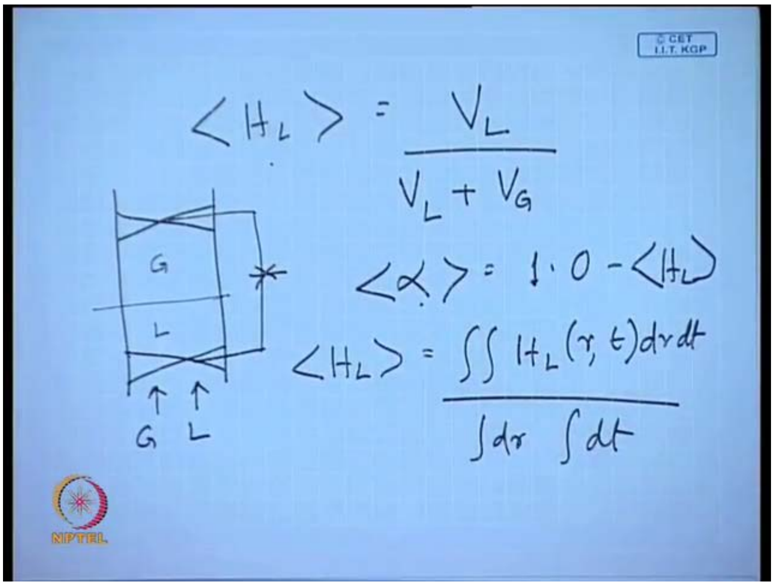

$$\langle H_L \rangle = \frac{V_L}{V_L + V_G}$$

$$\langle \alpha \rangle = 1.0 - \langle H_L \rangle$$

$$\langle H_L \rangle = \frac{\iint H_L(r,t)\,dr\,dt}{\int dr \int dt}$$

It as the fraction of the volume which is occupied by the liquid phase or in other words the volume occupied by the liquid phase divided by the total channel volume v total. So, therefore, suppose we have a channel in this particular way and suppose in here say suppose a gas and a liquid mixture is flowing. So, what we can do is suddenly at one instance, suppose we have a valve here at one particular instance, we simultaneously close both the valves. Then, in that case what happens instantaneously, the two phase mixture gets trapped here and then once they are trapped then they start separating by due to density.

And then the heavier phase if it is a liquid phase it settles down here, the gas phases at the top if we have a graph paper or something here. We can easily measure the amount of the volume which is occupied by the liquid phase. We know the total volume of that conduit or the channel cross section which has been isolated. So, therefore, accordingly we can measure the liquid hold up, in this particular case or we can measure the gas hold up or the gas voidage as the case may be. So, therefore, this is the single most important parameter as far as your two phase flow is concerned and we can measure it in this particular way and we can relate it with the gas voidage in by using this particular equation.

Now, remember one thing when the flow is not uniform it is not possible for us to measure either alpha or H l over a large length of the pipe as I have shown in this particular case. Under that circumstances, what we do? You already know we take a large number of infinitesimal measurements over say length b l and then we can perform a time average at a given location. And under such circumstances your H l when there are both temporal variations as well as variations at with actually distance. It is usually given as H l as a function of r and t d r d t divided by this is simply the normal averaging law which you already know for circular pipes we can use in this particular way.

Now, remember one thing that all though we know that they usually we assume one dimensional flows. For most of our cases we assume one dimensional flow; what is this one dimensional assumption? That; what is this one dimensional assumption, can you tell me? Exactly it means that all the properties they vary in the direction of flow and there is no variation across the flow. Usually we assume that, but the assumption is not always correct under such circumstances, we find out some sort of a correction factors in order to incorporate the three dimensional effects.

And we also assume steady state conditions under several of the applications which show the flow does not vary with time. But there can be circumstances when there temporal variations as well as variations along the length. Under such circumstances we have to use some sort of a averaging and here this is the averaging which we do now. So, remember one thing that we have measured this your H l as the volume fraction of the total volume, which is occupied by the liquid phase. Or in other words we specify the in-situ composition in terms of the volume fraction.

And this is the actual definition we would always like to define the in-situ composition in terms of the volume fraction. But remember one thing this has to be measured, this cannot be controlled by us, this cannot be an input no flow meter directly will give you the measurement of the in-situ composition, is it not? So, therefore, it may not always be possible to measure the volume average composition. Why because as I have showed to you that to measure the volume average composition, what we have to do? We have to instantaneously stop the flowing mixture. So, in industrial application, in practical situation it will not be possible to stop the flow and to take measurements of the in-situ composition.

So, therefore, under such circumstances we might have to measure the in-situ composition across a particular area or across may be across a particular cord. Accordingly we have different definitions of liquid hold up. For example, we have the volume average liquid hold up, we have the area average liquid hold up, we have the cordial average liquid hold up and we also have something like the time average liquid hold up. But before we go to these definitions I would also like to define certain other terms which we shall be using quite frequently. Now, since I have defined the in-situ volume fraction definitely there is something like the inlet volume faction and that is the input parameter which can be easily measured, is it not?

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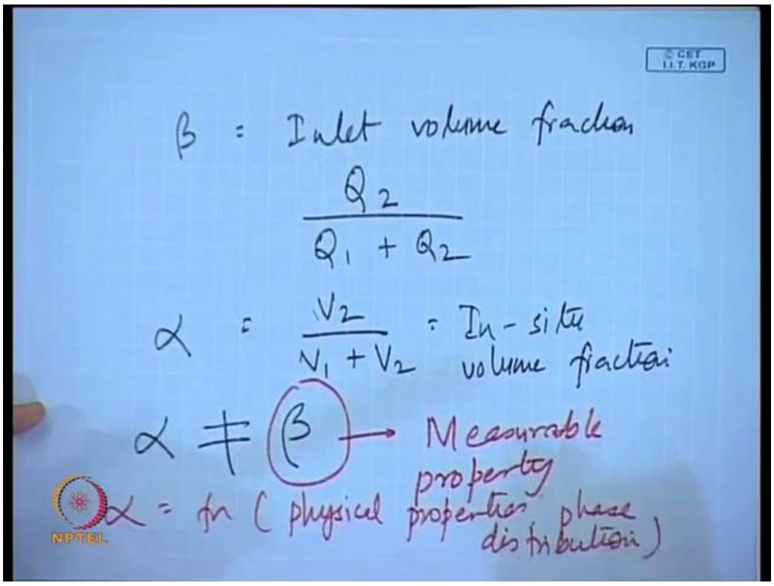

β : Inlet volume fraction

$$\frac{Q_2}{Q_1 + Q_2}$$

$$\alpha = \frac{V_2}{V_1 + V_2}$$: In-situ volume fraction

$$\alpha \neq \boxed{\beta} \rightarrow$$ Measurable property

α = fn (physical properties, phase distribution)

So, that inlet volume fraction that is usually refer to as beta, this is the inlet volume fraction which can be given as Q 2 by Q 1 plus Q 2. So, therefore, remember one thing alpha was defined in terms of the volume occupied, remember all sorts of volumes specific volume every volume is defined by v. Therefore, please do not use v for velocity which you have been doing so long, otherwise we will be creating terrible conclusion and specific volume small v all other volumes are capital v, please remember these things. So, therefore, remember one thing the inlet volume fraction is defined in terms of the volumetric flow rate.

Whereas, the in-situ volume fraction this is defined in terms of the volume occupied inside the actual cross section. And therefore, as I have already mentioned alpha is not equal to beta as a result of which all though beta; this is a measurable quantity. But since we do not have any direct correlation between alpha and beta. So, therefore, alpha has to be determined, it cannot be controlled, it depends upon the physical; it is a function of the physical properties of the fluids the density etcetera. And the physical properties as well as the phase distribution, this is the thing that you should remember.

Apart from this there is one more quality one more quantity also which I would very much like to mention this is particularly applicable for boiling and condensation sort of things. That is the mass fraction of the total flow which comprises of the vapor phase or the liquid phase. So, initially it was the volume fraction which comprised, next it was the in-situ volume fraction, next it was the inlet volume fraction usually under adiabatic conditions there is no mass transfer. And therefore, if you introduce w 1 amount of phase one w 2 amount of phase two then throughout the entire channel flow w 1 and w 2 does not change agreed.

But, when we are having some sort of heating arrangements there is boiling there is condensation the naturally there is change of phase under that condition w 1 and w 2 they are not constant. And under such circumstances it is necessary for us to define the mass fraction, which comprises of either the vapor phase or the liquid phase from thermodynamics we know that usually.

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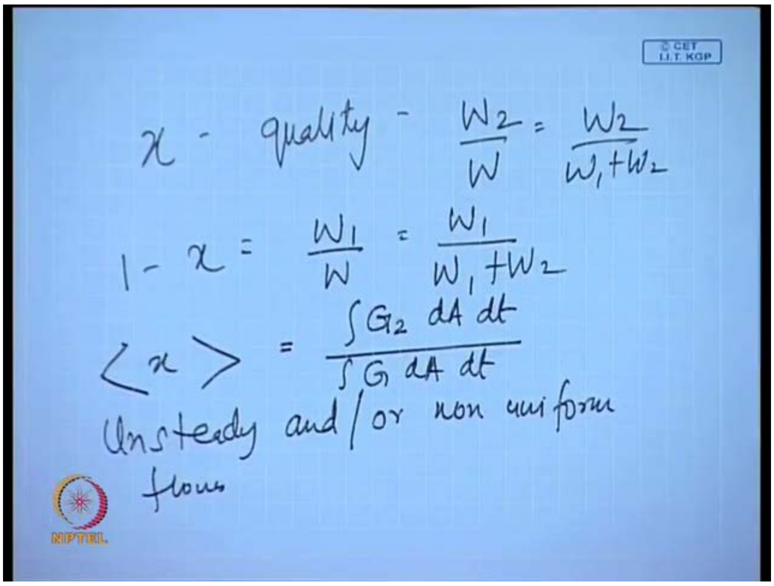

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$$x - \text{quality} - \frac{W_2}{W} = \frac{W_2}{W_1 + W_2}$$

$$1 - x = \frac{W_1}{W} = \frac{W_1}{W_1 + W_2}$$

$$\langle x \rangle = \frac{\int G_2 \, dA \, dt}{\int G \, dA \, dt}$$

Unsteady and/or non uniform flows

The mass fraction it is defined as quality x, where x is nothing, but w 2 by w, where remember two is the lighter phase or discontinuous phase it usually refers to the vapor phase or the liquid phase in this particular condition. And one minus x is naturally w 1 by w or it is w 1 by; we can write down in this particular way. So, therefore, we know that we can also write certain other equations for; and in the same way just as I have told you for the void fraction in this particular case also. Remember that there can be temporal variations, there can be variations across the flow.

So, therefore, when we are talking about quality usually we refer to the average values under normal circumstances we do not put these brackets. We assume that x refers to the average property itself, but when we have unsteady and or non uniform flows. Under such circumstances x has to be subjected to averaging properties the average has to be taken over a specified surface for a particular period of time. And this is usually refer to as integral of the mass flux G 2 d A d t divided by integral G d A d t. So, remember one thing unless it is absolutely necessary we do not put these brackets, but whenever we have unsteady or non uniform flows under that circumstances quality is also subject to averaging.

And average is taken over a specified surface for a specified period of time and it is defined in this particular form. Now, remember one thing, just as we were discussing the flow patterns for a heated tube, we had inserted pure liquid at a temperature just below the saturated temperature and as it was flowing up it reach the saturated temperature vapor started forming and then we had bubbly flow and so on and so forth. So, remember one thing this quality, this can be a input parameter because this can be obtained if we know the amount of heat which is entering the pipe, that can be easily measured. If we know the heat flux then it is very easy to find out the quality. So, therefore, unlike alpha or unlike the void fraction or the liquid hold up quality is an input parameter.

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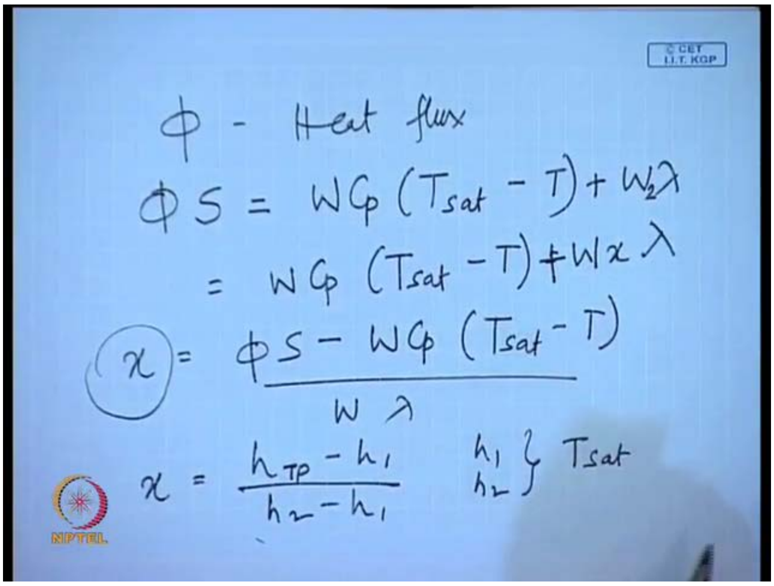

ϕ - Heat flux

$$\phi S = W C_p (T_{sat} - T) + W_2 \lambda$$

$$= W C_p (T_{sat} - T) + W x \lambda$$

$$\boxed{x} = \frac{\phi S - W C_p (T_{sat} - T)}{W \lambda}$$

$$x = \frac{h_{TP} - h_1}{h_2 - h_1} \qquad \left.\begin{matrix} h_1 \\ h_2 \end{matrix}\right\} T_{sat}$$

How to relate quality with the heat flux? Please note that heat flux I am denoting it as phi if you want you can denote it as small q as well, but since already capital q is volume flow rate. So, therefore, usually I would prefer it to mention it as heat flux phi. Now, for heated tube in that particular case we can always write down that phi into the circumferential area through which it is applied. This much amount if heat it goes into heating the liquid from; it is actually temperature to the saturated temperature and then vaporizing that amount of liquid from where; sorry it is not w into alpha, it is w 2 into alpha very sorry.

And what is this w 2 the amount of w which has vaporized, is it not? Or in other words this can be written down as w c p t saturated minus t plus sorry plus w x into lambda, yes or no. So, from there we can find out x this is nothing but equal to; do it and tell me? Phi s minus w c p, (No Audio From: 43:25 to 43:31) is it not? So, therefore, we find that we can measure the heat flux the circumferential area or the perimeter that is very well known. All these are simply properties and therefore, x it is a measurable parameter. Now, if we have liquid and vapor; any questions, any doubts you are free to ask me, any questions and any doubts you are free to clarify it from me.

So, this is the expression when we find that liquid at below saturation temperature is flowing. Now, suppose we are we have a liquid vapor mixture in equilibrium with one another. Under that circumstances say if it is steam water flow we can directly refer to the enthalpy values from the steam tables and we can find out x, is it not? These things you already know there is nothing to tell you in that case x is equal to h 2 phase minus h 1 by h 2 minus h 1.H 1 is the enthalpy of the saturated liquid, h 2 is the enthalpy of the saturated vapor, under the same conditions as the saturated liquid that means, h 1 h 2 both of them are measured at the saturated temperature T sat.

And this is the two phase enthalpy. So, remember one thing we are using small h to denote enthalpy. For; if you are doing heat transfer then we will be using this small h probably to denote the heat transfer coefficient as well. But then, according to the application you will be able to understand, we will not be doing much of that. So, I am not going to differentiate between the two all though there are text books who have differentiated. If in the later stage, we require then probably I will be going for some differentiation for the time being, I am not using heat transfer coefficients.

So, my small h refers to the enthalpy with a subscript denoting whose enthalpy it is measuring, whether it is enthalpy of phase one the enthalpy of phase two or it is the two phase enthalpy. So, therefore, the thing is whatever I wanted to emphasis is that, all though your void fraction was or your liquid hold up is not an input parameter, we cannot control it your quality x is definitely a input parameter, we can control it. Now, if we can control it, if we know that x is a measurable parameter. We would naturally like to correlate x and alpha for heated tubes, is it not? We would also like correlate the velocity and x. So, therefore, for heated tubes for unheated tubes, how to measure velocity, how to measure void fraction? Those things we can easily deal with.

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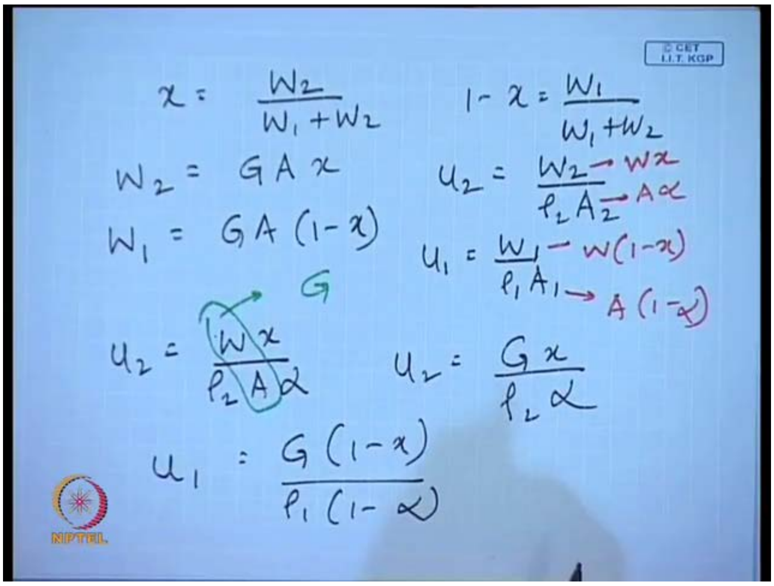

$$x = \frac{W_2}{W_1 + W_2} \qquad 1 - x = \frac{W_1}{W_1 + W_2}$$

$$W_2 = G A x \qquad u_2 = \frac{W_2 \rightarrow W x}{\rho_2 A_2 \rightarrow A \alpha}$$

$$W_1 = G A (1 - x) \qquad u_1 = \frac{W_1 \rightarrow W(1-x)}{\rho_1 A_1 \rightarrow A(1-\alpha)}$$

$$u_2 = \frac{\overset{\rightarrow G}{\cancel{W}} x}{\rho_2 \cancel{A} \alpha} \qquad u_2 = \frac{G x}{\rho_2 \alpha}$$

$$u_1 = \frac{G(1-x)}{\rho_1 (1 - \alpha}$$

For example, Let me tell you as I have already mentioned that your x equals to I have already said it is w 2 by w 1 plus w 2, 1 minus x equals to w 1 by w 1 plus w 2. So, therefore, I can write down w 2 it is nothing, but equal to your G into A this is nothing, but w into x, is it not? W 1 it is nothing, but G A into 1 minus x. Just tell me anywhere if you have any doubts, u 2 what is the velocity this is nothing, but equal to w 2 by rho 2 A 2 u 1 it is nothing, but w 1 by rho 1 A 1. So, instead of this w 2 we can substitute this w 2 as w into x, yes or no?

Same thing here we can have w into 1 minus x agreed, can we do this instead of a two what can we write can we not write it down as a into alpha, yes we can do it instead of a one can we not write down A into 1 minus alpha. So, if we make these substitutions, what do we get? We get u 2 this will be equal to w x by rho 2 A alpha. Where this particular; what is this w by A term can you tell me? This is nothing, but G. So, therefore, this term can be written down as G. So, therefore, u 2 equals to G x by rho 2 alpha, is it not? So, this shows that x is an input parameter, G you already know if you know the total mass flow rate and the total cross sectional area rho 2 is a measureable parameter.

So, if you measure alpha you can find out u 2 if you measure u 2 you can find out alpha. So, therefore, among the variables on which you have no control you can find out a relationship. Same way for u 1 you can write down this will be G into 1 minus x by rho 1 into 1 minus alpha, this can very well be written down agreed. So, therefore, what were the parameters that we defined; first we defined the volume fraction or the in-situ composition. Next we defined the inlet composition after that the quality we defined and two other very important parameters they have to be defined one of them.

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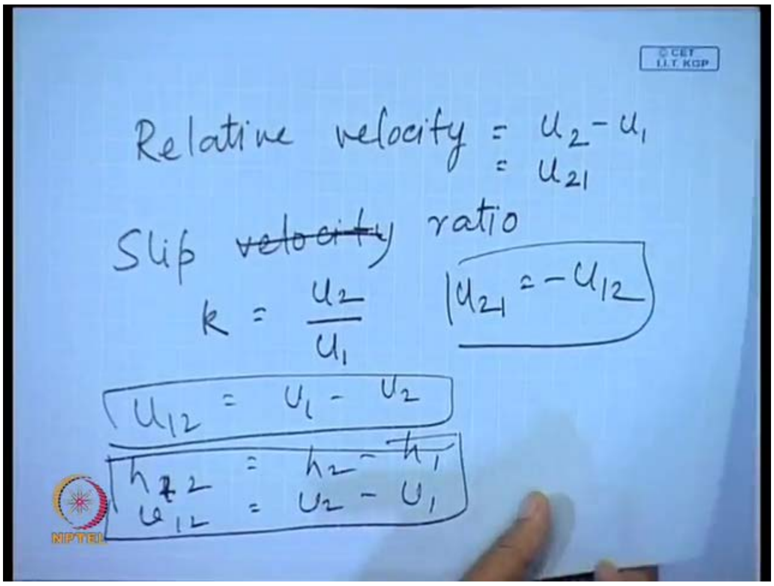

Relative velocity $= u_2 - u_1$

$= u_{21}$

Slip ~~velocity~~ ratio

$k = \frac{u_2}{u_1}$

$\boxed{u_{21} = -u_{12}}$

$\boxed{u_{12} = u_1 - u_2}$

$h_{\cancel{7}2} = h_2 - h_1$

$u_{12} = u_2 - u_1$

It is the relative velocity, since all the problems arise due to the difference in velocity. So, therefore, your relative velocity and the slip velocity, these two are very important or slip velocity or in other words this is usually known as the slip ratio, these two are very important. Slip ratio usually it is denoted as k this is equal to the ratio or rather it is the ratio of the in-situ velocity of phase two divided by the in-situ velocity of phase one, usually we know phase two is the lighter, phase phase one is the heavier phase. So, therefore, k is always greater than 1 and relative velocity you already know it is u 2 by u 1 and this is denoted as u 2 1, is it not?

So, therefore, there is one very important thing which I would like to point out at this particular juncture. Just note, when you refer to relative velocity, it is u 2 one is u 2 minus u 1, you agree. If we define it as u 1 2 this will be u 1 minus u 2. But in thermodynamics if you remember what does h 1 2 refer to h 2 minus h 1, when we say v 1 2 it is v 2 minus v 1. So, remember one thing the sign conventions in case of thermodynamics and in case of your multiphase flow is slightly different. So, therefore, the two other terms which I had wanted to define one is the relative velocity other is the slip ratio, these two are again very important. And we already know that u 2 1 equals to minus u 1 2.

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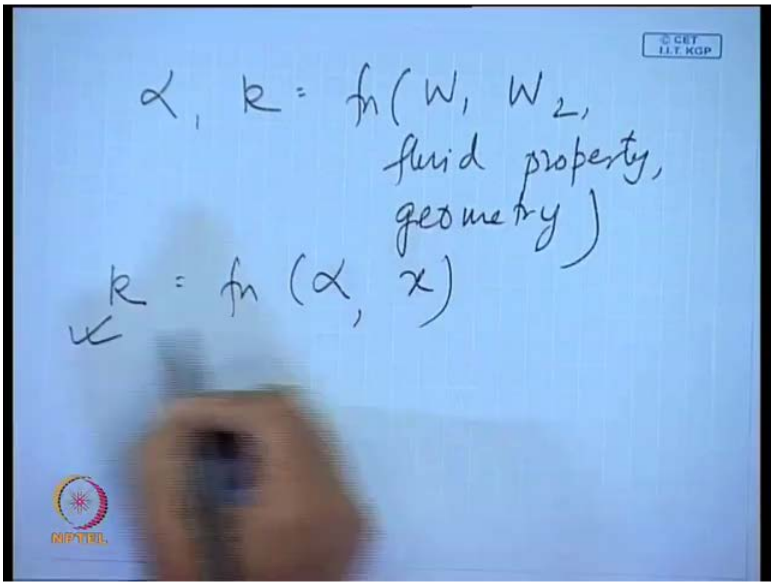

$\alpha_1\ k = fn(W_1\ W_2,$ fluid property, geometry$)$

$k = fn(\alpha, x)$

This Also you know and remember one thing, both alpha as well as the k the slip ratio they are functions of w 1 w 2 fluid property as well as conduit geometry. So, they are function of all these things. So, I would be ending up here in the next class, what we will be doing is we will be finding out a relationship between k and; say the other measurable and non measureable see k arises due to the difference in the in-situ velocity. So, k should be a function of alpha when we have phase transitions then x should also come in. So, we will try to define a relationship between k and alpha x etcetera etcetera. Based on, whatever we have done today and then we would also go to define a few other parameters which we could not define today. So, maybe we will be doing those things and we will be continuing with our nomenclature chapter tomorrow as well, Thank You very much.