Cryogenic Hydrogen Technology
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Week - 07
Lecture 34
Cryogenic Liquid Level Measurement

We are welcome to this lecture on Cryogenic Hydrogen Technology. We were talking about cryogenic hydrogen storage and in that connection, we have already talked about the different components of a storage container. We have seen that it is a double walled container and it has to have some insulation. In the previous class we have talked about multi-layer insulation and today in this lecture we will try to ah cover up something like it is also it is a part of that ah you know hydrogen storage at cryogenic condition. And ah today in this lecture we will be talking about the liquid level measurement. We have understood that it is a double walled vessel and it is made of you know metallic container.

So, we cannot see anything inside from you know looking at outside and ah, but we have to know how much liquid we are filling it is not like that it has to overflow. We have to keep something like 80 percent to 90 percent of the liquid we have to fill in, we have to leave some space on top of the liquid. So, it is ah necessary you know to have a liquid measurement liquid level measurement system. So, now if we look ah there are numerous ok not numerous, but there are so many number of you know liquid level measurement ah.

We have to ah depend on a particular or we have to select a particular type depending on our application. And ah there we will find that later on that it is ah the level of accuracy that we are looking for the cost or the sensitivity all these things will come in picture. So, let us look ah at the type of different type of ah I mean ah level gauges we have ah. So, these are the typical level gauge we you know come across there are many of them, but we will be mainly discussing about the hydrostatic ah then we will talk about the capacitance type gauge and also, we will talk about the electric resistance type ah gauge. So, you can understand that when we are talking about the hydrostatic gauge ah it it is mainly based on the difference in the density of the liquid and the vapor that property we will try to you know ah use to decide the liquid level.

And again, in terms of capacitance ah level gauge we will try to correlate it with the difference in the dielectric constant of the gaseous ah hydrogen and ah the liquid hydrogen. So, they have dissimilar dielectric constants. So, we will try to ah utilize that property and you know we will try to decide how much is the liquid level. Then we have ah another ah type which is called ah I mean all these types are giving you the continuous ah level measurement. And here the last one is the electric resistance basically we want to decide how much is the resistance of or the change in resistance in presence of liquid and in presence of the vapor and that will you know tell you ah I mean the level of the liquid.

So, ah in that connection in connection to the electric resistance ah gauge we will be trying to talk about ah superconducting ah resistance or superconducting ah where based ah you know ah level gauge. So, let us start ah one by one, ah first of all this hydrostatic gauge if we look at we will find that we have ah this container we have talked about. And there is some liquid in it ah the height of the liquid is say ah Lf and the height of the vapor ah is Lg on top of the liquid we have Lg ah height of I mean this is basically ah cross section we have taken. And that you know it is a ah I mean two dimensional thing and where we are trying to find out the liquid level how much ah height of the liquid is there. So, what we do is that ah we try to find out the ah difference in or the ah differential pressure between the top and the bottom ah level.

And so, it will be finally, comprising of the if you look at ah this part we will be ah you know determining the ah pressure difference or the delta P that is there between the ah we have a tapping point here we have a tapping point at this level. And we are trying to find out what is the delta P. So, this delta P will be comprised of ah the level of the liquid that is ah you know the liquid column. So, that is ah Lf and then you know ah it would be rhof that is the density of the liquid level multiplied by g. And then ah we will also have the vapor column which is of Lg ah rhog into g is the acceleration due to gravity.

$$\Delta p = L_f \rho_f g + L_g \rho_g g$$

$$L_f = \frac{\Delta p - L\rho_g g}{(\rho_f - \rho_g) g}$$

So, now, this ah this total length ah of the column is that is Lg plus Lf. So, we can ah find out how much is the delta P and once we know the delta P ah we can you know try to find it out like we also know what is the total length of this column or total height of this ah container. So, this is rhof into g plus this Lg will be substituted from here we can write it as L minus L f and it would be multiplied by rho g into g. So, we can in that case calculate this ah Lf from here it will come as ah this is Lf we can try to find out we will have delta P on this side and we will put minus L into rhog into g then it would be on this side we will have rhof and we will also have minus rhog and into g. So, this ah you know we can cancel it out if then there would be ah I mean delta P, but otherwise it will be ah like this delta P minus L into rhog into g divided by rhof minus rhog into g.

So, this is the ah liquid height which will be there inside this container ah we are finding out or measuring this delta P and then we know the density of the gas and density of liquid depending on the operating pressure and temperature ah I mean either of them and then you have the knowledge of this total length of this container. So, we can then find out the amount of liquid which is there. So, this is ah the hydrostatic gauge and it is I mean low cost one and often we find ah you know ah wide application for this kind of ah hydrostatic pressure gauge in cryogenics. So, ah then comes another parameter as we have said that ah we need to see how much is the sensitivity of this ah ah gauge. Basically, ah this sensitivity means how sensitive ah it this instrument is ah per unit change in the level of the liquid.

$$S_0 = \frac{d(\Delta p)}{dL_f} = (\rho_f - \rho_g)g$$

That means, if there is a small change in the liquid level whether we are going to get a large or small or you know ah what is the kind of change in the pressure that it is ah showing. So, if it is a large change we are happy because it we will say that it is very sensitive to ah change in the ah liquid level or otherwise it is ah you know insensitive. So, let us look into that. So, the sensitivity ah we will define it as say S0 is equals to ah delta P or the change in delta P ok. It is the total derivative the delta P by ah d of say the Lf.

So, for a unit change in the liquid level how much is the change in the delta P. So, if we try to calculate ah this value we will find that ah this is the expression ah we have already obtained and accordingly you know if we use this expression we will find that this becomes rhof ah into g and from here this L is the constant. So, it will not be there ah it would be rhog into ah g. So, that means, basically it is coming as rhof minus rhog into g that is what is the multiplied by the acceleration I mean ah g the acceleration due to gravity. So, this is what is the sensitivity ah it will depend on the difference between the ah liquid density and the vapor density multiplied by the ah g.

So, this is you you can understand that this is for hydrogen ah it will be something different and ah for ah you know gaseous nitrogen and liquid nitrogen if we are ah trying to ah you know put this kind of differential pressure gage. So, it will be different. So, we have to ah first of all I mean calibrate this system ah or the label with respect to this delta P. So, this is about the hydrostatic gage and you can easily ah find out what would be the ah sensitivity ah this unit of sensitivity is basically the delta P by delta Lf. So, it is Pa per unit meter.

So, if there is a small change ah in a in the liquid level how much change in level of Pa that you are in the level of ah in terms of Pa you are obtaining. So, accordingly you have to use ah sensitive ah instrument if it is of the order of some Pa ah difference then you should put ah you know ah per unit of course, a change in meter or so, ah you have to employ a good or you know sensitive ah delta P measurement unit. So, now we come to the other type as we have talked ah you know it is a capacitance gage where we are trying to take the advantage or you know the property difference or in ah dielectric property difference of the gaseous and the liquid ah level. So, this is a capacitance liquid level ah device. So, it is basically ah if we look at it is a ah double walled or say concentric ah you know ah this is this inner rod and we have another coaxial you know tube ah if we look at this is the liquid levels we have already talked about and this is the cross sectional view if we ah look at it there is an outer cylinder and there is an inner rod.

So, they are not connected with each other except you know we are putting to a wires out of this this inner rod is ah connected with the ah you know wire and this outer ah rod is also connected with the wire where we are measuring the delta C ah or same the capacitance basically I am sorry this is the capacitance we are measuring and if we are measuring this ah capacitance then we will try to let us see how we we can you know ah correlate it with the liquid level. So, we know that ah this capacitance ah you know we have said that this ah when it is in the vapor it is having a dielectric constant of epsilon g and in the liquid level ah in the liquid we have ah corresponding dielectric constant of epsilon f and ah we have said that this length is a Lg and this length is ah Lf and we will try to find out how much is the ah total capacitance ah based on this 2 length. So, now, this C will comprise of Cg plus Cf what does it mean ah Cg plus Cf that means, ah we have ah assumed that not assumed it is basically they are in parallel connection you can understand that there are 2 you know ah capacitance. So, one is as if you know between the ah this level and ah where you know this internal one and this one is connected and this is basically another ah capacitance where we have this and this is also connected to this where this is a continuous ah one. So, ah then you can understand that we have 2 you know ah capacitance say ah we can say that this is like this ah and we have another capacitance like this say.

$$C = C_f + C_g = \frac{2\pi L_f \epsilon_f \epsilon_o}{\ln(\frac{D_o}{D_i})} + \frac{2\pi L_g \epsilon_g \epsilon_o}{\ln(\frac{D_o}{D_i})}$$

So, one is the C ah g and the other one is Cf. So, when these 2 capacitances are you know connected in parallel you know that the equivalent capacitance is basically ah ah ok. So, this is not their ah this is what is C. So, we can calculate that to this total capacitance Cg and Cf and let us see how we can ah finally, you know ah correlate it with the ah length of the liquid. So, this total capacitance C can be ah you know written as 2 parts where one part is basically we can say that 2 pi then for the Cg we have Lg epsilon ah g into epsilon 0 where epsilon 0 is the permittivity of the free space then we have ah we have not written it here.

$$L_f = \frac{C\ln\left(\frac{D_o}{D_i}\right) - 2\pi L \epsilon_g \epsilon_o}{2\pi(\epsilon_f - \epsilon_g)\epsilon_o}$$

So, this is ln we have this ah external diameter as D0 and this internal rod that is that diameter if it is Di we will have D0 by Di. So, this is 2 pi Lg epsilon 0 ah into epsilon g ah multiplied by ah I mean divided by ln D0 by Di. Similarly, you will have another expression for 2 pi Lf epsilon f into epsilon 0 divided by ln D0 by Di basically these are the 2 you know this denominator is the ah same. So, we can combine them together ah like this ah ln D0 by Di ah in the denominator and then we have ah 2 pi ah L g we will change as we have done it earlier because we know that the total length L is equals to Lg plus Lf. So, we can you know change it to this value epsilon g epsilon 0 plus 2 pi Lf epsilon f epsilon 0 and this is what is there in the ah expression.

$$S_O = \frac{d(C)}{dL_f} = \frac{2\pi(\epsilon_f - \epsilon_g)\epsilon_o}{\ln\left(\frac{D_o}{D_i}\right)}$$

So, this is the total capacitance ah and the relation with the the f Lf and L0. So, we can try to simplify this to find out the Lf in that case what we will have is C into ln D0 by Di and ah then it would be 2 pi ah L epsilon g epsilon 0 then we have the other terms containing Lf epsilon 0 and ah so, plus we have 2 pi Lf is common epsilon 0 is also common. So, we can take it as Lf minus ah I am sorry Lf is there. So, epsilon f minus epsilon g. So, we can ah now rearrange it to ah like this C ln D0 by Di then ah minus 2 pi L epsilon g epsilon 0 divided by 2 pi epsilon 0 and epsilon f minus epsilon g that is equals to Lf.

So, this is the value of the liquid level ah and it is changing with this capacitance value C ah with ah you know this is the thing which is constant this L is also constant Lg epsilon g and epsilon f both are constant ah I mean of course, it will change depending on the ah say the pressure ah or you know the liquid we are using. So, we have here ah that it is ah hydrogen. So, for hydrogen epsilon g and epsilon f will be known. So, if we are measuring the capacitance that will tell us what is the level of the liquid that is there. So, again in this case ah we can try to find out what is the sensitivity of this instrument and in that case what we have to do is ah we have to calculate ah basically ah the parameter that we are trying to find out is the sensitivity.

So, it would be ah the change in the capacitance per unit change in the liquid level. So, that is what is the sensitivity. So, this is sensitivity S0 equals to d C by d Lf and ah we have to then you know ah put this equation where we have everything in terms of the Lf because this was in terms of Lg and Lf, but here this expression if we look at we have everything you know written in terms of the Lf. So, what we have common is ah 2 pi epsilon 0 by ln

D0 by Di that is what is common and what is there inside this L is a constant one. So, this is constant you know it will move out.

So, what we will have you know left with is epsilon f minus epsilon g. So, here also you can see that ah it depends on the I mean ah of course, the ratio of D0 by Di not only that, but that is there in the denominator and ah in the numerator ah the primary thing that is ah there is a epsilon f minus epsilon g that is the difference between the dielectric constant of the ah you know gas and the the liquid. So, this is epsilon f is the liquid ah level and epsilon g is that of the ah gaseous state. So, again ah this is another I mean capacitance ah level liquid level gauge which is often used in ah cryogenic application ah and this gives fairly good amount of accuracy in terms of ah ah the liquid level. Then ah we ah are also going to talk about another ah liquid level gauge that we have said that ah it is a electric resistance ah gauge ah where we will find that we are ah putting this ah ah resistance a continuous resistance ah we have a continuous resistance and ah we are basically trying to find out ah what is the resistance of this wire because we know that the portion ah of the resistance which is there inside this ah liquid that will have some kind of ah resistance on the other side which is there exposed to the ah ambient I mean not ambient this is the vapor space that is having a different ah ah heat transfer ah.

There are 2 way of determining it ah if we put a small amount of current through it we will find that ah you know and we also try to ah measure the voltage. So, basically it is ah the ah 2 current and 2 voltage leads will be there say small amount of current will be flowing through it and it will slightly heat it up ah this part where you know this is the dissipation of that heat that is taking place in the liquid and the you know dissipation of ah that heat in the vapor ah that is quite different. So, accordingly we will find that the resistance of this wire ah is changing and ah that can also be correlated with the liquid level. Now, ah that is about an ah ordinary electric ah resistance, but ah often ah you know for ah I mean ah for cryogenic applications ah particularly for hydrogen application also we put ah what is called ah superconducting wire. Superconducting ah wire is basically ah this is a type of ah you know ah material which shows almost negligible or zero resistance ah you know below a particular temperature and ah ah below a particular ah what is called temperature magnetic field.

So, these superconducting wires are such that if it is dipped below a particular critical temperature we call it and if it is below ah say a particular temperature it will not have any supercond I mean any electrical resistance, but if it is not ah or if it is if it is above that critical temperature ah in that case it will be behaving as a normal resistance. So, imagine that this electrical resistance is ah basically a superconducting wire where we will have ah both ah I mean a part of it when it is dipped in ah liquid. So, that is in the superconducting state and it will not have any ah electrical resistance. So, the electrical resistance will be because of that part which is exposed to the vapour part. So, ah, but as it as as we have said earlier that we part ah pass a very small amount of current and we try to see how much is the resistance of this total wire and if we find out that you know this resistance is ah if it is completely dipped in liquid we will find that every there is almost a negligible resistance that is the resistance of that connecting wire, but the superconducting wire will have ah completely if it is dipped in liquid it will show 0 resistance.

But if a portion of this wire is in the vapour state or exposed to the vapour ah it is above the critical temperature and in that case ah it will be ah basically ah normal it will be behaving like a normal conductor and there would be finite ah resistance and that measuring that resistance we have to basically ah calibrate this ah system and we can try to ah or I mean relate it with with the liquid level. So, that is how this electric resistance ah gauge will be ah you know used to determine the ah liquid level in a cryogenic tank. So, other than that there are ah thermodynamic gauges where we ah you know put basically we have a double walled vessel where we try to ah just I will talk ah in terms of qualitatively where we put us in a small ah tube or ah micro tube of known volume and there would be a large bigger volume and with that one we will connect ah gauge and this cross sectional area of this micro tube and ah this ah you know this volume if it is known. So, basically it will be a constant volume ah ah gauge which will be dipped in ah liquid. So, if a portion of that ah part is in ah contact with the liquid and the rest of it is ah you know in terms of the in it is in contact with the vapour partially ah with the ah vapour on top of the liquid and the rest of the portion which is there ah this particularly this large volume ah which is connected to the ambient condition this this whole volume if you ah you know ah is constant.

So, m0 is basically ah the total mass which is there inside it will be comprising of this portion say which is in contact to mf and then we have some portion of it is which is there at mg this is at some average temperature vapour space temperature Tg prime and the rest of it is ah ah you know outside this is ah say we call it ah 0 ah not let us not put it as 0 this is or this is say total this V0 is m0 mass. So, this total mass now you can you know ah put it in terms of ah PV equals to nRT or you can also use PV equals to ZnRT and from there you can find out the liquid level. So, that thermodynamic gauge is also ah you know often used for the ah for measuring the ah vapour ah sorry the liquid level in a cryogenic tank. So, that is about ah in a nutshell about the ah level gauges and let us try to summarize it. So, these are the I mean ah references you can refer to Barron's and Thomas Flynn and in conclusion we can say that ok sensitivity of this liquid level gauges ah are ah particularly we have talked about the capacitance type and the hydrostatic type.

So, in the hydrostatic type we find that the density difference is ah determining the sensitivity of the ah instrument and for the ah I mean sorry the capacitance type ah gauge we have the dielectric constant of the liquid and the vapour state is determining the sensitivity of the instrument. Similarly, in case of the um I mean the superconducting level gauge or the electric resistance gauge ah it is the difference between the ah resistances in the liquid and the vapour condition that is what is the determining the sensitivity. So, thank you for your attention.