Cryogenic Hydrogen Technology
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Week - 08
Lecture 40
Hydrogen Safety

Welcome to this NPTEL course on Cryogenic Hydrogen Technology. So, we have almost come to an end. Now, in this lecture we will be talking about the safety. Particularly ah this is though it is hydrogen safety ah we will be talking initially on two topics ah particularly if you will the the broad concept is hydrogen safety. And in that aspect, we will be mainly talking about the cryogenic fluid handling and also in particular we will be talking about the hydrogen safety. So, why it is cryogenic fluid handling? It is because ah we know that we have talked about this cryogenic hydrogen technology.

And a major part of this discussion was related to the cryogenic hydrogen where ah this hydrogen we have seen that it will be existing in cryogenic condition. So, in general ah it is not like that it will be always in the cryogenic condition. So, the I mean a part of it is its production say when it is taking place around 300 Kelvin or around room temperature to ah I mean liquefaction of it or its use or storage in particularly cryogenic condition if we look at ah it covers the entire ah temperature domain. So, one of it is you know cryogenic ah fluid ah.

So, we need to know specifically about the cryogenic fluid handling. So, the if we ah look into the I mean cryogenic properties. So, just let us try to recapitulate ah some of the numbers we have seen that its normal boiling point is 20.3 K and critical temperature critical temperature is 33, critical pressure is 13 bar and ah triple point around 13.9 K, triple point pressure is 7.2 K and the density of hydrogen it is 0.08 kg per meter cube. So, that means, it is lighter than the air. So, in the gaseous condition this hydrogen will be lighter in air lighter than air, but on the contrary if you look at this liquid hydrogen vapor. So, nearly around 23 or 20 K.

So, that ah liquid nitrogen or saturated vapor if we look at that is heavier than the air. So, we have to keep it in mind that ah when any case of in case of any accidental release definitely initially ah particularly if it is you know ah released in the form of liquid ah that liquid I mean will be trying to remain in I mean at the ground level, but immediately it will pick up the heat and it will try to escape you know, but being the being lighter than air. So, it will always have a tendency to fly towards the roof and ah we will while talking about the I mean the safety aspects we will ah I mean one of the safety aspects of particularly for the cryogenic fluids we will see that it should have ah I mean ah ah well ventilated ah room ah for any cryogenic application. So, ah in a confinement if any gas is getting released or particularly any cryogenic fluid is getting released ah it can create some problem ah we will look into that ah later on. So, we have to keep it in mind that ah this density of ah liquid hydrogen vapor or saturated vapor that is denser, but when it is in the gaseous condition it is quite you know ah ah I mean ah lighter than the air.

So, it will have a tendency to move upward and it is in terms of its buoyancy if we look at it is the I mean lightest element and it will have the maximum buoyancy ah. So, it will try to fly off immediately when it is released. So, these are the ah hydrogen properties. So, we can understand very well that if it is in the liquid condition ah it will be at low temperature in the cryogenic condition. And as such ah for cryogenic fluid we have ah certain you know ah safety precautions.

So, that we will talk in general at the beginning then we will go ah you know specifically for hydrogen what kind of ah safety rules that we should take into ah consideration. So, any kind of cryogenic fluid handling ah the hazards are associated ah in I mean ah with the fluid itself say if it is the cryogen that cryogen may be a fuel it may be oxidizer it may be some other kind of ah inert you know liquid. So, ah, but ah what happens ah by itself it will have certain kind of ah ah you know problem or the safety rules, but when we are storing it in a particular ah container ah if if we try to confine it within a small or large volume we will find that the material properties ah are again playing an important role in the safety aspect. So, there I mean basically both this fluid as well as the material and the fluid interaction that is very important. And as such ah I mean the hazards will enhance with the volume of the liquid.

So, if we are storing or handling with a small amount of liquid definitely the ah I mean the relatively we can say that the hazards are less, but if we are handling a large amount of ah liquid ah then you know the it may cause a larger ah problem or associate the hazards will be or the safety aspect has to be you have to be very careful about the safety aspects. So, now, let us start with the fluid properties of the cryogen then we will slowly move into the ah system property or material properties and look into specifically for hydrogen what are the safety ah you know aspect that we have to consider. So, now, if we look at if it is a cryogen it is normal boiling point is ah less than the ambient condition ah it is normally you know ah liquid ah below 123 Kelvin. So, wherever we store it is a I mean it has to be well insulated, but even then there would be some amount whatever be small there would be some finite amount of heat that is going to get in and if it is in a confinement at that means, you know we can think of ah storing this cryogen in a open system that also we have talked about or we can think of you know storing it in a confinement or closed tank.

So, some of the ah you know cryogens like nitrogen we can think of ah keeping it in the open condition.

So, if it is getting released to atmosphere we do not mind or even for oxygen also you know if it is getting though we try to you know ah confine it within a small ah you know or we do not want to waste it. So, ah, but for hydrogen definitely we do not want ah you know to release it in atmosphere because ah that is the fuel and if it mix with the air or oxygen ah it can make a combustible mixture. So, ah that means, at any time this heat leakage to this cryogenics ah storage tank particularly if it is a confined or closed tank then ah there is a pressure rise in the system is inevitable. So, up to a certain pressure level it will be able to withstand afterwards we have to ah release ah or you know we have to ah make an arrangement. So, that this safety relief valve will be activated to release that excess pressure.

So, any time you are designing ah storage tank it has to be designed for a particular ah I mean internal pressure. So, and there would be a design pressure of course, depending on the working pressure. So, if it is exceeding that limit a particular set ah I mean preset value the safety relief valve will be released to you know will be open to release the excess pressure at any time you know it should not be over pressured and or it the I mean ah pressurized unnecessarily beyond a certain limit. So, that there is no rupture is taking place ok. And the amount of pressurization or the time it will take to ah reach that kind of you know pressurization limit ah will depend on the ah fill level.

So, whether it is come I mean the filled up to you say 80 percent ah. So, you know already we have discussed about that ah on top of this liquid we always keep some empty space. So, that is what is called the yellow space and ah I mean if it is getting depleted ah that means, with the withdrawal or etcetera and if we are filling it say ah you know up to 50 percent or so, after we or taking out some of the liquid then ah and then if we left it just like that you will find that the pressurization is taking place and that pressurization ah will be ah I mean time taken to reach to that bursting pressure will be different than in a situation if it is filled to 80 percent level or so. So, like that ah I mean we need to ah always keep a provision of the overpressure I mean pressure will evolve particularly if it is a closed tank. Now, in case of ah you know there is another ah important aspect of this kind of cryogen is that ah if this liquid is evaporating and it is ah you know converted into vapor at room temperature or it is coming to the gaseous condition at room temperature. So, this ah volume of the gaseous cryogen or gaseous ah say this gas from a particular cryogen ah and the volume of the liquid or the cryogen volume. So, it is quite I mean large. So, about it it attaches from 450 to 850 ah so that means, unit volume of cryogen will be ah vaporized if vaporized to room temperature it will be coming to about say 850 times. So, that occupies a very large volume and if you can understand that if this accidental release of this cryogen is taking place ah in a confinement it will immediately ah you know in a closed room it will be confined with ah this cryogen. So, and if it is an inert gas like nitrogen or you know ah then it will be there will be a problem of like ah if it is nitrogen or argon, liquid argon it is getting evaporated in a closed room there will be a problem of asphyxiation.

And ah then ah if it is ah say oxygen getting released to an ah I mean this kind of closed room or if it is say hydrogen getting released ah then it will be ah creating a problem in terms of the combustion or in terms of the fuel. So, hydrogen is a fuel this O2 is ah ah basically oxidizer. So, if it is getting released ah anything that comes in ah ah because of the accidental release of this O2 you can understand that everything is ah basically a fuel in presence of this oxidizer. But later on, we will see that it is not only the oxygen and I mean fuel oxidizer that is the only thing that will be needed. So, we will look into that part later on.

So, ah you can understand that ah one of the safety ah part that has to be followed for any kind of cryogenic experimentation it should be an well ventilated room. Now, if we ah look into this ah say we will give you a practical ah example of say ah handling of cryogen for example, say if we are transferring the liquid from one point to the other we have already talked about the storage of it and you know the release of this cryogen. But if we are trying to say ah you know transfer the liquid from one point to the other. So, here you will find that the operator will be ah asked you know to say the first of all it has to be ah what is called say this ah this is how this liquid is coming from here to here and ah once this transfer is over. So, first of all this valve should be ah closed.

Once this valve is closed this liquid whatever there in this you know line should come out or it should we should do wait ah you know till this liquid which is confined in this line has to ah evaporate and then only we are supposed to you know close this valve. But ah you know ah it is ah always there is a chance of error and if it is you know so happens that ah by chance if we are closing both the valves and ah this liquid is getting entrapped in this location. So, there is ah every possibility that this ah pipeline will be getting damaged because of over pressure and you know the liquid is getting evaporated, entrapped liquid anywhere if there is a chance you know you should avoid to avoid any kind of damage you should put ah separately valve. Similarly, if we look at this ah you know storage tank and if you are using another you know ah small tank inside this ah where you know some other liquid for example, this is say liquid nitrogen in a bath and if you are using some other you know experimentation for which some other liquid will be you know confined to this we should ah preferably use a safety I mean if it is in a of course, a closed condition then you should have a ah relief safety relief valve associated with that tank equally. So, like that wherever ah there is a provision or there is a possibility of entrapment of the cryogen we should take ah the safety ah aspects of safety release accident I mean adequate release in time to avoid over pressurization of the tanks.

So, this is the these are the general aspects I mean for any kind of cryogenic fluid handling ah you are supposed to follow this. So, general safety precautions are that ah we have to avoid ah direct physical contact of the cryogen or cold vapor like you know we do not put our fingers into a boiling water boiled water or you know ah which is ah or I mean water at 100 degree centigrade, but similarly we should avoid this cryogens equally we should treat it like that we should not I mean avoid ah in physical contact of this this cryogenic fluid because it will ah I mean create ah this ah I mean almost similar kind of damage if not even severe then this ah hot water. So, we should not even I mean we should take adequate precautions to while handling the cryogenic fluid ah should use gloves and you know protective ah ah glasses etcetera that we will talk about later on. So, avoid entry to confinement or tank or pipeline ah particularly if it is a large ah you know ah ah storage divar or storage tank and if it has been purged or if it was storing nitrogen or argon ah kind of stuff ah one should avoid going inside that tank ah you know without precautions because it may have a kind of ah I mean environment inert environment that may cause you know as fixation.

So, and then you know this unavoidable release of air into cryogenic system. So, it should be avoided because this ah I mean atmospheric air will have moisture CO2 etcetera and in case of you know cryogenic liquid if it is coming in contact there is a possibility that it will get condensed ok. So, ah and in case of this low hydrogen you say for hydrogen particularly it is density is very low. So, if you are storing the liquid in a particular container I mean if it is designed for storing liquid hydrogen for example, and if we are ah you know typically all the hydrogen I mean ah all the cryogenic containers look alike, but often these cryogenic containers will have a neck support. That means, ah they are designed ah this is a kind of neck support what I mean is that ah this is the internal container and the other outer vessel is supported with the help of this neck. And if it is designed for say liquid hydrogen ah and if we thought of ok using it for some heavier ah cryogenic like nitrogen and so, ah it should be avoided because if it is designated for liquid ah hydrogen we should use it for liquid hydrogen. Because this is a much you know lighter in weight compared to any other ah cryogen.

So, if it is designated for liquid hydrogen we should use it for liquid hydrogen only not for any other gases if it is particularly ah neck supported. If it is for other support or you know many a time if this container which are designed for ah say ah side supported or this supports will be you know particularly for cryogenic fluid like ah hydrogen this support system has to be ah very you know ah small contact ah area would be there. So, that you know the evaporation losses are less. So, ah it always it may have a risk of you know storing some other cryogen designated for the other type of you know cryogens. Find so, ah I mean avoid as I told you earlier the release of ah cryogen in a confinement and ensure that it is adequately adequate ventilation is there and then cool down of this ah cryogenic line or equipment ah it may ah always ah have a possibility of generating the thermal stress.

So, that has to be you know taken care adequately while designing the system otherwise thermal stresses may cause ah you know damage to the system. So, we have to either put some kind of below or we have to some ah you know provide a kind of U bent U type bent has to be provided in the line. So, that ah these thermal stresses are taken into account. So, ah sometime this is again another big problem you know particularly while transferring the ah hydrogen or liquid helium for example, that can you know ah I mean create a kind of ah hydro oxygen enrichment and that oxygen enrichment imagine ah somewhere where this air condensation is taking place where you know hydrogen is getting transferred and because of ah you know inadequate ah what is called vaporization of the liquid say if if it is you know ah coming at very low temperature and giving rise to air condensation. So, that condensed air if it is falling on any system where say for example, if it is a condensed air is falling on an outer shell which is made out of ah I mean ah what is called carbon steel they may you know get damaged because of that condensed air ok or liquid air.

So, we have to be careful about this ah O_2 enrichment that is ah taking place ah due to condensed air condensation. So, again ah in terms of this ah cryogens while using cryogen you should be ah you know using the protective clothing and ah safety glasses full face shields ah and loosely fitting gloves. So, these are the ah I mean precautions one should take ah while ah taking ah I mean using the cryogen. Find some let us get into the ah specifically in terms of the liquid hydrogen we should be ah careful because almost all the gases except helium ah you know it will condense ah this if it is in liquid nitrogen contact all the gases except helium will be getting condensed. So, in case of ah you know of while filling any ah liquid hydrogen ah in a tank or so or in a pipe for example, we first of all you know purge it with the gaseous nitrogen and once we in to remove the air because if it is air is present in the system that is always ah you know it it will create a kind of ah blockage ah if it is coming in contact to the liquid hydrogen not only it will create ah ah blockage of by condensing say liquid say this nitrogen or oxygen or say ah the moisture or CO_2 etcetera present in air, but ah it will it may ah form a combustible mixture with the oxygen present in air.

So, ah first of all we should get rid of this air from the system using gaseous nitrogen and once we purge it with nitrogen we should you know ah purge finally, with the gaseous nitrogen and subsequently ah or dry gas we will be ah putting in then finally, we can you know ah fill in with the liquid hydrogen and so on. And preferably ah not it may not always be possible, but ah we should you know ah put this plant or say this ah l into system or say equipment at a positive ah pressure. So, why this positive pressure ah it is preferably if it is in a positive pressure then the you know ah ah leakage of air from outside to inside that possibility is reduced and if there is any kind of you know release that will be taking place or if it is a you know any very small amount of leakage that is there. So, the that will you know cause the leakage from inside to outside not from the other way. So, you can understand that ah that release of you know accidental release of this hydrogen from inside to outside is also not good. So, we should have a leak proof system. So, high degree of leak tightness must be ensured fine.

So, now let us look into this ah fire triangle or basically as we are talking about that ah this hydrogen and oxygen ah if it is ah basically getting mixed it forms a combustible mixture and this hydrogen ah over a wide range ah you know is formed it can form a combustible mixture ah between 4 to 75 percent by volume in air it is combustible and in terms of ah you know only O2 that is oxygen it is between 4 to 96 percent of it is ah it can form ah combustible mixture, but in terms of it is detonation range it gets intO220 to ah 64 percent in air and the similar thing in ah you know volume of O2 it number will be 50 to 90 percent almost ok. So, if we compare it with the ah corresponding values with the methane you will find these are the numbers corresponding numbers. So, ah it is not only that ah as we have we are talking that it is not only the ah I mean fuel and oxidizer you need another ah you know element that is ah the fuel oxidizer we have already talked about the third part is the ignition or the heat thermal energy.

So, when all 3 of it is you know present in the system it will catch fire and in case of this you know hydrogen the ah energy that is needed is only 0.02 ah mega joule milli joule. So, that is a very small amount of ah energy that will be necessary to catch a fire of hydrogen and oxygen. First of all, it is you know in presence of oxygen it ah forms a very ah I mean large ah you know volume of it is combustible mixture, but at the same time we have a very small energy that is needed sometime you will find some electrostatic force itself ah you know is good enough to cause a fire. So, we have to ah you know try to avoid this you know this fuel is of course, hydrogen is already present and oxidizer oxidizer.

So, if it is getting mixed to ah hydrogen we should be able to you know ah avoid this ignition ah if it is not possible to you know ah detect that we will come to that part. So, this ignition ah sometimes it ah it is a you know if we look ah this it is a ignition temperature in air it is auto ignition temperature is 858 Kelvin. So, that is a quite high, but this ignition energy ah that is very small ok. So, ah if we look at this ah safety triangles. So, if one of them is absent say if ah particularly say ignition if it is absent it will not catch fire.

So, but ah if there is any kind of you know accidental release and if it is ah is having a fire then we should try to ah you know ah stop this ah I mean ah source of this fuel. So, we should be able to close it down as early as possible. So, now, here what happens this ah emissivity of this hydrogen flame it is very small and when it is burning ah you know this burning hydrogen with a low emissivity ah it is ah that means, it is not releasing the heat to the atmosphere or anywhere where it is ah burning. So, that is one way it is good that you know it is not ah I mean dissipating it is energy ah, but at the same time that makes this flame of this ah you know hydrogen invisible. So, once this ah flame becomes invisible you are not able to know ah that there is ah you know unless this hydrogen is mixed with some impurities you would not be able to detect that fire and often it so, happens that you know trying to ah figure out this ah hydrogen ah burning ah may people will be getting injured. So, ah if there is any kind of accidental release of hydrogen one should you know have sensors at the top of the laboratory or in the industry. So, ah those should be able to you know sense the release of hydrogen and immediately you know you should be able to ah I mean stop ah the release of the hydrogen or try to detect the release of this hydrogen. And if there is any kind of fire it is very difficult unless otherwise there is some kind of what is called impurities associated with it. We cannot it is a order less gas it is ah I mean ah it we cannot sense it is release ah of this hydrogen with our sensors.

So, I mean I mean human senses ah ah. So, ah we have to put some additional sensors like thermal conductivity sensors or etcetera to detect it is presence ah. So, and those should be located as I told you on the rooftop or at the highest level in the ah room. So, we should ah avoid ah I mean any sparks in the lab. So, ah if we detect any accidental release of hydrogen. So, no sparking switches should be used as far as possible and locating electrical equipment and you know switches etcetera as far as possible should be you know out of this hazardous area where hydrogen is there it may not always be possible.

And of course, we have to ah appropriately ah put the hydrogen sensors. So, now, ah in terms of materials ah you know there are this is a stress strain curve ah I am not going into the details of this ah you are familiar with the ah you know this curve particularly for you know ah ductile material. And we should have basically the high ah yield strength ultimate tensile strength and toughness and you know fatigue strength for the material which are ah chosen for cryogenic application. And not only that you know the good weldability and thermal properties particularly in terms of it is expansion ah coefficient and emissivity etcetera ah are needed. And with respect to this hydrogen we should be careful about choosing the material because some of the materials may have you know hydrogen embrittlement.

So, this hydrogen embrittlement ah I mean when it is getting exposed to ah I mean ah hydrogen ah if it is not reacting ah we are not talking about the hydrogen reaction or it is safe the by ah while making some of the materials you know we may put it in the hydrogen environment, but we are not talking about that. But if we are storing hydrogen in a confinement or in a storage they were made of this kind of ah you know ah I mean ah basically the materials which are designated for cryogenic applications if we are storing in that material you will find there is ah you know degradation of the in terms of this ah yield strength and ultimate strength of this material. So, particularly with the high strength steels nickel and it is alloys I mean these are the ah well known material for ah the cryogenic application. So, they are basically the FCC material typically and ah so, in terms of this materials and ah you will find that they are having I mean this aluminium alloy and ah say the copper alloy or these are the materials which will be these are the stabilized stainless steel. So, they are the materials hydrogen embrittlement in terms of what is called it is a susceptibility at room temperature.

So, this aluminium alloys or copper alloys are best suitable for hydrogen application or you know in terms of ah it is a it is a you know in terms of it is a I mean increasing susceptibility ok. So, fine that is about the material part we should be careful about it is strength while ah designing the ah storage container for this hydrogen. And in terms of vehicular application ah if we look into ah because we have talked about the high-pressure storage containers. So, we have to follow the codes and standards and ah you know accidental release in case of any high pressure or temperature say if it is exposed to ah say ah burning condition or so, ah we should be following there are certain ah regulations and the standards and codes are there we have to strictly follow that. And ah and not only that we have to ah make use of this thermally activated pressure relief valve.

So, pressure relief devices. So, which will ah basically open up during ah the I mean if it senses high temperature and etcetera. So, these are the typical a kind of ah PRD ah the pressure relief device and they are thermally activated. And release of hydrogen one should be ah I mean be careful it cannot be ah inside towards the electrical terminals or towards the passengers, but it has to be or the luggage compartment it should be ah towards ah this direction they should be away from the ah I mean car. So, these are the references you can follow this is cryogenic fundamentals by Haselden and then Edeskuty is this cryogenic safety in handling cryogenic fluids. And in conclusion let us say I mean ah put it like this the precautions are necessary regarding the selection of the construction materials. And in every phase of the designing you know one should follow the safety rules standards and codes and follow the standard operating practice. And the safe operation has to be done by the trained operators ok. So, the I mean there should be trained manpower. And not only that in a nutshell if we can say that this ah ah risk management in terms of ah say the other cryogenic fluid ah the risk involved with the hydrogen is almost similar to any other ah fluids like or any other fuels like gasoline and etcetera. So, one has to be very careful about ah handling the hydrogen. So, thank you for your attention.