Hydrogen Energy: Production, Storage, Transportation and Safety

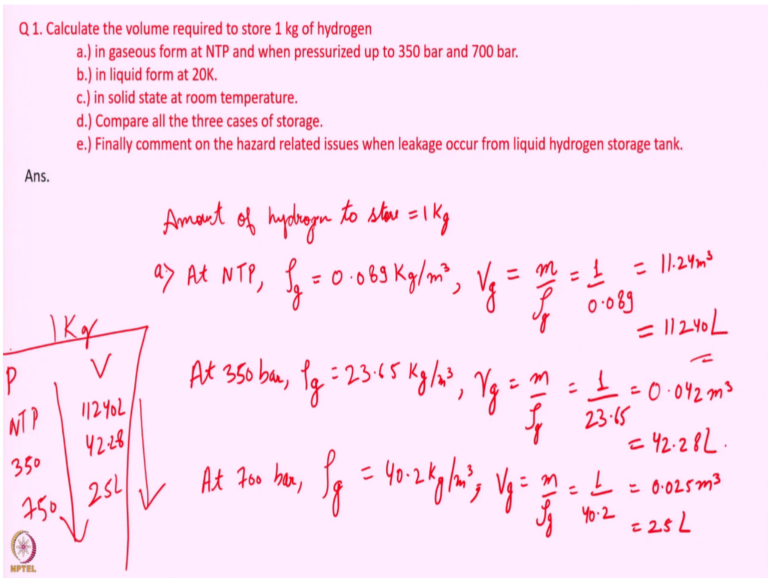
Prof. Pratibha Sharma
Mr. Saurabh Tiwari
Department of Energy Science and Engineering
Indian Institute of Technology, Bombay

Lecture - 41
Tutorial - 5

Hello everyone my name is Saurabh Tiwari; I am PhD student at IIT Bombay, I am also course TA of this course. In the previous lecture you have studied about the various method through which you can store hydrogen in different ways. Also, you have studied in the previous lecture, the various method of compression of hydrogen using different type of compressors.

In this lecture we will go in more detail by taking some of the examples how the hydrogen will be compressed, how the volume of storage will change, when the hydrogen will be stored in different phases.

(Refer Slide Time: 00:56)



So, in the first question we have to calculate the volume required to store 1 kilograms of hydrogen. First, the first question is that it will how what amount of volume we require to store in gaseous form at normal temperature and pressure. And when you pressurize it up to 352 or bar to 700 bar; then we will store we will try to find out the volume when hydrogen will be stored in liquid form of 20 kelvin, in then in the solid state at room temperature.

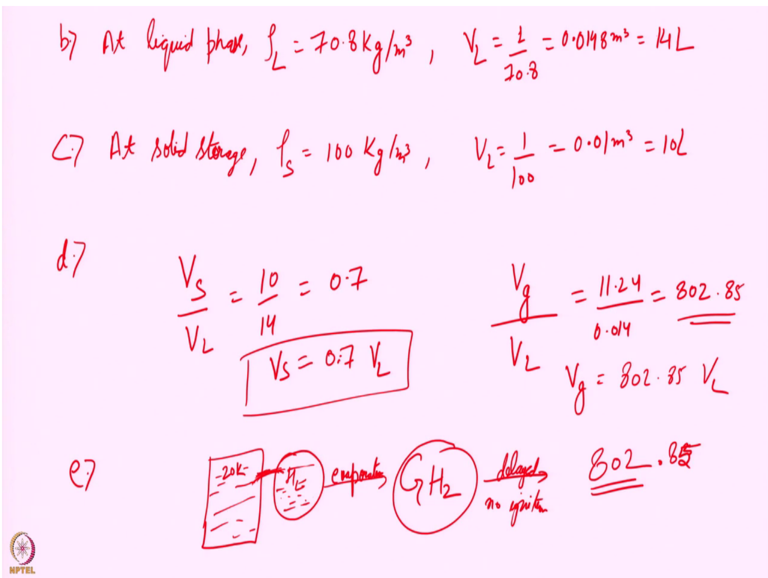
Then we compare all these three cases of storage and we will and finally, we will comment on the hazard related issue when leakage occur from liquid hydrogen storage tank. So, we will start with the first; so, the amount of hydrogen to store is 1 kg. We will start with the first case, at NTP density of hydrogen gas is 0.089 kg per meter cube. So, at NTP the volume required to store 1 kg of hydrogen is which gives us 1/0.089 around 11.24 meter cube, which will convert into liter gives us 11240 liter, this is the first case.

When you pressurize this hydrogen up to a pressure of 350 bar, the density of hydrogen gas will change and it will change up to 23.65 kg per meter cube. Now, if we calculate volume from this, this comes out, the because when you pressurize the gas the amount of volume required will be less. So, now, the volume comes out to be 0.042 meter cube which is around 42.28 liter to be exact.

After that we will see at 700 bar the density of hydrogen gas is around 40.2 kg per meter cube which will gives the volume to be 1/40.2 which comes out to be 0.025 meter cube and in liter it is 25 liter. So, from here we have seen that when the pressure is increasing from NTP to 350 bar up to 750 bar. The volume to store 1 kg of hydrogen will be at NTP is 11240 liter.

At 350 we have calculated as 42.28 liter and at 750 it is 25 liters. So, as we increase the pressure, we have seen that the volume requirement will continuously go on decreasing. So, this is the this is one of the method to store hydrogen. In the second in the second question it is given that we have to store this hydrogen 1 kg of hydrogen in liquid form.

(Refer Slide Time: 05:16)



So, in case b, in liquid phase, the density of liquid hydrogen is 70.8 kg per meter cube. This will give us the liter the volume required to store 1 kg of hydrogen as 1/70.8 which is 0.0148 meter cube which is around 40 liter. Now, in the case c; we see that at solid state storage the density of hydrogen comes out to be 100 kg per meter cube which will give us volume of around 0.01 meter cube which is around 10 liter.

Now, in the case d, we have to compare all these type of storage system that in different phases. So, we have from the first of the calculation we have seen that when we want to store hydrogen in gaseous where form. The volume required is high as compared to the liquid phase and the solid-state storage. Now, if we can if we just compare that where the volume required in solid state is to 1 kg of hydrogen versus when we store the same amount of hydrogen in the liquid phase.

So, this comes out to be; so, in solid state storage the volume required is 0.7 times of what is required in the liquid form. If we compare the another case, if we compare that with the to store the same amount of energy at during the gas phase form the volume required. And to store the same amount of energy in the liquid phase, when you then we have seen that this comes out to be 802.85 this is a very big number.

If we store hydrogen in gas phase form then the volume required is 802 times of what we want in liquid phases in liquid phase. In the next part, it is seen that what is the hazardous condition which will create when the hydrogen will be leakage leaked from the liquid phase. So, this is the from the last answer we have seen that the volume required to store gaseous form is 802.85 times of V_L.

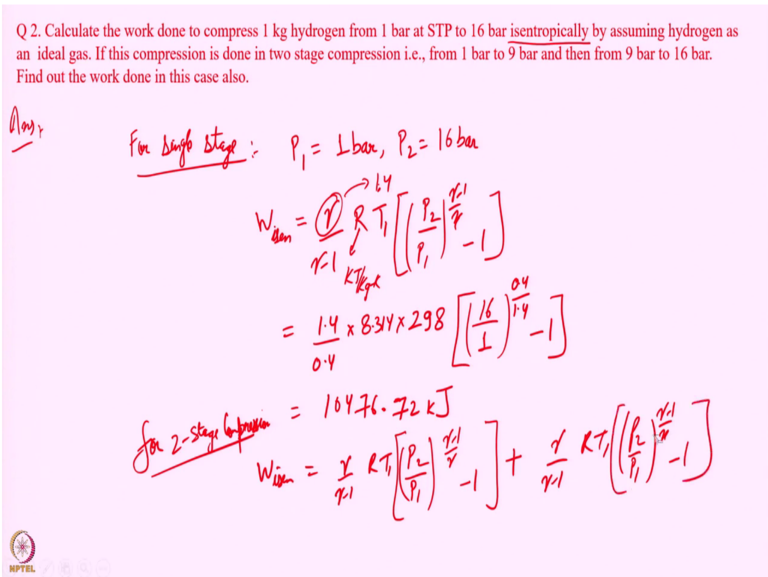
So, when they if we have a tank of tank in which the liquid hydrogen is stored and if there is some leakage from this portion. So, the hydrogen will be liquefied at a temperature of around 20 kelvin. So, when there will be some leakage, this will continuously go on in the outer portion and in the atmosphere and this will produce a cloud of liquid hydrogen in this portion.

Then after forming a cloud at 20 kelvin this will continuously go and evaporate because its when it comes to in the context of atmosphere as temperature goes on increasing. Then there will be evaporation converted into gaseous hydrogen, if there is no ignition if there is no ignition and there will be delayed the conversion of liquid hydrogen into the gaseous hydrogen. The volume occupied by this gaseous hydrogen is around 802 times.

So, what we have seen is if there is a tank in which the liquid hydrogen is present and there is leakage of liquid hydrogen. So, there will be initially the cloud of liquid hydrogen then it will start expanding which is known as the expansion ratio and it will expand up to a point of 802.85. If this times the expansion of volume is 803 times as compared to what is seen when it converted into the gaseous forms.

So, this will prove that the how much the hazardous is the gaseous hydrogen when the liquid hydrogen is converted into gaseous phase. In the next question after seeing that what the volume is required to store a certain amount of hydrogen, it is also sometime important to compress hydrogen up to a higher pressure; so, that there will be requirement of less volume in it. So, the compression of hydrogen is also a very important topic that is covered in the last lecture by Professor Pratibha Sharma.

(Refer Slide Time: 10:32)



So, for doing the for doing a small calculation how the compression is being done, the question is we have to calculate the work done to compress 1 kg of hydrogen from 1 bar to 16 bar at standard temperature and pressure by assuming hydrogen as an ideal gas. If this compression, we will do in two stage compression that is initially we will go from 1 bar to 9 bar and then from 9 bar to 16 bar then we have to calculate the work done in this case also.

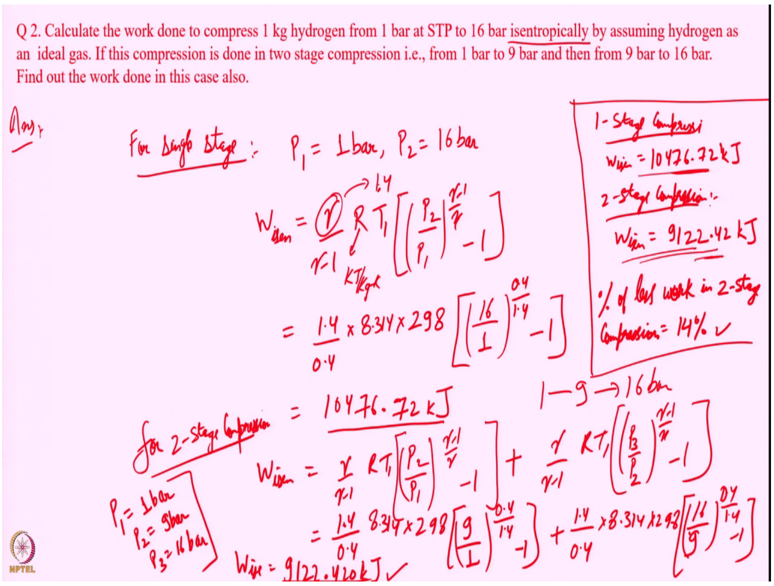
And then you compare which way is better to compress hydrogen up to this bar. So, initially it is given that for the for single stage compression for single stage P_1 is given as 1 bar and P_2

is given as 16 bar we have to compress it isentropically. So, the work required to compress hydrogen isentropically is given by $(\gamma/\gamma\text{-}1)\times RT_1[(P_2/P_1)^{(\gamma\text{-}1/\gamma)}\text{-}1]$.

This is how the work done by isentropic compression of hydrogen can be described. So, the value of γ is 1.4, because it is a diatomic gas; so, if we put this value as (1.4/0.4)× 8.314 this is kilo joule per kilogram kelvin multiplied by if it is an atmospheric temperature, then 25 degree taken as 298 kelvin.

P_2 is given as 16 bar and this P_1 is 1 bar raised to (0.4/1.4) and subtract 1. If we solve this values, we have found that kilojoule this is what we have seen from single stage compression. For 2 stage compression the isentropic work will be given by $(\gamma/\gamma\text{-}1)\times RT_1[(P_2/P_1)^{(\gamma\text{-}1/\gamma)}\text{-}1]$ + $(\gamma/\gamma\text{-}1)\times RT_1[(P_3/P_2)^{(\gamma\text{-}1/\gamma)}\text{-}1]$.

(Refer Slide Time: 13:53)



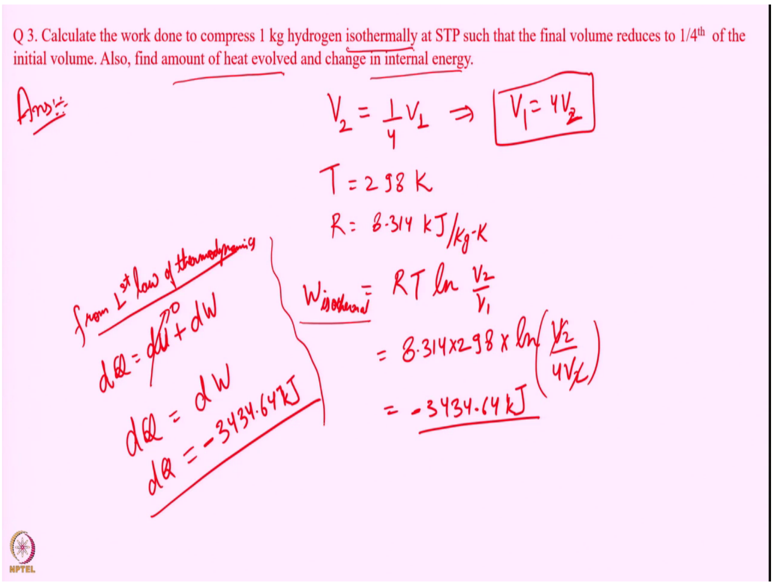
So, initially we have to compress it from 1 bar to 9 bar and then from 9 bar to 16 bar. So, in this case P_1 is equal to 1 bar, P_2 is equal to 9 bar and P_3 is given by 16 bar. So, now after that we have to put the value of these, it is 1.4/0.4. Similarly, the R value is 8.314 T is 298, initially the P2 is we have to compress it from 1 bar to 9 bar; so, P2 is 9, gamma minus 1 is 0.4, 1.4 minus 1.

After compressing it from 1 bar to 9 bar we have to compress it from 9 bar to 16 bar. So, this is given by $(1.4/0.4)\text{x}8.314\text{x}298\text{x}[(16/9)^{0.4/1.4}\text{-}1]$. If when we solve this equation this W isentropic comes out to be 9122.420 kilo joule. This is the single when the compression will be done by single stage this is the amount of work done, when we have to done for the 2 stage compression this is the work done that is being required.

So, for 1 stage compression Wisentropic is given by 10476.72 kilo joule and for 2 stage compression Wisentropic is given by 9122.42 kilo joule. Now, if we see that from here it is seen that if we want to compress hydrogen from 1 bar to 16 bar. And if we will done into by using the 2 stage compression the amount of work done required is lesser in case of 2 stage compression as compared to the 1 single stage compression.

If we see how much amount is this increment is there; so, the percentage of less work in 2 stage compression, it is nearly about 14 percent. So, if we want to compress hydrogen from 1 bar to 16 bar, there will be 14 percent less work we have to done in 2 stage compression as compared to the 1 single stage compression. The the next question is also about the compression, if the process is isothermal that there is no change in temperature.

(Refer Slide Time: 17:24)



So, what is the amount of work that need to be done to compress 1 kg of hydrogen isothermally at standard temperature and pressure. Such that the final volume will reduce to one-fourth of the initial volume, we have to also find out the amount of heat evolved and change in internal energy. So, here it is given that the of such as the final volume reduces to one fourth of the initial volume.

So, if we see that the final volume is one by fourth of the initial volume. So, the temperature we are assuming at 298, the value of R is around 8.314 kilo joule per kilogram kelvin we want to compress 1 kg of hydrogen. So, the isothermal work to compress this if hydrogen is assumed to be as ideal gas is given by $RT\ln(V_2/V_1)$.

From here V_1 is given by $4V_2$; so, if you put this value in it, it comes out to be $8.314 \times 298 \times \ln(V_2/4V_2)$; if you solve this if we solve this equation, we will get a value in kilo joule. Now, we have to find out the amount of heat evolved and the change in the internal energy also. So, this will be; so, from here we have find out we are able to find out the work required to compress hydrogen from when the final volume is one-fourth of the initial volume.

Now, from the first law of thermodynamics $dQ = dU + dW$. Now, it is given that the process is isothermal; so, the change in internal energy comes out to be 0; so, from here is given by dW. Now, the work done is this, this is the amount of energy that is being evolved when the hydrogen will be compressed from 1/4 to the initial volume of the final volume.

So, this is a method of compression of hydrogen from at by different methods which is isentropically and isothermally also. We have also seen that how the storage volume is changing when the hydrogen is stored in the different phases like in liquid phase, in solid phase, and in the gaseous phase.

We have also seen that there will be a there will be a problem when there will be leakage in the liquid hydrogen tank. And the there will be expansion of volume when the liquid hydrogen is converted to gaseous hydrogen by 803 times which is very hazardous in our case.

Thank you.