Introduction to Explosions and Explosion Safety
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Lecture - 31
Physical Explosions: Physical Explosions from Flash Vaporization, Metastable Liquid, T-v Diagram, Examples

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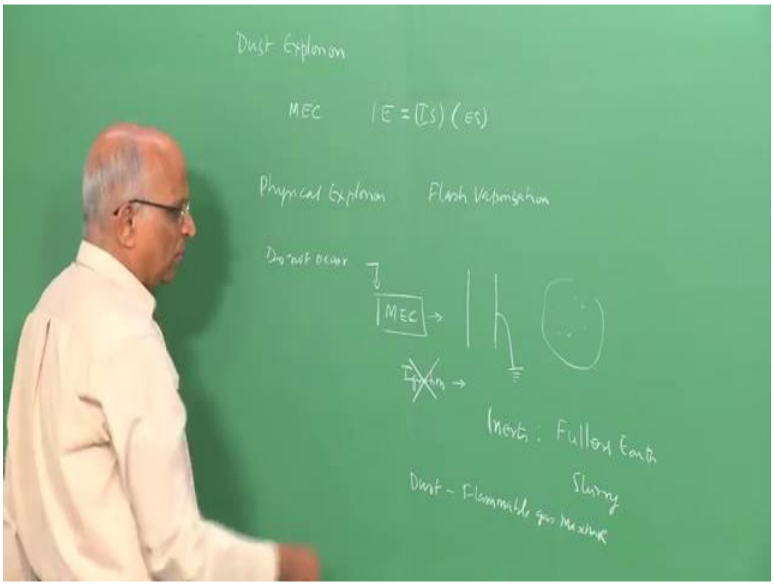

Good morning, you know in the class, which we just in which we covered the portion of dust explosion, we looked at the different types of dust, we found that a dust air mixture is explosive.

We also found the concentration below which, something like a minimum explosive concentration, is required to form a dust explosion, but we also found that the dust explosions are numerous and there must be methods to control them. In fact we looked at the sensitivity of the dust mixtures to explosions, we also looked at the consequences of the explosion in terms of its explosion severity. And also defined something like an index of explosibility IE and we said it is the product of, let us say ignition sensitivity and the explosion severity.

You know in today is class we take a slightly different topic, namely we look at physical explosions. That means, we are looking at explosions being driven by some physical processes such as, the flash vaporization, but before getting into this particular topic, maybe I like to spend a couple of minutes on. Since, we said dust explosions are dangerous and there are numerous instances, wherein they occur the organic, inorganic dust mixtures are a problem. Something which we did not do was how to ensure, that such explosions do not occur, or what are the safety features we incorporate to prevent a major catastrophe involving dust explosion.

See immediately we will say, since we talked in terms of a minimum explosive concentration required, the easiest thing is to make sure that the dust should not form this particular explosive concentration. That means the minimum explosive concentration in the particular chute, or in the particular hopper, or in the particular system by which the dust is being transported or in the confinement, the dust air mixture. Such that it is concentration is less than the minimum explosive concentration, which we determine for the different dust mixtures.

Having said that you know, an ignition sources is always required to start a and explosion, but you know to be sort of able to prevent an ignition source from occurring is always difficult. Only thing is that maybe we should take some precaution such that, in the in the particular conveyor in which the dust is being transported, maybe we should properly earth it. Such that, the chances of forming an accidental spark is less, but you know this is whatever said and done ignition sources are present, and the safest thing to do is to ensure that a minimum explosive concentration of the dust air mixture is not formed this point one.

Supposing, we have to handle concentrations which are greater than the minimum explosive concentration, maybe we have to add some inert. And some of the inert which are which have been added are, some substances like fullers earth, something like mud powder, what is being added. Such that, you bring down the concentration from the actual value, and when you added may be the concentration of the particular dust reduces below the MEC value.

The other alternative is, maybe you make a slurry of the dust, and handle the slurry instead of handling the dust air mixture, but again you know you have to remove the liquid and it is somewhat a laborious process. The other type of safeguards which we could have is, maybe instead of having something like, you know after all the dust mixture, forms a flammable gas mixture. And what we could do is, we could have something like say phosphorous compounds, and what do these phosphorous compounds do?

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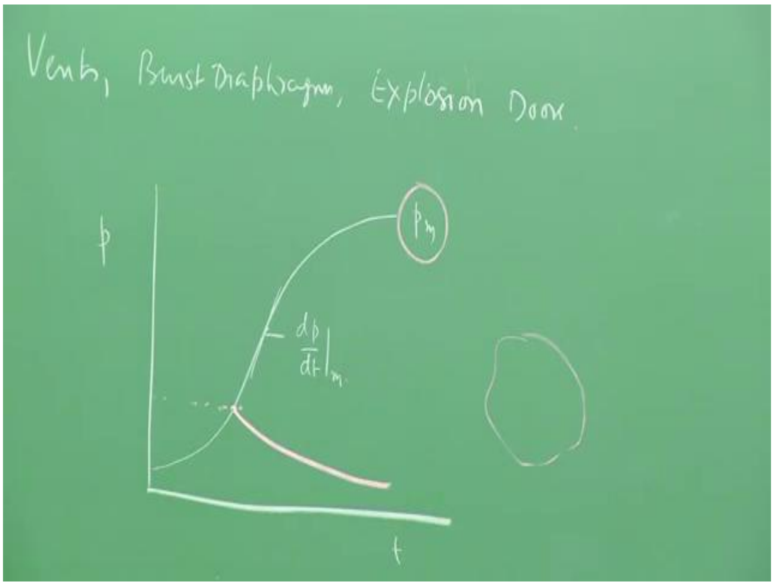

Something we add, something like ammonium phosphate. And when some chemical reactions occur, the ammonium phosphate takes in the active radicals and sort of impedes the chemical reaction. And therefore, the type of maximum pressure the type of rate of pressure rise, namely the severity of the pressure rise could be reduced by adding such substances.

This is a way of inhibiting the fire, or the chemical reaction. This is in terms of bringing down the minimum explosive concentration. But in spite of all that, one of the safety features which we talked in case confined explosion, we could also adapt here such as providing vents, providing may be the burse diaphragms, and also providing something like explosion doors in the particular appliance which involves the dust, they say explosion doors.

What it essentially does is, when the rate of pressure rise, if I plot the pressure, as a function of time, well the pressure increases in an explosion to the maximum pm value. The corresponding to the inflection point, I have the value of dp by dt, which is maximum. What this vent or this burse diaphragm does is, if I can appropriately, cause it to burst at or cause it to vent out the burned products, or unburned products, or the unburned dust, and the burn products of dust well, the pressure falls over here. And in this case, well I am guarding against the value of pm happens to be the pressure at which the diaphragm gives way or the explosion door opens, or the value of the pressure rise can also be controlled over here.

Therefore, provision of this is important, but me must also remember that, when you sort of vent out of fire, you must not vent it out, or vent out the explosion. You must not vent it out into the neighboring areas in which explosives might be housed that, precaution must be taken. Therefore, we tell that, well the methods of preventing a dust explosion or somewhat taking some precautions are, maybe try to see that the accidental sparks are not there. Such that, the fire triangle is not complete, you have fuel, you have air, you have the spark, over here or the ignition sources sort of removed.

Or may be bring down the minimum explosive concentration by fullers earth, or otherwise or using slurry, or else may be you just ensure that some chemical inhibitors, like ammonium phosphate are added which brings down the rate of the reaction. This is the method of controlling a dust explosion having said this, well it is time to get into the physical explosions. Let us see what it is about let us start with the few examples, you know because examples are illustrative, and we will be able to study the mechanisms using these examples.

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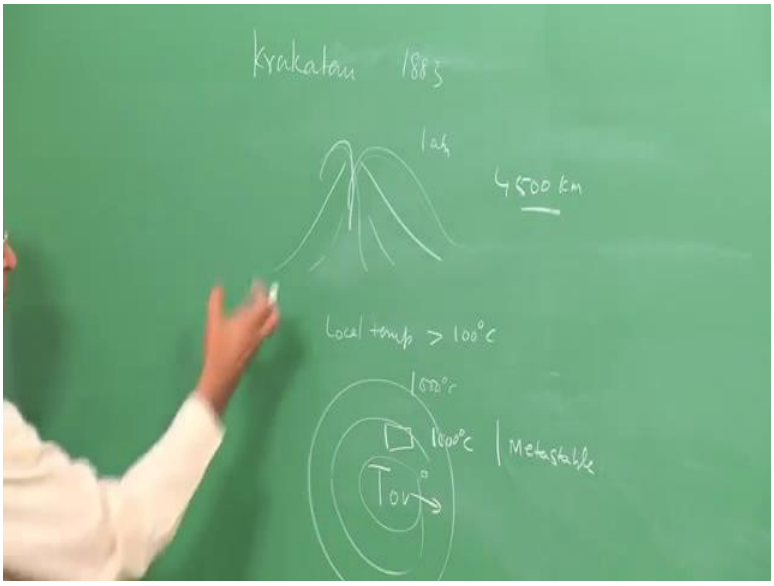

Therefore, we get started with the very famous example which we talked in terms of natural explosion and in this explosion, this is the one which happened in Krakatau. We say it happened around 1883 or so. In which you have the huge volcanic eruption, and what happened is you have volcano lava being generated. You have due to tidal wave lot of water, sea water getting into the volcano. And you know the volcano is hot and the mass of the heated substances lava is enormous, something like they are the thermal mass of this hot substance is large.

Into it a huge quantity of water is getting in, and the water gets locally heated. That means, the ambient pressure is 1 atmosphere, the ambient pressure inside the volcano, mind you it is not chocked, it is also 1 atmosphere. You have the local temperature of water exceeding the ambient temperature at which the water boils, water boils at ambient at a 100 degree centigrade. You have the temperature here which is so hot, that you know this hot value could be around almost let us say, 1000 degrees centigrade is the temperature of the molten lava.

And this molten lava heats water locally to around 1000 degree centigrade, but you well know the water cannot exist at these high temperatures of say 1000 degree centigrade as a liquid. With the result, this state is sort of a Meta stable state. That means, the water is something like overheated to a very large temperature, let us say temperature over heated to a very large value. And at this temperature, the water cease the ambient pressure and at ambient pressure, water can exist only up to a temperature of 100 degree centigrade.

And therefore, lot of energy gets locked in to the water, and it just flashes into a vapor. And this flashing of vapor, in this particular volcano, generated blast waves or shock waves, and we said well the shock waves are heard up to a distance of 4500 kilometers away from the volcano, such is the power of this physical process of flash vaporization. Flash vaporization is because a Meta stable water is formed. This Meta stable substance cannot exist as a liquid, it flashes into vapor. The large volume of vapor compared to the volume of water, drives or forms a shock wave or a blast wave which is so strong, that it travels over a distance of 4500 kilometers. Well, this is the first example, we also talked of a smaller example.

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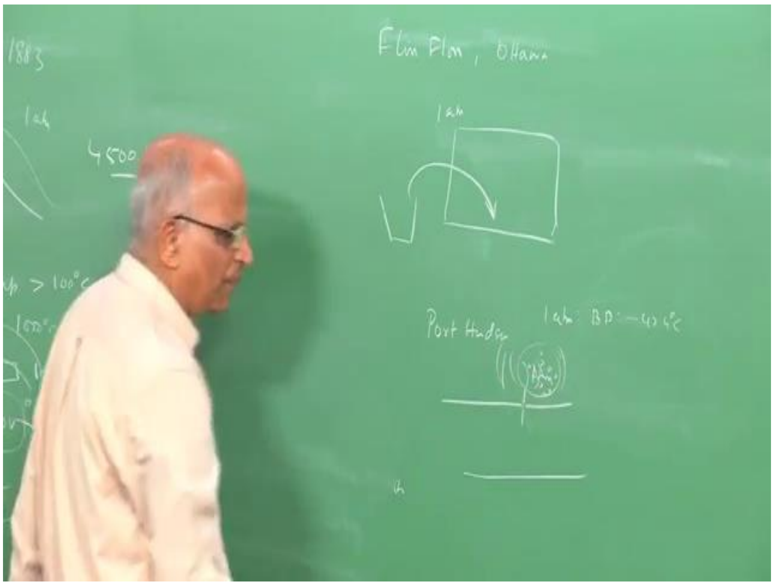

We said Flin Flon in Canada at a place near Ottawa. We said around in the year 2000 or so. The people wanted to go home early, there was a hot furnace may be let us say a crucible furnace, or a reverberatory furnace. The furnace is still hot, they still want to go home. They take water in a bucket or a pale, and pour it into the furnace. And since, the thermal mass of the furnace was still very large, and thermal mass is very much larger than the mass of water which is cooling.

The water instantaneously attains a higher temperature, much higher temperature than the normal boiling point at the pressure of one atmosphere and it flashes into vapor, and it caused an explosion. We also talked in terms of the explosion at port Hudson, this is the third example. And in this example we had a pipeline taking liquid propane, transporting liquid propane at high pressure, at high pressure. The propane, the liquid propane is at the ambient temperature, but at one atmosphere pressure, the boiling point of propane is something like minus 42.4 degree centigrade.

Therefore, the propane at ambient temperature and at high pressure comes out, it cease the lower pressure of the atmosphere may be one atmospheric pressure. Propane boiling point is minus 42.4, it can exist as a gas only at this particular temperature or a liquid below this particular temperature and immediately flashes into vapor. When it flashes into vapor, you know what happens, it absorbs the latent heat from the liquid coming out, and use sort of form the fog.

We will take this example for analysis a little later, but all what we are saying is well, we had the case of a volcanic eruption this is known as a hydro-volcanic type of an explosion, or just a volcanic explosion involving water. We talked of water being poured in a furnace which creates an explosion. We talked of some substances which are at a temperature which are stored at a temperature, higher than the normal boiling point corresponding to atmosphere which can again cause flash vaporization.

We want to quantify this, we want to quantify this for the energy release. We want to see the mechanism by which an explosion will take place. And therefore, let us get into some details of how to go about it. Well, the first point we notice, well we are all always thinking in terms of a Meta stable condition for the liquid.

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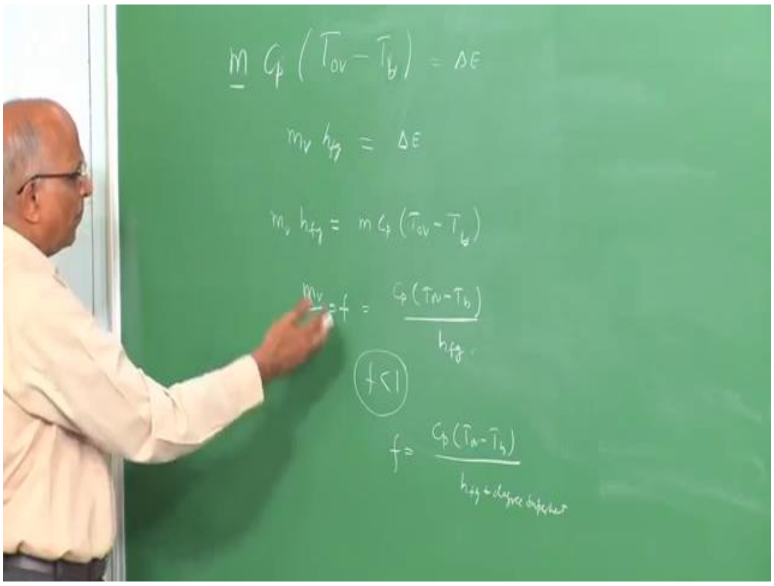

We say well, the temperature is over heated much above the boiling temperature, and since it is you have a certain mass of the liquid which is over heated it also has a specific heat. Well, the energy content of the overheated liquid that is, it is at this Meta stable temperature, it cannot exist in equilibrium at this temperature. It has to, it can exist at equilibrium only at the boiling temperature therefore, it is at this unstable state and therefore, it is the excess temperature and this specific heat let us say is Cp.

We are talking of atmospheric pressure Cp, and you have the mass of the particular liquid which is available, this is the excess energy which is available. And what does the excess energy do? You know this particular mass you know it is, it has a latent heat of vaporization, at the atmospheric condition corresponding to hfg. And therefore, part of this mass gets evaporated mv into hfg. And this heat is derived from this excess energy or rather mv into hfg is equal to the excess energy contained.

At this unstable condition and this is waiting to get released and it gets released by vaporizing part of this particular mass which is, which is in this meta stable state. And therefore, we have m v, that is the mass which gets vaporized into the latent heat of vaporization is equal to m Cp into T that is the overheated temperature, that is the unstable temperature which we call as meta stable temperature, minus the boiling point temperature which let us call it as Tb small b.

Therefore, I can now say mv by m, which is the fraction of the liquid which evaporates is equal to, I can write it as mv by m comes over here is equal to Cp into T overheated minus the boiling temperature, divided by the value of the latent heat over here. Now, when I consider this well the fraction has to be less than 1. But in case the explosion is such that the overheated temperature is very much greater, like in the hydro-volcanic eruption that means, you heat it to extremely large temperatures.

Well, this particular formula can give a value f greater than 1 which is not possible in practice. In that case, what happens is, the water instead of being saturated that means, instead of forming vapor which is saturated. I also have to take into account like f is equal to the value of Cp into T over heated minus the boiling temperature at atmospheric pressure divided by hfg into the degree of superheat.

That means, I still form vapor, and this vapor has even a higher volume and therefore, the type of pressure wave which is generated is even higher. I think we have to look at this under what conditions f is equal to 1, f should be less than 1, or f cannot be greater than 1 in which case, I have degree of super heat. But let us, let us look at this particular formulation in a slightly expanded form. See we are thinking in terms of let us say the over heated temperature or the meta stable temperature…

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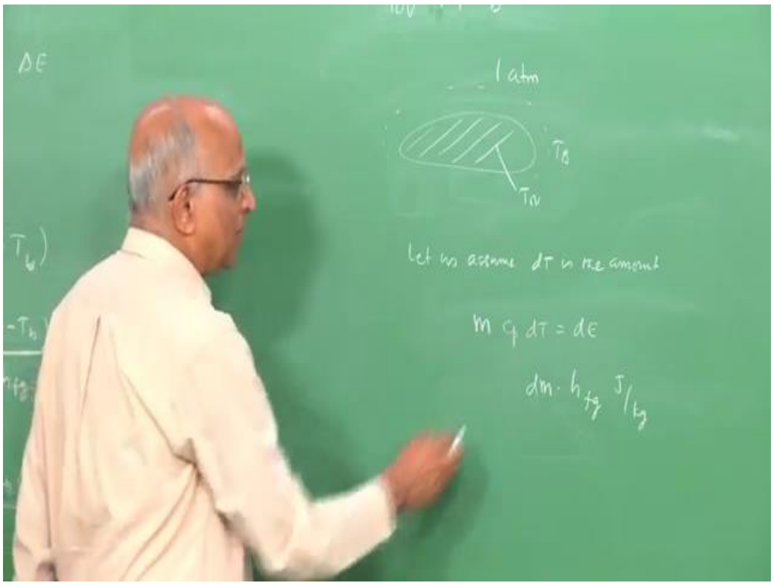

T over heated being very much greater than the boiling point temperature. That means, what has happened is, initially I have a liquid which is very much higher that means it is terribly over heated.

Well, the boiling temperature of the liquid can only be much smaller than this therefore, it contains an excess energy just waiting to release it, and it just flashes into vapor and the fraction of this mass which flashes into vapor is what I have written over here. But you know, we are talking of this temperature distance being large, we also talk in terms of the specific heat Cp, We also talk in terms of hfg. You know whenever we talk of these things, I cannot talk in terms of a larger number.

Let us for the present, let us presume, let us assume let us say, that the degree of overheat compared to the boiling point is, let us say the let us assume dT is the amount by which, is the amount by which the overheated temperature exceeds the boiling temperature, and let it be a small number to begin with.

Therefore, the mass, the energy associated when the non-equilibrium temperature, compared to the equilibrium boiling point temperature, is greater by dT, is m into Cp into dT, which is equal to the small value of energy which is over and above the value of the boiling point. That is this is the excess energy, which this substance has since its temperature is greater than the boiling temperature locally by some particular amount, mind you the ambient pressure is still 1 atmosphere.

And what does this energy do? It causes some evaporation. Let us say the evaporation, the mass which gets evaporated is dM, and at atmospheric pressure the value of the latent heat, we say hfg is the value of latent heat in joules per kilogram, dM mass is in kilograms.

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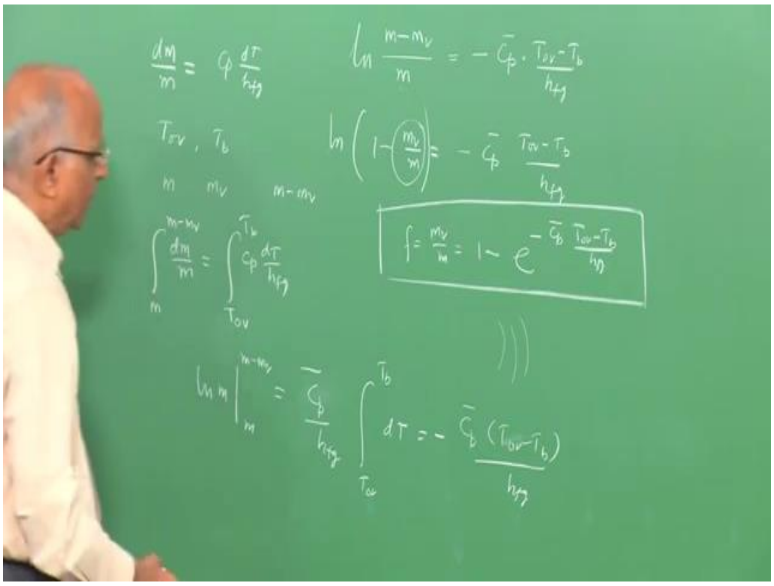

And therefore, we can write this equation as equal to dE, let us write it over here, dE is equal to mCp into dT which is equal to the energy supplied for vaporization which is equal to dM into hfg over here. Now, if I, if I were to bring the dM divided by M, take M on the right hand side. I take dM over M is equal to I get Cp into dT divided by the latent heat over here, dT by hfg.

Now, you know in practice we see well, the overheating is not by a small amount, but I find that the overheating is T overheated, the boiling temperature is Tb this is sizable. And therefore, what is happening is, in the process from the initial mass of the liquid which is available, a mass mv gets evaporated. And therefore, the final mass is equal to of the liquid is equal to m minus mv and therefore, if I were to integrate this equation, I get integral of dM divided by m is equal to Cp dT by hfg.

As the temperature, from the temperature of the overheated value, that is the overheated temperature to the boiling temperature that is when it is releasing a particular mass or it is flashing into vapor and what happens initially. I have a mass m and the final mass of the liquid is m minus the 1 which is evaporated.

In other words mv is the mass which is evaporated, and initial mass is m and the initial mass of the overheated that is, unstable liquid or the meta stable liquid, corresponding to temperature T ov corresponds to m, corresponds to the boiling temperature when it evaporates the mass left is this. Therefore, when I integrate out I get log m, going from m to m minus mv. And on the right hand side, I get, I get Cp now, but you know Cp is also a function of temperature and that is the main reason why we are doing this. Therefore, we say in the region between Tb to T overheated, let us presume that the mean value of specific heat Cp is, let us say is equal to Cp bar such that, I can take it outside.

And then, well this is corresponding to hfg 1 atmosphere pressure, I can say it does not depend on these temperatures, it is a totally different variable. And then, I say it increase in temperature from temperature of the overheated value or the meta stable temperature to Tb of dT over here, which gives me the value of minus since, overheated is higher, I put this with a negative sign over here is equal to Cp bar into T over heated minus Tb divided by hfg.

Therefore, if I were to look at the left hand side, on the left hand side I have log of m minus mv minus log m which I can also write as log m, divided by m because, log m minus mv minus log m is equal to log of m minus m v divided by m, is equal to I get the value as equal to minus Cp bar into the value of T meta stable temperature, minus a boiling temperature divided by hfg. Now, if I simplify this expression, I get 1 minus mass evaporated divided by the mass of the overheated liquid, is equal to minus Cp bar into T over heated minus Tb divided by the latent heat of vaporization.

Or rather this is the fraction I am looking for the mass which gets evaporated, and this evaporated mass has a very large volume compared to this we will put some numbers and see we get, the value of f is equal to mv by m is equal to 1 minus. No mind you, this is again within the log, log of 1 minus this therefore, 1 minus e to the power minus Cp average over the temperature into T over heated minus Tb divided by hfg, this is the expression what we get.

Therefore, we find well the, if the value of the latent heat is very high that means, this becomes 0, 1 minus 0 that means, nothing gets evaporated. If the overheated temperature is very near to the boiling temperature, well not much evaporation takes place. And therefore, when I talk in terms of flash vaporization taking place well, the temperature to which the water or any liquid is locally overheated must be very much higher than this. Such that, I generate lot of vapor and this vapor is what, since it has a larger volume it is in that particular confinement it creates a high pressure and therefore, a blast wave.

Well this is how we estimate the particular fraction f, but let us go back and try to understand the problem a little bit further, by looking at may be, the diagram for let us say water or some other liquids in the let us say in the temperature versus the volume diagram.

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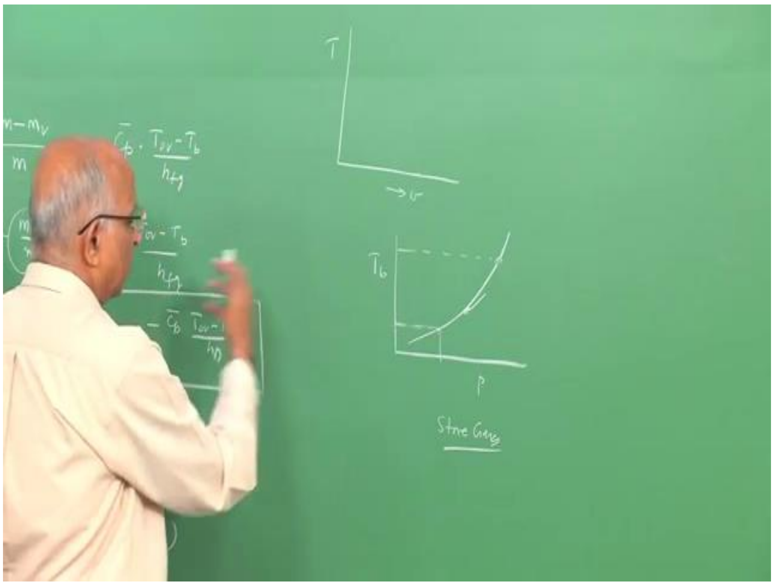

You know in thermodynamics we say well pure substances can always be talked in terms of two property rule, and therefore, we try to find it out, we try to apply it for steam water mixtures. And therefore, let us use this diagram, but before using this, we must realize that whenever we are talking of such things flashing into vapor, why does it happen?

As a function when we say when pressure changes, the boiling point changes and what is this boiling point corresponds to the saturation vapor pressure, as pressure increases the boiling temperature increases. And therefore, it is this variation which essentially causes may be at some point the pressure is very high, the liquid is at high pressure, all of a sudden the constraint of this high pressure is removed, like for instance there is a leak. It leaks into atmosphere corresponding to that you have a lower boiling temperature, this is the original value.

When I look at this particular pressure which is the atmospheric pressure, the boiling temperature is higher, but it was originally at this pressure therefore, it still retains the memory of this. The liquid is at this temperature, but now the pressure is low therefore, it feels that this temperature is sort of a Meta stable value, it just flashes because, it has to reach this value, and this is how a flash vaporization takes place. We have to look at it in the Tb diagram, but before I do this.

Since, this particular process namely, the depending the dependence on the boiling temperature, with respect to the pressure is what is used to store, gases, many of the gases like let us take one or two examples such that, the problem gets a little more focused. Let us say we consider the example what we used in our kitchens normally, is the butane gas it comes by different names.

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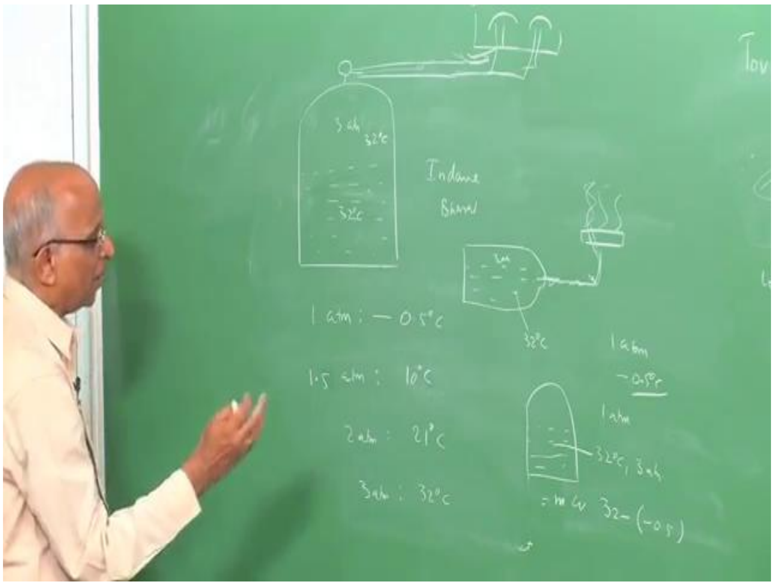

Let us say well, I store butane gas in a gas cylinder in the kitchen I have a cylinder, I have a pressure regulator over here, I connect the gas over here through a particular cable, to a stove. And this stove has different burner heads, I allow some air to get entraining over here and I supply the fuel air mixture to the particular burner heads over here. I put my vessel here, and boil my water or whatever food cooking.

Therefore, in this cylinder I have butane, and if I look at butane per say let me take you through some properties so that, we can put the problem a little more clearly. At 1 atmosphere pressure, butane has a boiling temperature, it boils at a temperature of minus

0.5 degree centigrade. If the pressure is 2 atmospheres, butane boils at a temperature of 10 degree centigrade, at no I am sorry this is 1.5 degree atmospheres. It boils at 10 degree centigrade. At 2 atmosphere pressure, it boils at a temperature of 21 degree centigrade, and if it is at 3 atmospheric pressure, well the butane, liquid butane boils at a temperature of 32 degree centigrade.

That means, below this temperature, if I were to store butane gas that means, if I can increase the pressure to something like 3 atmospheres, I can store it as a liquid and that is how the gases are stored in small cylinders. That means, the butane gas which we know by name we call it as Indane gas we call it as Bharth, whatever these gases are there these are all commercial names.

Essentially butane with other hydrocarbons, you store it as liquid like for instance maybe, I store it at 3 atmospheric pressure at 3 atmospheric pressure, may be when my ambient temperature is around 30 or 31 degree centigrade. Well, I have butane as a liquid. And this liquid is in equilibrium with the vapor here. The vapor is also at let us say 32 degree centigrade, it is a liquid both are at 30 atmospheres, I also have the gas at 32 degree centigrade. And when I open my regulator, I get the gas coming at the pressure of around 3 atmosphere, which is not a very high pressure, it enters here and mixes and comes.

But supposing by chance, you know normally the rule is you must keep the cylinder vertical. Supposing, I were to keep my cylinder horizontally like this, and let us say my cylinder is full, and I have the liquid butane over here, again it is at 3 atmosphere pressure. I allow a hose and connect it to my stove over here, and what is going to happen, the movement. I open the regulator well the liquid gets into my line, and the liquid comes here it flashes into vapor because, this liquid which is at a temperature 32 degree centigrade.

This is a liquid at 3 atmospheres, and this liquid when it comes over here, it sees a pressure of 1 atmosphere may be much before when it starts entraining the air, it sees a pressure of 1 atmosphere, which it will boil at a temperature of minus 0.5 degree centigrade. That means, you know it is the ambient temperature is something like 30 or 35 degree centigrade, it is going to just boil off because, it cannot exist as a liquid at 1 atmosphere pressure, when below its boiling point of the above its boiling point of 0.5 degree centigrade. It just flashes into vapor and I will have all sort of problems over here.

In fact, if the cylinder explodes let us say, if I consider this cylinder by some mechanism let us say by heating or otherwise, let us say the cylinder explodes then, what is going to happen? I have the butane liquid now, at the temperature of 32 degree centigrade, and a pressure of let us say 3 atmospheres. And when the cylinder burst, it the gas immediately or the liquid is going to see a pressure of 1 atmosphere and now, I have excess energy corresponding to 32 minus of minus 0.5 into this entire mass into the specific heat. I have so much excess energy available because, it has to reach the equilibrium value.

And this energy is what causes a spurt in the volume, and it leads to an explosion. This is the practical case in which you know explosion or sort of storage of liquid gases which we use in our daily lives could be a cause of problems. Therefore, we have to handle them carefully and we have to understand this particular aspect of physical explosion, which involve the flash vaporization.

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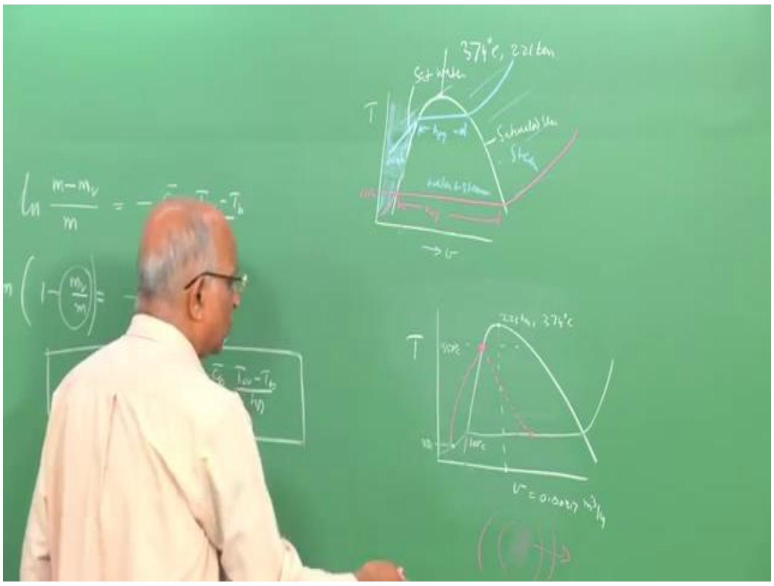

Let us get back to this particular one, wherein we wanted to plot on the Tb diagram. The plot for water and if you know for water we can extend it to further other substances. What we say is well, I want to find out the region in which water exists, the region in which the water and steam exists, the region in which steam alone exists as superheated.

Therefore, you will recall on the Ts diagram, we had something like a dome shaped. And in this particular dome shape, we said yes it is in this region, in the left side of the dome. Wherein, we have water as a liquid, we had steam over here on the right side of this, this is also steam over here and in this region we have water and steam.

You know if I, if I consider a line corresponding to let us say, atmospheric pressure. Well, atmospheric pressure I heat water, I increase in temperature to around 100 degree centigrade, 1 atmosphere pressure then, I go horizontally in the water stream line and this corresponds to the latent heat which we call hfg over here. And once all the water has become steam, well any further heating causes the temperature water to increase. If I talk of slightly higher temperature, let us plot that higher temperature let us say, much let us say higher pressure. Well the temperature is higher at the boiling temperature is higher, this is water, it goes over here and I have the constant pressure.

In other words, at this particular pressure, this is the latent heat of water. That is the latent heat for vaporization, that is the heat required to go from water to this. The line over here on the left hand side, is the saturated water line. And the line on the right hand side is the saturated vapor line, or saturated steam line. They meet at the triple point, and they triple point temperature is typically around, for water it is equal to 374 degree centigrade. And the critical pressure that is the pressure corresponding to the particular point is 221 bar. This is the temperature for water, you have the water line, steam line, you have the two phase wet steam over here.

And therefore, let us consider one example, let us consider the example of let us say this water being thrown into the furnace. Let us say at Flin Flon, and what is happening? Well I have T and V, you have the water line, you have the steam line over here, corresponding to this particular critical point over here. The critical point means, there is no distinction between vapor and liquid, both the density of the vapor is as high as the liquid, it is, it cannot be distinguished. Well, corresponding to something like 221 bar, and let us say 374, the specific volume of vapor which we are plotting here, temperature was a specific volume of vapor is around 0.00317 meter cube by kilogram, this is the volume.

Now, what is happening, we have atmospheric pressure, atmospheric pressure and now, we have let us say this temperature is 100 degree centigrade, and 1 atmosphere pressure.

We have water which is at 35 degree centigrade over here, and this water is suddenly let us say, you pour it into a very hot substance, at let us say temperature of the order of let us say 350 degree centigrade. This is 350 degree centigrade because, the critical point temperature we just now saw is equal to 374 degree centigrade.

Therefore, what happens, when I pour this water on a plate or plate having a large thermal inertia, which is at this temperature, what is it I do? I sort of push the water into this particular state over here. And this is the state at which water is available to me, at this hot condition. But the ambient pressure is still one atmosphere pressure and therefore, if this is an Meta stable state and therefore, the water evaporates and I get steam at this particular dryness fraction that means, I have so much of liquid and so much of vapor.

And if I look at the vapor content, well the difference in the volume of the fluid here, and the fluid here is not very small, we will do a problem relating to that whereas, the volume of the vapor corresponding to saturated is very much higher. You have an intense quantity of vapor being generated from this quantity of water, and that is what creates a blast wave. Therefore, if I have to solve this problem, let us put a few numerals down or few symbols down, and again calculate the mass of vapor been formed in the energy which gets released.

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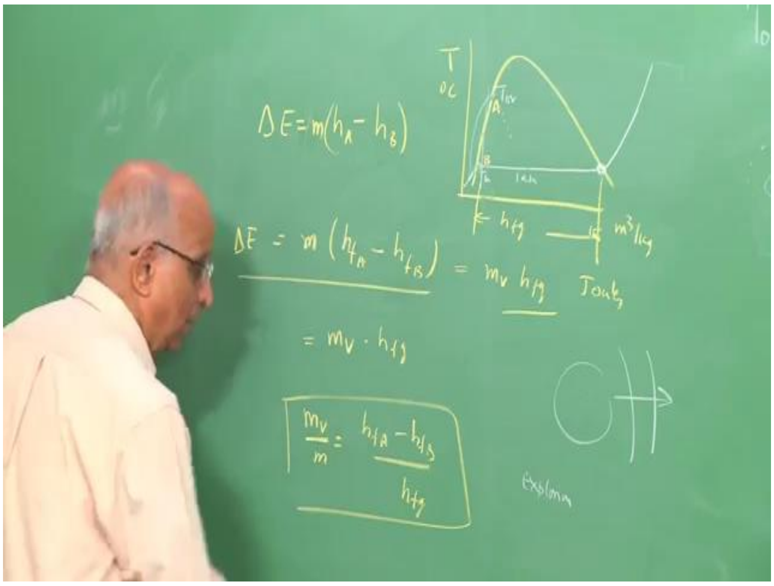

We have delta e that is the energy which gets released is equal to well, I think we have to have the guidelines of this particular figure. We have temperature versus specific volume, meter cube by kg, let us say temperature is in degree centigrade over here. We have the initial line for water at 1 atmosphere pressure, this is water line comes here saturated water, wet steam and then saturated vapor goes into superheated vapor. This is the stable boiling temperature at one atmosphere pressure, this is the one atmosphere line.

Now, when suddenly water at this temperature is heated to a value of this high temperature over here that means, this is my locally overheated temperature or my unstable temperature. And therefore, you know it is sort of, it is not able to say this therefore, excess heat which the water contains is, it can only exist final state can only be here whereas, it is locally heated to this. Therefore, the condition if I say this point is A, this point is B over here, delta e corresponding to 1 kilogram, is going to be the condition at A. That is the water at state A, this is Meta stable, the state B, which is stable this is the heat content per kilogram.

Or rather if I have mass, which is equal to m, the total energy that is the excess energy over here compared to this, which it wants to get rid of, is equal to m into h a minus h b. If I talk of h a well it is a liquid, and liquid we say is h f and the corresponding state is A minus h f, this is again water fluid at temperature B into something like m which is equal to the excess content.

Now, you know when this water, when this excess energy, you know what does it do? It wants to, it has to overcome it has to supply this latent heat because this excess energy goes into the water. And therefore, I have a vapor which is formed which corresponds to hfg over here, or rather I say that this energy which is sort of locked into the water at this meta stable state, vaporizes and forms m v h fg of vapor. And I know that the value of the latent heat corresponding to atmospheric pressure is so much from here to here is this.

Therefore, I get this corresponding to the latent heat and therefore, mv divided by m is equal to h fa minus h fb divided by hfg. This is in terms of the enthalpy. Therefore, I find this is the mass of water and, what is the energy locked in? The energy locked in is this amount, which is also equal to the value of mass of water evaporated into hfg so, much joules. And it is this energy which drives the explosion or equivalently, we can tell, well you know you form vapor which is a very much higher volume, compared to the initial volume which is very much smaller.

And since, I generate some vapor having large volume well, I increase the pressure inside my particular appliance, or inside my volcano, or inside my furnace, and I generate a blast wave. And this is the mechanism by which a flash vaporization drives explosion. Let us do this one particular numerical example so that, things become more clear, let us take this example of the Flin Flon incident.

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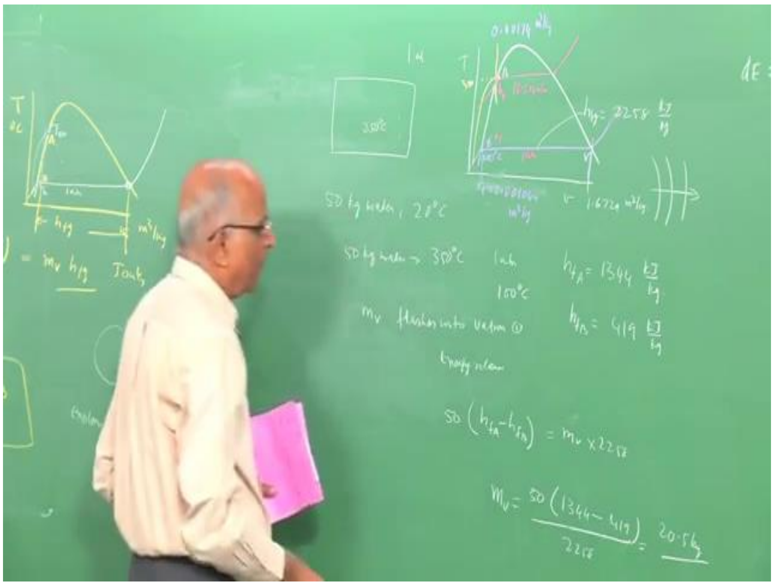

Let us assume, that may be in a particular furnace, which is kept at a temperature you know the operating temperature of the furnace would have been higher, the furnace has cooled down to 350, but as it takes more and more time to cool as the temperature decreases. You know what people do is, they take some water, they take some 50 kg of water, maybe at the ambient temperature, that day the temperature was let us say 20 degree centigrade and throw it into this particular furnace. And let us also assume, that the thermal inertia of this furnace is large because, furnace has a large mass anyway compared to 50 kg of water.

And therefore, what happens this 50 kg of water, immediately when it is exposed to this particular temperature that is all along, it just touches the metal it increases the temperature to something like 350 degree centigrade. And therefore, at 350 degree centigrade the ambient pressure is still 1 atmosphere the furnace is exposed to the ambient. And therefore, it is still at 1 atmosphere pressure wherein, the boiling temperature is equal to 100 degree centigrade.

Therefore, what happens is, the water just flashes into vapor. I want to calculate the mass of water which evaporates point one, or which flashes into vapor, point 1. And second, I also want to calculate the energy released in this particular flash evaporation process. Therefore, we again draw the T V diagram because it is the simplest thing to do, or we could use the formula what I derived earlier, in terms of fraction is equal to 1 minus e. But then we need the value of Cp we have steam tables, we have tables for all the liquids, we can do this particular problem.

Therefore, when I draw this I again note on the T V diagram where V is the specific volume, T is the temperature. The ambient line, let us draw the ambient line, ambient pressure line, 1 atmosphere pressure, 1 atmosphere pressure, 1 atmosphere. The temperature here is 100 degree centigrade over here, and the volume, if I were to make a note of it at 1 atmosphere pressure, the specific volume that is v f that is v of the water at this particular point.

Let us use the same terminology, we use A and B, we said well this is the point B, at which the boiling temperature which is the stable point v f is equal to, we take it as 0.001044 meter cube by kilogram. What happens is, the water is at 20 degree centigrade, somewhere over here. You suddenly throw it at a temperature of 350, you suddenly increase it to this value even though the pressure is atmosphere because, the body is this. It attains the temperature of the body this is what the temperature is like, this is at 350.

At 350, the specific volume is equal to 0.00174 meter cube by kilogram. The pressure corresponding to this particular point of 350, if I were to draw the constant pressure line, through this particular point the pressure corresponding to this red line is going to be 16.514 atmospheres. Therefore, what is happening is, the moment I throw water at 20 degree centigrade, it reaches this temperature 350. It can be in equilibrium only at this particular pressure because, this temperature, but it cease only the ambient pressure of 1 atmosphere here.

And therefore, I find yes I need to evaluate what is the value of enthalpy over here, what is the value of enthalpy over here. This is the energy locked in for unit mass of substance let us put down the, let us get the values on the steam table. I have h f corresponding to point A over here, h f A is equal to if I look at steam table I get the value of h f A is equal to 1344 kilojoules per kilogram.

If I take the value h f, at B point B which is the normal boiling point, normal boiling temperature, of the saturated liquid at 1 atmosphere pressure. The value is 419. And the last thing is, the latent heat of water that is the heat required to change the state, from B to the evaporation condition over here that is the saturated vapor. The heat require to go from here, there something like hfg latent heat, which is equal to at 1 atmosphere pressure it is 2258 kilojoules per kilogram.

Therefore, if I were to solve this problem, what is it I am looking at? Let us say the original mass of water is 50 kg. The excess heat which it contains at this particular point is equal to h f A minus h f B over here. Because, this is stable, this is pseudo stable, this is the heat which is contained, and how much of it evaporates mv evaporates into steam, and how much is there to be able to evaporate it needs 2258. Or rather, the mass of water, mass of vapor formed is equal to 50 into h f A is 1344 minus, I have 419 divided by the latent heat which is 2258 and this comes out to be equal to something like 20.5 kg.

Now, what we find is, if I take a look at the volume of vapor here, the volume here corresponds to 1.6729 meter cube by kilogram. That means, you know the 20.5 kg of steam at this condition is formed. It as a volume which is may be more than 1000 times this original volume. And therefore, you find that it just generates a high pressure within the furnace, and you have something corresponding to this energy I have a wave which is being formed. And therefore, this flash vaporization leads to a blast wave, which causes an explosion.

I should not really be talking in terms of the pressure being formed. All what I say is a large volume of vapor is being formed, which results in an explosion. And this is the phenomenon behind an explosion. And therefore, to sum up what we have been talking today is, maybe we are telling, that a physical process like sudden a vaporization.

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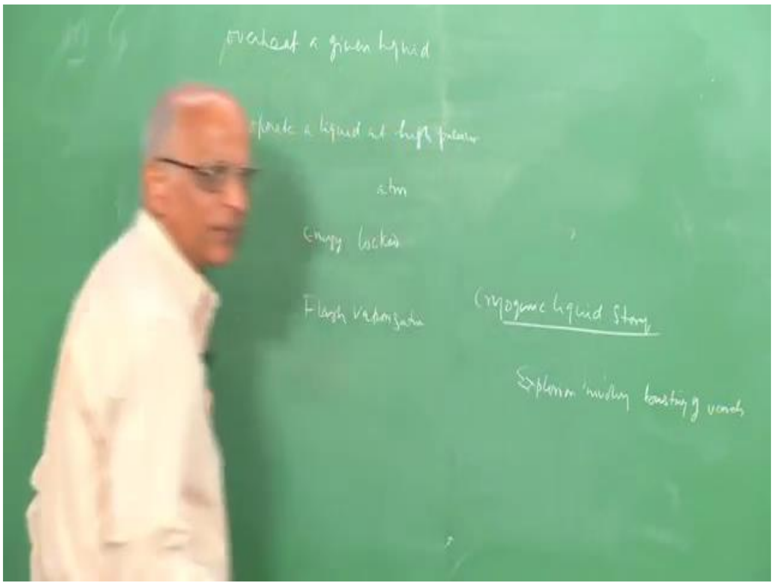

Because, we either over heat a given liquid, or it could be any liquid or else we operate a liquid like we say butane at high pressure. And when we relax the high pressure to the atmospheric pressure, or when we overheat the liquid at atmospheric pressure, there is some lot of energy which gets locked in. And how do I calculate this energy in this particular example which we forgot to do?

Well the energy which is locked in is, well 20.5 kg of vapor, into the latent heat 2258 is the amount of energy which is locked in this, or alternately, I just say 50 into 1344 minus 419 so much kilojoules is the energy which is locked in. And this gives me the value of energy which is locked in, which in turn drives the explosion. Well, this is all about the case of flash vaporization. But flash vaporization has a lot of applications and it leads to different types of explosions involving, maybe the cryogenic storage, cryogenic liquid storage.

We will talk in terms of some explosions involving cryogenic liquids in the next class. But we will also see whether, we will talk in terms of shock waves and it is quite possible that the vapor also condenses, under some critical conditions. We have something like a Meta stable vapor being formed, it could also drive a blast wave. Therefore, we will talk in terms of cryogenic liquids and vapors, and also we will take a look at explosions involving maybe bursting of spheres in the next class.

Well, thank you.