Introduction to Explosions and Explosion Safety

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Lecture - 30
Dust Explosions: Parameters of Dust Explosions
Ignition Energy
Violence, K st Values
Ignition Sensitivity
Explosion Severity
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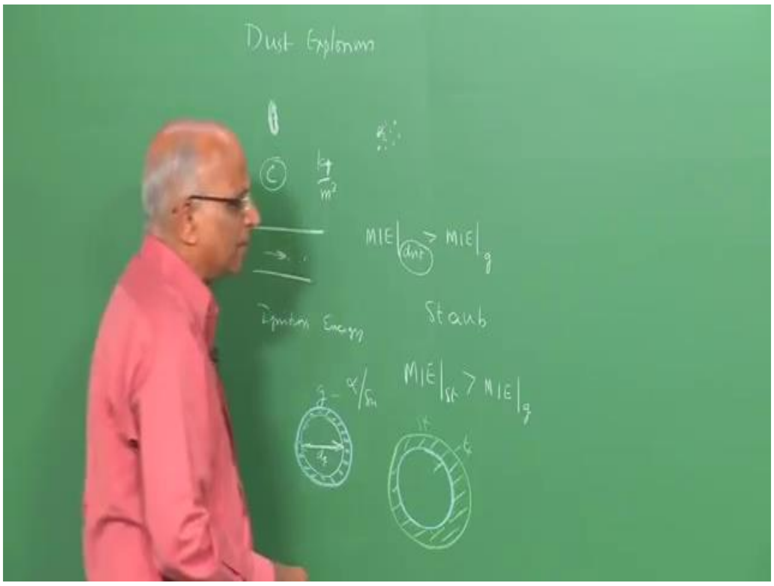

Good morning, you know we already discussed yesterday about fine particles of dust when distributed in air and if some ignition source is present, in the dust particles since they are of small particles they readily ((Refer Time: 00:28)), release the let us say the hydrocarbon vapor if it is organic. This hydrocarbon vapor mixes with air forms a combustible gas which can then burn or which can detonate and in which case we can also have something known as dust Explosions.

We also learnt how to estimate the concentration of dust which we said had units of kilo grams per meter cube. For the particular case when dust falls under gravity or when it is forced by air like it is under forced draped in a pipe when dust is smeared all along. Having learnt how to determine the concentration of dust and also beyond a certain concentration of dust in air, we found that it is an explosive we wanted to determine what is the type of ignition possible.

You know we wanted to determine what is the ignition energy required to start off a dust explosion. We readily find since dust is in the initially in the solid state smeared in the air and the duty of the ignition source is first to make sure that the dust particles release the hydrocarbon vapor or if it is some other substance release the vapor of the particular substance. Well the minimum ignition energy for the dust particles should obviously be greater than the minimum ignition energy of the same vapor or let us say in this case it releases hydrocarbon gases. It will be greater than the minimum ignition energy of the particular gas in the air mixture.

Therefore, we say well minimum ignition energy of dust is expected to be greater than the minimum ignition energy of the gas and when we say dust, you know dust is normally denoted by the symbol s t. The symbol s t comes because you a lot of work on dust explosions happened in Germany and they are pioneers in dust explosions and dust and German is known as staub s t a u b. Therefore, we show the value of minimum ignition energy s t meaning dust is greater than minimum ignition energy for a gas.

For the same gas mixture, for the same dust air mixture, the minimum ignition energy for the dust air mixture is greater than for the gas mixture. You know for a gas we said well I need to form a flame kernel. The flame kernel has to be of the size greater than the quenching distance and around the flame kernel what is it we have to do? We have a thickness of the flame which is to be ignited by this particular kernel of gas.

And therefore, the minimum ignition energy corresponds to the volume that means the thickness of the flame around the flame kernel which must be ignited and this is how we estimated, the minimum ignition energy for a gas. If we have to do the same thing for a dust mixture you know what is happening I am talking of a kernel of ignition for a dust mixture and around it. You know, I have the dust particles and the dust particles have to initially vaporize and mix.

Therefore, the expected thickness of the flame is going to be larger. In other words, the thickness of the flame is going to be more for the dust air mixture than for the equivalent gas mixture and since the flame thickness is larger, I require a larger kernel size to be able to ignite it. And the volume of the gas which is required, or the energy required must correspond to the diameter that is the surface area into the particular thickness over here.

And therefore, the minimum ignition energy for the dust mixture will be much greater than for the equivalent gas mixture. Having said that, you know to estimate the thickness of the flame in a dust air explosion or dust air flame is going to be more difficult than we estimated it, mind you for a gas we estimated is equal to the thermal diffusivity divided by the flame speed it is going to be more difficult. And we experimentally evaluated in some apparatus known something similar to the Hartman tube.

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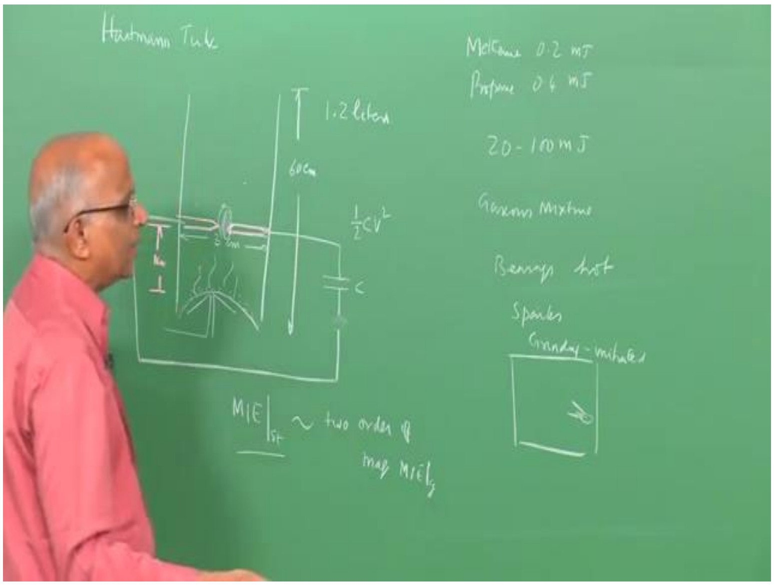

You know, what is this Hartman tube? It consists of, it is a modification of the original Hartman tube in which it is a straight pipe, at the bottom of the pipe you know what you do is you have a shape like this, you have a shape like this on which may be the dust are given over here a mass of all the dust particles are accumulated over this particular shape. And the diameter of this particular tube is typically around 3 centimeters and the length of this particular tube is something like 60 centimeters giving the volume of this tube is something like 1.2 liters.

Now, what is done is through this particular shape what is done is you allow compressed air to come, this is all porous bottom surface and you allow the compressed air to grow the dust into the mixture typically at a pressure of around 4 bar or so. It is forced and what happens, the dust comes up along with a u form a dust air mixture in this particular enclosure. This is a transparent pipe and into this transparent pipe or tube as it were what you do is you provide something like at a distance of something like 1 centimeter from the bottom you put two electrodes and create an electrical spark something like this you create an electrical spark over here.

How do you do that? You connect the electrodes to a capacitor which is charged to high voltage and this capacitor discharges across these two electrodes. That means I will have something like a power supply which charges the capacitor to high voltage and then you discharge it. And the energy released by the high, by the capacitor charged to high voltage is something like half capacitance into v square.

I know the energy which is released in this gap I disperse the mixture in this particular volume as it were and then I find out what is the minimum energy required. I do a series of experiment, find out when it ignites, I slightly reduce the energy make sure that before the reduced energy it does not ignite at all may be in 10 out of, 11 out of 10 experiments it must not ignite at all. And therefore I determine the minimum ignition energy for the dust explosion.

Therefore, I know how to create the minimum ignition energy and since the thickness of the dust explosion is much larger than the flame and we also say intuitively that the minimum ignition energy is greater than the, for the gas things. You know when we find that these values are something like two orders of magnitude greater. That means something like almost 100 times greater than for two orders of magnitude greater than minimum ignition energy for a gas mixture.

Now, we know when we look at the gas mixtures we found for something like hydrocarbon mixtures like methane for something like propane, propane air mixtures, methane air mixtures, the ignition energy is where between 0.20 milli joules. Something like 0.4 or so milli joules. And when we talk of dust air explosions the ignition energies are typically between 20 to 100 milli joules.

That means typically about 100 or larger. Therefore, we find well to ignite a dust air explosion is not going to be that easy as it is to ignite gaseous mixture, but then we must realize that yes in practice yes we do get such type of energy release. May be if we have bearings which are supplying the dust to be hot, well I can have these type of ignition energies I could have electrical sparks which can deposit energy by arch discharge which can typically of a few 100 milli joules.

I well, I could even have you know in a dusty environment supposing somebody is having a grinding wheel and sparks are flying. Well the sparks from the grinding wheel can as well initiate a dust explosion and dust explosions are initiated and are source of problem like what we discussed today it happens all the time in food industry. However, if the confinement is open that means unconfined geometry. Then in that case, you know the occurrence of dust explosions.

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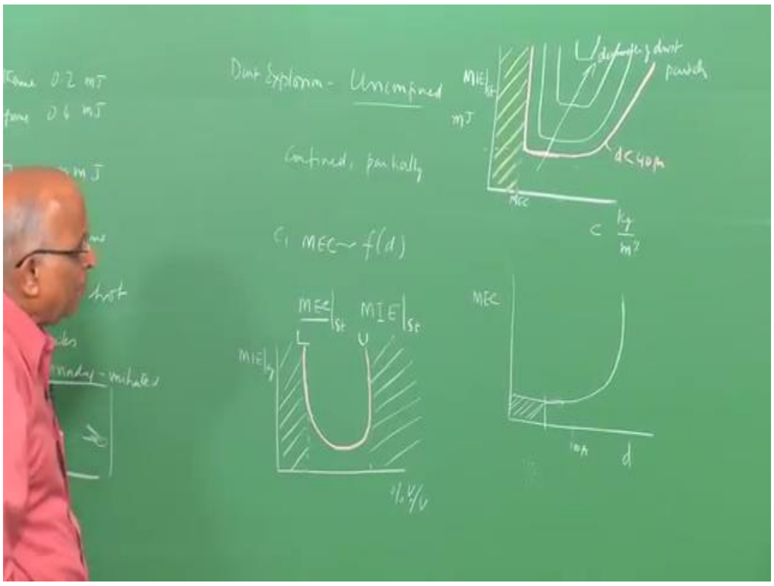

In an unconfined geometry, like a very open space just because it relaxes it is not possible for dust to be collected and we need a certain minimum ignition energy or an ignition time and during that time you know what will happen in an unconfined geometry, the dust particles may not be there to sustain the ignition. And therefore, in an unconfined geometry it is not possible, but any confined or partially confined geometries well dust explosions is a source of danger.

Therefore, we say yes this is all what we learnt, we learnt all about finding the concentration, we also talked of minimum explosive concentration what is required to cause the dust, we related it the minimum explosion concentration to the diameter of the dust particles. You know can we go ahead from this and put all the things together.

Like for instance, yes we talked in terms of minimum explosive concentration. We also talked in terms of, today we were talking in terms of minimum ignition energy for a dust mixture. Therefore, we are talking of minimum ignition energy, minimum ignition energy MIE, we talked of MEC minimum explosive concentration. Are there some relations? You know like for instance we had the gaseous mixtures we plotted percentage volume of the fuel vapor or volume of fuel in the volume of the mixture as a percentage of minimum ignition energy for a gas and we found below some threshold value of the fuel in the volume of the mixture the gas just does not ignite.

We also said, above a certain threshold value well the gas does not ignite and when the gas does not ignite what does it imply? Well even if I give infinite energy the gas cannot ignite. And therefore, the shape of the minimum ignition energy versus the percentage volume of the fuel in the volume of the mixture has a typical curve something like this, something like this followed by a flat bottom.

That means you have a u shaped curve. This is the type of curve we have a minimum ignition energy for a gas versus the percentage volume. Is it possible to generate an equivalent curve for let us say minimum explosive concentration for a dust mixture s t for a minimum ignition energy for a dust explosion dust we said is s t. And therefore, what will this curve look like. Can I plot some equivalent curve here.

Therefore, let us try to plot it over here. Well, I have concentration here. I talk concentration of the dust particles. Let us say in so much kilogram per meter cube. I talk in terms of minimum ignition energy for a dust mixture in terms of let us say milli joules because the energy level is of the order of milli joules and what is going to happen we said just like in a gas mixture. We also found yesterday that well below a certain threshold value of concentration, well the mixtures just does not ignite what happens is this is something which cannot ignite at all. What did, how did we come to this?

We said well, I plot the diameter of the dust particles over here. I plot over here the minimum explosive concentration MEC for the dust mixture and what did we find well if the diameter is quite small. Well, I have some minimum concentration is required such that flammable vapor air mixture can form just at the limits of claim ability.

And therefore, I requires a minimum explosive concentration when the diameter is typically less than around 100 micron or so below 40 microns it is constant above that it slightly increases. And when the diameter exceeds something like 120, 130 microns, well the particles of dust can no longer vaporize and form this mixture and this is the type of curve we have.

Therefore, this is the absolute lower value corresponding this. That means I must have minimum explosive concentration corresponding to this and this is the value what is given this is equal to MEC over here corresponding to the small diameter dust particle. And therefore, the energy for ignition if I were to plot it on same curve well over here the energy is very large at this I have a threshold value of ignition energy which comes like this. As I increase the concentration, well I am able to form the gas the minimum ignition energy is at this level, but the moment a large number of dust particles accumulate.

Well it gets starved of air, not only that may be you have pockets in which I have rich dust and weak dust and with the result the ignition energy goes up. Therefore, the shape of the curve is going to be a straight line, followed by a line followed by an increasing line. For the typical case, in which the diameter was less than around 40 micron, the dust particles if the size of the dust particles went up well the minimum ignition energy goes up like this.

Well, if it is the diameter is still larger if the diameter is very large ultimately if the diameter exceeds this it cannot ignite well this is the place of the increasing diameter of the dust particles. Therefore, we will find well the minimum ignition energy for a dust particle corresponds to the case when for a threshold value of concentration exceeding some limits. But less than some limits sits there and this is the figure corresponding to the u shape curve corresponding to u and l lean flammability, limits upper flammability, limits of a flame and this is the type of figure of, what we should get for a dust explosion.

It is time to go forward and try to see whether we can also get some figures for the maximum pressure, maximum violence of the explosion involving the dust mixtures.

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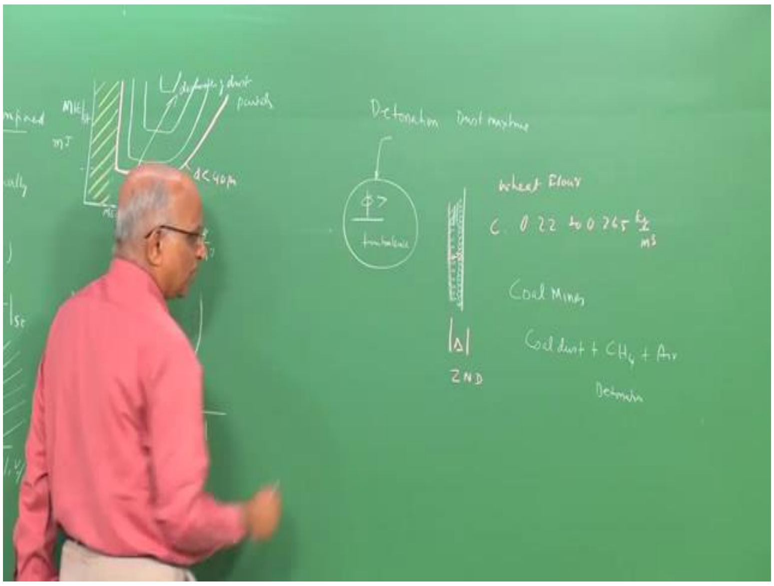

But before we do that let us just spend a couple of minutes on may be is detonation which is much more violent than burning or let us say flame in a dust mixture. Is detonation in a dust mixture possible? And if detonation in a dust mixture is possible, in the one dimensional modal of a detonation well we should be able to form a shock wave.

A shock wave is formed by the ignition source behind the shock wave well you have the dust particles which volatilize release the vapor. The vapor has to mix with air and then well the chemical reaction should go on and it is this chemical reaction which occurred behind the shock wave, which should drive the detonation. Therefore, we say well immediately will tell, you know we talked in terms of an induction distance behind the detonation and we talked in terms of a one dimensional model, which was the Zeldovich Von Neumann Doering model of a detonation.

Is it in the model of detonation? Well, in this the thickness of a detonation is large, but it is still possible under the condition that the total induction distance, if it is still, not to large, it can still maintain a detonation at high speeds and cause a large value of pressure. And such type of detonations have been observed, may be in wheat flower. Mind you, we are talking of wheat which is grown, typical dimensions being 40 micron to 60 micron wheat flower and for concentrations between 0.22 to 0.265 kilo grams per meter cube concentrations.

Well, detonation is possible. Why not only for wheat flower, we also have in the mines. In the mines, wherein let us say coal mine we take. In the coal mine people remove the coal and in the process have the dust of carbon whole dust is available. Therefore, you have coal dust in the mine sometimes methane gas is also available and this with air that means dust along with a fuel gas and air also form severe detonations at high pressure and the dust explosions or dust detonations are also possible.

Therefore, we say well dust is as dangerous as a gas, as long as the dust size is less than some threshold value. If the dust particles are of large size well it is not a problem, but we also must remember that if the humidity of the medium is large then you know it is difficult to volatilize the dust. And therefore, may be relative humidity turbulence are additional factors, which influence the formation of dust explosions. Having said these things, it is time to determine the maximum pressure from a dust explosion. Therefore, let us put the last point across. For the particular case of gas explosions, what did we tell?

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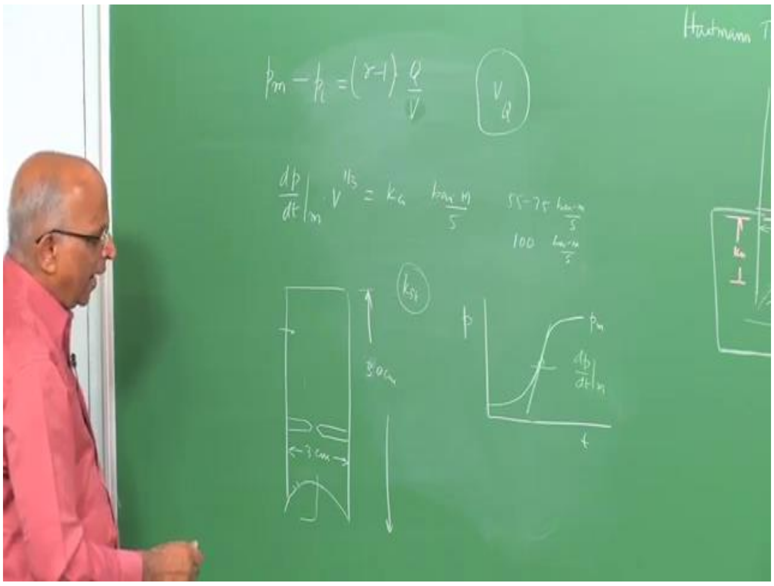

The maximum pressure of gas mixture in an enclosed vessel minus the initial pressure is equal to gamma minus 1 into the energy density. Energy released in the particular volume of the enclosure that is a fixed volume divided by the particular volume of the enclosure.

That is a fixed volume of V, energy release or heat release is Q, gamma is the specific heat ratio of the gases the maximum pressure is related through this particular expression. We also had an expression for dp by dt maximum into volume to the power 1 by 3 was equal to K G, where K G denotes the particular violence rate. The unit is equal to bar into V to the power 1 by 3 meter divided by t second. So much K G bar meter per second and we said for hydrocarbon gases typically the value is around 55 to 75 bar meter per second.

For the case of hydrogen air mixture, it is much higher of the order of may be 100 or 110 bar meter per second. What are the values for the dust mixtures? For the dust mixtures we would be interested in kst we would be interested in the maximum pressure and such maximum pressure and dp by d t. You know it is difficult to calculate like in the case of a, we did do these calculations we use the, we use the internal energy of formation and calculated the value of Q, we calculated V, we were able to calculate this. And unfortunately for the dust mixture it is a little more difficult and again what we do is we have the Hartman tube as it were.

Now, in this case it is made of solid material and in this case the dimension is a little smaller of the order of 60 centimeters length. You know it should be 30 when we had the ignition test in the transparent it was a little larger. In this case, it is of the order of 30 centimeter, the diameter is around 3 centimeters.

Again, we have the dust being smeared from the bottom, you allow the dust to get smeared. We allow an ignition source to ignite it may be a high voltage ignition source and then we measured the value of pressure with respect to time, rather we determine the value of pressure as a function of time pressure gets started reaches the maximum and we measured the pm, that is the maximum value of pressure and the maximum value of dp by dt for the dust mixture. And where does the dp by dt maximum occur? It occurs at the inflection point and at the inflection point we have a slope over here and this slope is what is dp by dt maximum. Therefore, we measured this pm and dp by dt maximum and we used this to calculate the net violence of a particular dust explosion.

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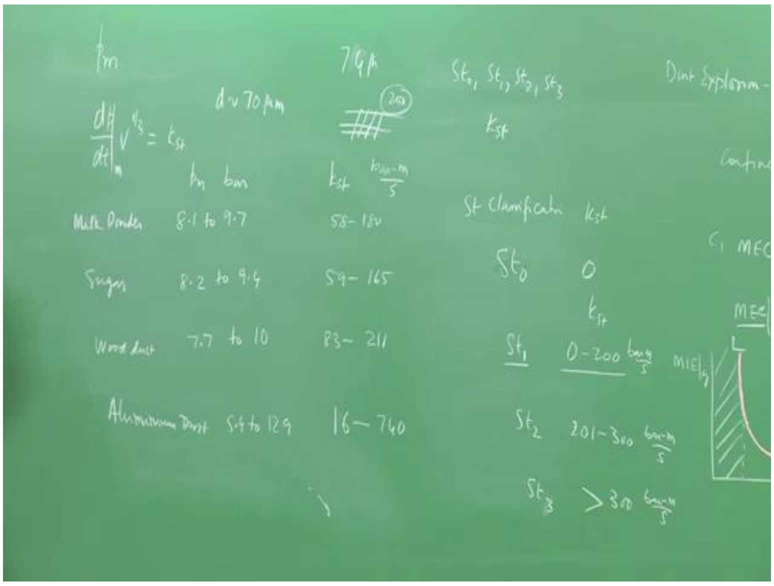

Let us see how to calculate it. Let us say, the consequences of an explosion are the following. The two consequences are, well I have a high pressure, I also have dp by dt into V to the power 1 by 3 is equal to kst because it is dust. And typical values of kst for a dust are somewhat higher than for hydrocarbon gas mixtures. Let us put some values for Pm and dp by dt for the dust mixtures.

Well, if I if I take the value, let us just consider for simple cases milk powder. Milk powder of small dimensions typically 40 micron to 60 micron particle size of milk powder, the value of the maximum pressure what we get is something like 8.1 to 9.7 bars or atmospheres. If I have something like sugar, yesterday we talked of sugar we said it is sucrose and the values are very near to milk powder 8.2 to 9.4.

You find it is over a small region between 8.2 to plus minus 1 or so. Right? 8.2 to 9.4. If I take wood dust the scatter is even higher because depending on the type of wood namely you have something like 7.7 to something like 10. Mind you, all these are based on dust particle diameter being of the order of 70 micron. You know, somewhat not talking of the very low threshold value of 40 to 50 micron of this order and if you say 74 micron, if I say the dust particle is 74 micron size, it means through a sieve of size 200, sieve size I get a diameter of 74 micron. Therefore, corresponding to 200 is used. What is used as a standard.

Therefore, you have wood dust, the peak pressure 7.7 to 10 and the last one we take may be aluminum dust, the peak values are 5.4 to 12.9. You know, these values you know when we consider these are also hydrocarbon substances or organic substances. These are higher than the value of maximum pressure which we saw was between 5.5 to 7. This is the type of values we get for P m. When we take the values for the kst values, What is k s t? Is equal to dp by dt maximum into volume to the power 1 by 3 is kst value. And the unit is bar meter per second. For the milk powder, the value is something like 58 to 180, well a huge scatter 50 to 200, that is the type of value.

For sugar it is also, similar 59 to 165 bar meter per second. When we talk of wood dust, it is little higher 83 to something like 211 bar meter per second and for aluminum powder well the scatter is extremely large something like 16 to 740 bar meter per second. Therefore, you find in all these cases you know the scatter is large in fact the scatter for the kst value is higher than the maximum value what we determine in this experiments.

And the reason for the scatter is the thing is that you know it is very difficult to have consistently the same diameter dust particles of same concentration in a given medium and again turbulence may be the effect of other factors like you say the agglomeration in some particular place, turbulence tends to agglomerate. You have gradient and these are factors which tend to scatter the results. And therefore, whenever we talk in terms of dust mixtures, there is a tendency to not talk of precise numbers, but to put in terms of classes of dust. You know, what do you mean by classes of dust?

We said dust is denoted by the word S t from German being staub and when we say S t corresponding to 0 class of dust is 1 for which let us say S t classification let me put that down, it is very simple, we say S t classification of dust. We say when S t corresponds to 0, well I say it corresponds to S t 0, the value of kst corresponding to this is 0. That means there is no possibility of a dust explosion that means, the rate of pressure rise is 0. When I call of class one that means S t 1 class we say well the kst value is between 0 to 200 bar meter per second.

In other words, most of the organic substances like wheat flower, sugar, powdered sugar, may be corn flower. All the most of the organic substances are within this range which we call as S t 1 or the class one type of a dust. When we say S t 2, we mean values of kst between 201 to 300 bar meter per second. That is moderately high and these correspond to something like wood dust, good wood with if in fine powdered form can generate a high pressure, we call it as second class or S t 2 type of classification. And S t 3 corresponds to kst value greater than 300 bar meter per second.

That means these are a little violent and one must be careful. Essentially, the metal powders correspond to the higher values of S t, kst or rather when we say this is the kst values and we say that the classification is S t 3. Therefore, we classified dust into S t 0, S t 1, S t 2 and S t 3. For these depending on the kst values and kst is dp by dt maximum into v to the power 1 by 3.

However, we must remember one thing when we talk of metal dust, you know it is not that the metals essentially volatilize and the volatiles of the metal burn, but in case of many metals what happens is you talk of surface combustion and you know it is the surface combustion which dominates. And therefore, we must be careful when we interpret the results of may be metal dust which give rise to dust explosions.

Having said that, let us go still further and try to see whether we can put the ignition, whether we can put the severity of the explosion. Having talked of Pm and also dp by dt m that means the maximum pressure and the maximum rate of pressure rise.

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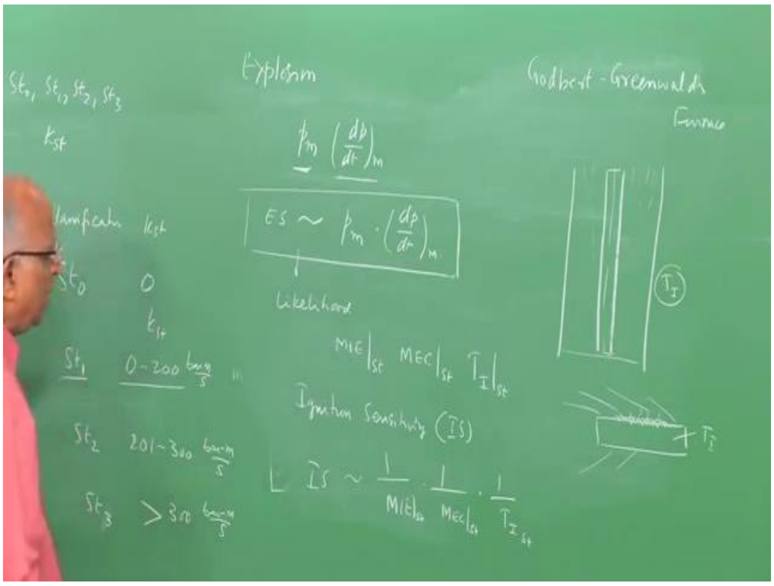

Well, we say when an explosion takes place rather when a dust explosion takes place, you have maximum pressure here the maximum value of dp t by d m. And therefore, I can now define explosion severity of an explosion that means the consequences of an explosion depends on the severity and see it is more severe when the Pm value is high, that is the maximum pressure is high. When the value of dp by dt maximum is high.

Therefore, I can say well the explosion severity will be proportional to the maximum pressure and also the value of dp by dt m. That means that the explosion severity is the product of Pm into dt by dp maximum value. If I say, well the consequence of an explosion can be seen by this particular expression. It does not tell us, it tells us only about the consequences. But it does not tell us anything whether the explosion is likely to occur.

That means even though it tells, if the explosion occurred, I would get an explosion severity of this order. It does not tell us on the likelihood of the explosion to occur and for likelihood of an explosion, maybe I must have the explosion to occur that means, if the minimum ignition energy is small, that means minimum ignition energy of the dust mixture is small, if the minimum explosive concentration of dust mixture is small.

Further, if the ignition temperature of the dust mixture is also small, well it is more likely to get into an explosion. This just says, if an explosion had occurred the severity would be so much, but for the explosion to occur well these three things should be as small as possible or rather, what does it say? What is the ignition sensitivity? What is the likelihood of ignition taking place or rather the ignition sensitivity of a dust explosion to occur should go as small.

Or rather it should go as 1 over minimum ignition energy for a dust mixture into 1 over minimum explosive concentration for a dust mixture into something like 1 over minimum ignition temperature, minimum explosive concentration for a dust mixture. Minimum ignition temperature for the dust mixture, this will be proportional to the let us say ignition sensitivity. I denote by I s. Well, I s should be proportional to this.

See, we have talked how to determine the minimum ignition energy using the Hartman tube which is a transparent form of a Hartman tube. We said well, I can determine minimum explosive concentration in the same experiment by finding the concentration at which it ignites. You know to get the temperature of ignition we use a furnace and this furnace is called as the Godbert Greenwald Furnace.

You know, in this furnace you have something like a pipe or something like this. You have a particular material here which is at constant temperature. The temperature can go to something like up to 800 degree centigrade. You allow a dust mixture to pass through and when the temperature of this particular central piece which is kept at constant temperature is able to sustain the ignition, right up to when the dust reaches the bottom. We say, that should correspond to the ignition temperature that means the temperature of this particular rod here which is kept at uniform temperature is able to ignite the gas and this is how we estimate the temperature of ignition.

It is also possible. In Germany, they have used may be a horizontal configuration of a similar system in which the dust mixture is allowed to come and fall on this constant temperature rod or an object. And when this happens, there is some level of accumulation and we saw when there is some accumulation. You know, what happens is initially you could have something like sublimation taking place and afterwards there could be a flash over and after a flashover that could be something like a secondary explosion. And therefore, the temperature what is measured in this particular configuration tends to be a little lower than this.

However, we always say well an ignition temperature could also be measured and the ignition sensitivity is proportional to this. Therefore, we are saying well explosion severity is product of Pm and dp by dt m. Ignition sensitivity is product of 1 over minimum ignition energy, 1 over minimum explosive concentration, 1 over the ignition temperature product of these three. But you know, we find there is a lot of scatter in this particular results what we obtained. We saw some values dp by dt scatters over a large range, Pm there is a smaller scatter.

Similarly, there is scatter in this, scatter in temperature of ignition. And therefore, it becomes desirable when we define explosion severity namely as a consequence of the explosion and ignition sensitivity as the ease with which an explosion, a dust explosion could occur. Can we put some standard and compare it with respect to some standard so that these things become more meaningful. And that is what we will do now. You know and the standard which is adopted is what we call as the Pittsburg coal.

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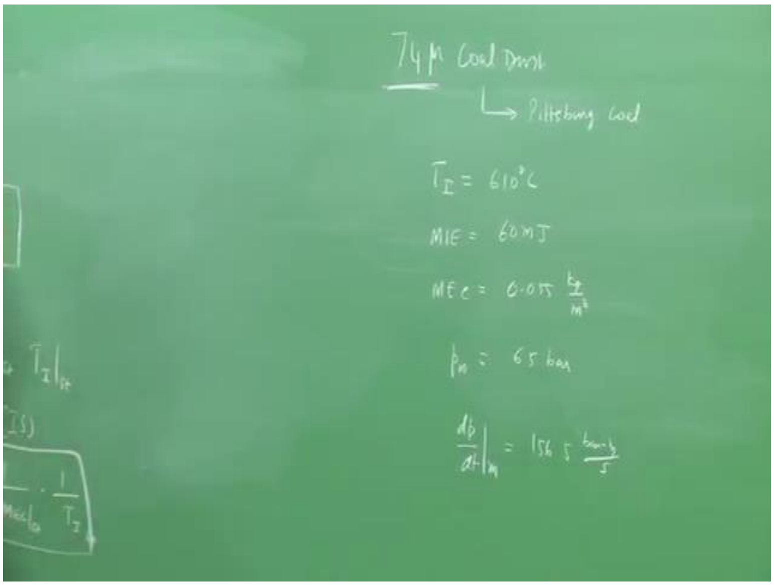

It is a 74 micron sized coal dust and the coal which is used is the Pittsburg coal, coal mine from Pittsburg. You know because each coal has its own characteristic and the values of the Pittsburg coal which are used are the temperature of ignition of the Pittsburg coal is something like 610 degree centigrade. The minimum ignition energy of this coal dust is 60 milli joules. The minimum explosive concentration is equal to 0.055 kilograms per meter cube. The maximum pressure of this particular coal dust is equal to 6.5 bar and the value of dp by dt maximum is equal to 156.5 bar per second.

This is the standard with which we compare. And therefore, if we have any other sort of a dust mixture, we would like to compare it with this particular Pittsburg coal which is of 74 micron size. And therefore, how will I now define my explosion severity and ignition sensitivity? Let us start, get started with ignition sensitivity. For how will I define? Well, I know ignition sensitivity is given as the inverse of 1 over MIE for the dust mixture, 1 over the minimum explosive concentration for the dust mixture, 1 over T I for the dust mixture.

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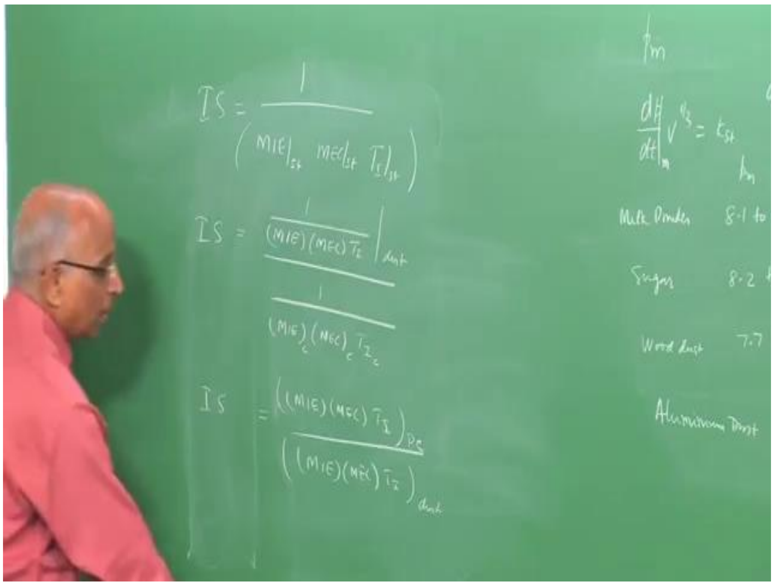

And now, if I were to say this is for let us say any dust mixture and now I want to say what is the ignition sensitivity for this particular dust mixture. Therefore, it is going to be 1 over this particular expression, let us write it again, 1 over M I E into 1 over MEC into 1 over T I for the given dust mixture divided by 1 over I have minimum ignition energy into minimum explosive concentration and the ignition temperature all for these standard coal dust of standard Pittsburg coal dust of 74 micron size and this becomes the relative ignition sensitivity of this dust mixture which works out to be MIE into MEC into T I for the particular case of the Pittsburg coal divided by MIE into minimum explosive concentration into ignition temperature for the particular dust mixture which we are evaluating and this becomes the ignition sensitivity.

Now, you know I would like to generate some numbers for this, but let us put the definition for explosion severity and then put the number together. If I were to similarly, take the case of explosion severity, well you know yes it depends on the consequences we are looking at the Pm into dp by dm.

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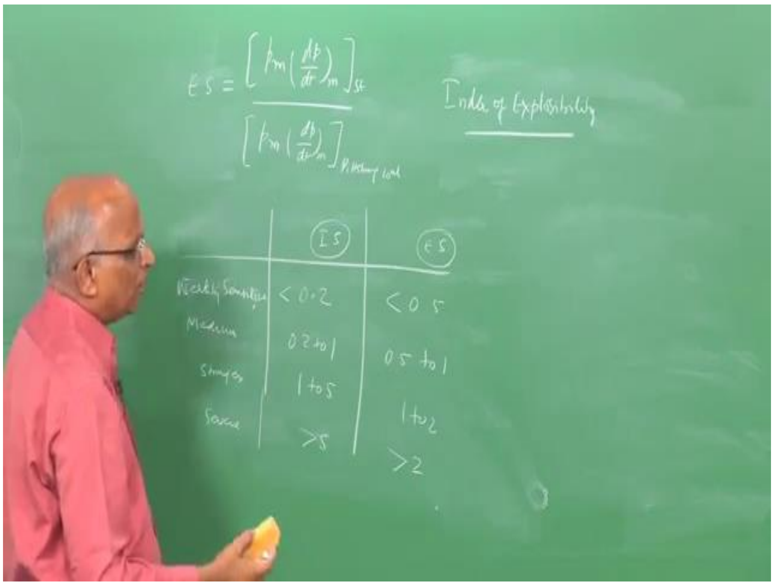

And therefore, when we say explosion severity, we are talking of Pm into dp by dt m for the particular dust mixture let us say divided by, I want to compare it with the Pittsburg coal. I have Pm for the Pittsburg coal dp by dt maximum for the Pittsburg coal over the denominator is for the Pittsburg coal.

And well, the values for the Pittsburg coal are available we just looked at the value of P m, we say Pm is round of the order of something like 6.5 bar dp by dt is equal to something like 156.5 bar. Similarly, we know the values of the M I E, MEC for T I. And if I can determine the values for my dust mixture, I can find out the relative value of explosion severity and the explosion and the relative values of the ignition sensitivity. Let us put down the values of the ignition sensitivity, let us put down the values of explosion severity for a few cases, in which we are comparing it with the standard coal mixture.

When we find that the ignition sensitivity is of the order of 0.2 for a given dust mixture may be it could be from something like 0.2 to 1, it could be between 1 to 5 in which case it is. You know this is relatively weak one compared to a Pittsburg coal, it is one-fifth of this. Therefore, let us say it is something like a weak explosion that is it is weakly sensitive, it does not immediately get into a sensitive. It does not readily get into an explosion 0.221, it is somewhat tending that it is, let us say medium 1 to 5, well it is much stronger than the Pittsburg coal.

If it is much greater than 5, well it tends to be very severe compared to the Pittsburg coal. Therefore, these are the relative grading of ignition sensitivity and depending on the mixture what we have, if the mixture is between 0.2 to 1 it is medium and most of the cases of our organic flowers fall in this category, wood dust falls in this category and when we say severe metal dust and some other substances fall, some other dust fall in this particular category. When we talk of explosion severity the values are somewhat different.

If it is less than, let us say 0.5 well it is not as sensitive as Pittsburg coal. If it is between 0.5 to 1, well it tends towards the Pittsburg coal, it is medium. When it is 1 to 2, the explosion severity in 1 to 2, it is stronger than Pittsburg coal must be careful. It is greater than 2, well it is much more severe than Pittsburg coal. But you know, some people instead of using to evaluate the sensitivity based on ignition sensitivity that is the proneness for the explosion to occur and consequences of the explosion through explosion severity, they define another term.

And that another term is known as index of explosibility. What we mean by index of explosability is, you know we want a single term, this is something like likelihood and the consequences. We want the net hazard of the dust explosion to be very clear that means the dust includes both the sensitivity and the consequences together and the index of explosion…

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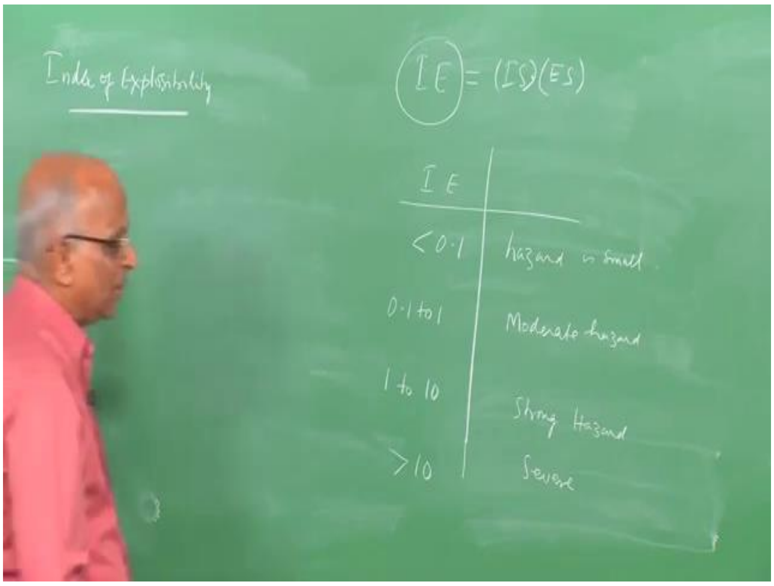

Index of explosion denoted by I E is product of the ignition sensitivity and explosion severity. That means ignition sensitivity into explosion severity is index of an explosion. And therefore, putting these figures together we tell ourselves with the, if the index of explosibility the value is less than 0.1, well the hazard is small. Well it is not likely to get into a dust explosion and even if it get into an explosion, the maximum pressure and dp by dt are not going to be very severe.

Therefore, we say well hazard is small if the value is between 0.1 to 1, then in that case well there is a significant hazard that means we are talking of a moderate hazard. The hazard is almost similar to what our Pittsburg coal dust has. It is moderate hazard. If it between 1 to 10, that is the index of explosability is 1 to 10, well it is a, it is a strong case, strong hazard must be careful to use it because the consequences as well as the sensitivity are larger, if it greater than something like 10, well it is severe and one has to guard against such dust explosions. And this is the way we categorize the explosions in terms of index of the explosability as it is for a dust mixture.

Therefore, this is all about dust mixtures and in the dust mixtures what we learnt are yes it is possible to have explosions in dust air mixtures. Especially, if the dust particles are small, the food industry especially we talk in terms of different organic substances. We also talk in terms of different types of dust may be the wood dust, may be the other types of dust which are available. They all can explode and if it explodes you have a large value of P m, large value of dp by dt that means you have explosions severity which is high.

And therefore, may be dust explosions requires attention. It has not been theoretically sorted out the way we have been looking at gas based explosions, but there are a number of experiments and modeling going on and it we also say well it can also detonate in which case, the hazard is much larger. The only relief what we get in dust explosions is, well if it is unconfined and you know in countries that is, in countries like India.

Wherein we handle food stuffs in open, the chances of a, of a dust explosion are not there because we said well what happens is it is difficult to get sustained dust being there for a long time and we are not able to get dust explosions normally in an unconfined geometry.

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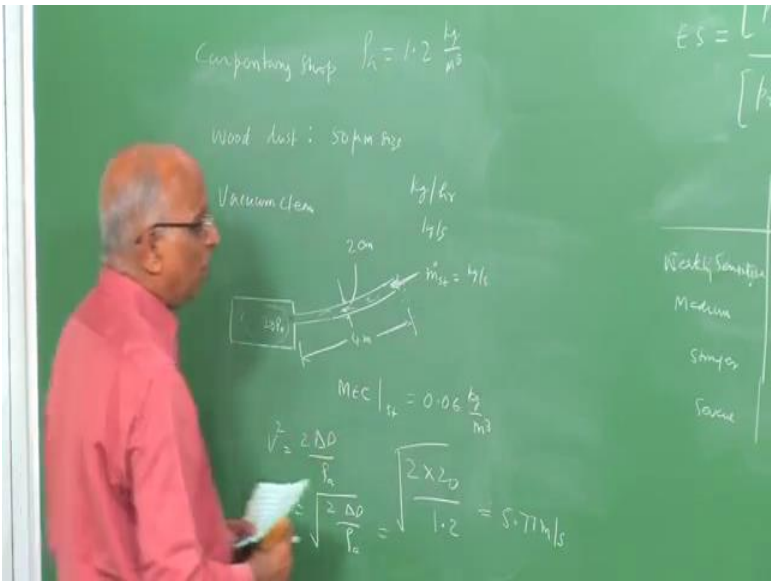

To be able to put things together, let us do one small problem involving the dust explosion such that the things we learned fall in place. And the problem I consider is, let us say I have a carpentry shop. In the carpentry shop I, you know during the different processes taking place in a carpentry shop, I generate wood dust and this wood dust let us say is of mean dimension around let us 50 micron size dust. You know, the place gets littered with wood dust.

And therefore, I use a vacuum cleaner to remove this wood dust and this vacuum cleaner consists of let us say a motor which generates a vacuum pressure of let us say 20 pascal and what it, what does the vacuum cleaner do? I have a long hose and this hose picks up that dust over here, dust particles which are smeared all over the floor of this particular carpentry shop. Let us presume that the length of this hose which collects the dust particles and gets into the bag of the vacuum cleaner here is something like let us say 4 meters long.

Let the diameter of this hose is something like 2 centimeters diameter. Now, I want to find out what is the maximum rate that means the maximum rate at which the wood dust can be taken through the hose such that an explosive substance is not formed here because during the movement of the air and dust, I could have sparks in this.

And if there is spark, the hose may just explode I do not want that to happen. Therefore, I want to make sure the mass of the dust particles which are entering the hose, I want to calculate it. What must be the value in kilograms per hour or let us say so much kilograms per second such that an explosive concentration is not built with air in the hose. Therefore, to be able to do that well I need the data and the data is minimum explosive concentration of the dust involving wood of the size 50 micron size, we say is equal to 0.06 kilogram per meter cube.

Therefore, we say well it sucked with the pressure of 20 p a with respect to the atmosphere. And therefore, the velocity of air flow in this particular passage is going to be V square is equal to 2 twice the delta p divided by the density of air in the medium, that is the velocity. How did we guess this? V square by 2 is equal to delta p by rho. And therefore, we say V is equal to under root 2 into delta p by ambient density of air and I take the value of delta p is given as 20 Pascal, that is 20 Newton's per meter square that is 2 into 20.

Well, the density of air is available. The density of air at atmospheric pressure atmospheric temperature is around 1.2 kilogram per meter cube. And therefore, it is into divided by 1.2 and the velocity with which the air is flowing in this direction is 5.77 meters per second. Therefore, but the minimum explosive concentration is given as 0.6 kilogram per meter cube. Therefore, I want to know, what is the rate that is m dot at which the dust is being supplied in terms of kilograms per second.

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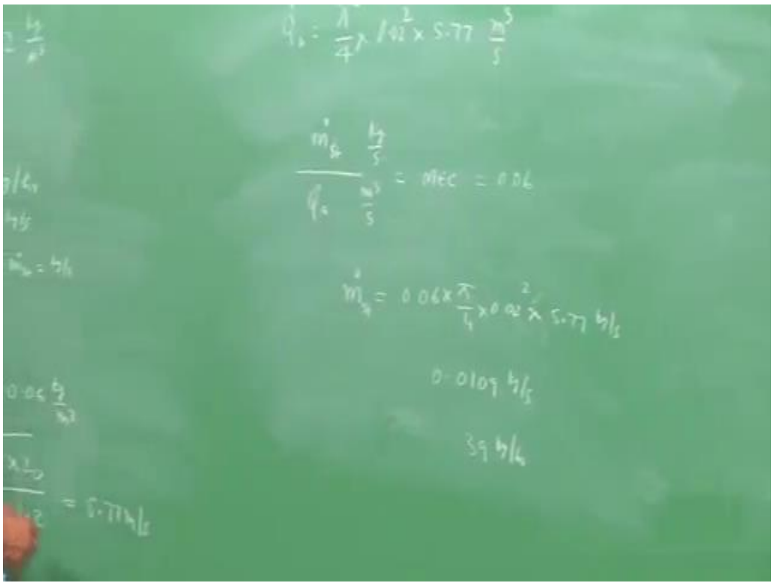

Therefore, to be able to do that I want to find out what is the volume flow rate of air and the volume flow rate of air is equal to Q for air , Q dot for air is equal to pi by 4 into the size of this hole which is equal to 0.02 square, that is 2 meter square that point 0.2 meter square into the value of V t which is 5.77 so much meter cube per second and if I assume that the value of m dot d, m dot dust which is being sucked over here is so much kilograms per second and the volume of air flow is Q dot a so much meter cube by second.

Well, I get the value of minimum explosive concentration and this value is given we know from data, that it is given as 0.06. And therefore, I get the value of m dot at which the maximum value at which the dust can take place because if it exceeds this value, well I get an explosive concentration which is greater than minimum.

Therefore, m dot dust is equal to I have 0.06 into pi by 4 into 0.02 square into 5.77 so much kilograms per second. And this comes out to be 0.0109 kilograms per second or in terms of hour, it is equal to 39 kilograms per hour. And this is how we use the data, one last thing supposing in the same problem let us presume that the rate at which the wood dust is taken in this hose is let us say greater than this amount.

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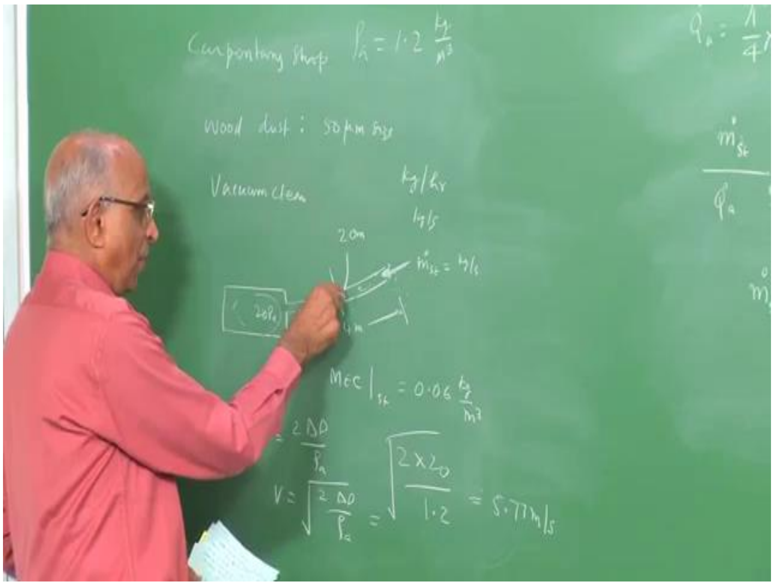

Let us say it is something like 42 or 43 and supposing by chance, an explosive concentration of dust gets built up and it is given to us that the value of the kst value for the dust is something like Let us say the value of kst for the dust is given as 210 bar meter per second.

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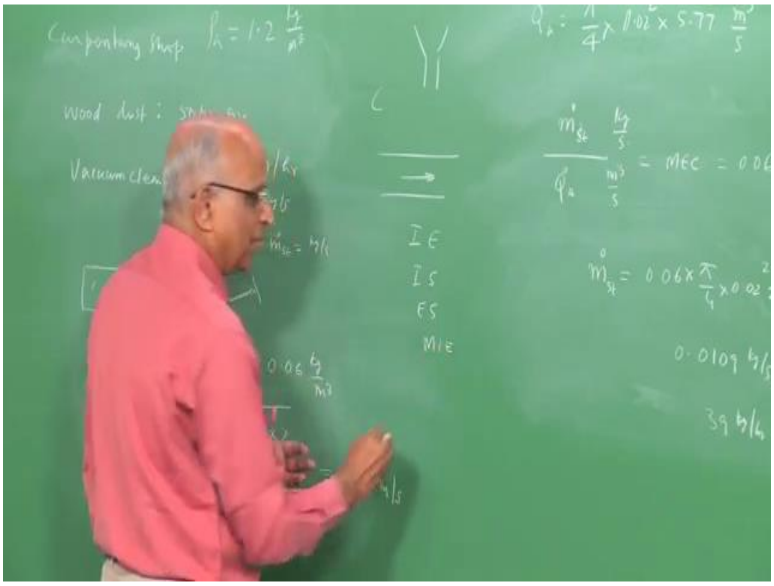

I want to find out the rate at which the pressure increases that is the violence that is dp by dt maximum in the hose. And therefore, I say well dp by dt maximum into volume to the power 1 by 3 is equal to the value of kst which is equal to 210. I know that the volume, volume of this hose you know essentially it is something like a closed volume because the opening here is small, opening here is small. Therefore, the volume is equal to pi by 4 into 0.02 square into the length 4 meters to the power 1 by 3 into dp by dt maximum is equal to 210 or rather from this I get dp by dt maximum in the explosion which would occur in case I am drawing more than this is about is given as 264 bar per second, which is quite a high value. And this is how you estimate the values in the different problem.

And therefore, to conclude we say well dust air mixtures are equally vulnerable to explosions and we know how to model it, we know how to calculate the concentration when we have feed under gravity. We know when it is being entering by an air flow how to calculate the concentration such as done in this particular problem. We also talk in terms of index of the explosability, we talk in terms of ignition sensitivity, we talk of explosion severity, we talk in terms of minimum ignition energy and this is all about the dust explosions. In the next class, we will deal with explosions involving flash vaporization that means physical explosions such as water exploding in the volcano or throwing a bucket of water into a hot furnace.

Well, then thank you.