Introduction to Explosions and Explosion Safety

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Lecture No - 29

Dust Explosions: Sizing of Vents, Dust Explosion, Estimation of Concentration, Minimum Explosive Concentration, Examples of Dust Explosions, Smoldering and Secondary Explosions

Good morning, you know in the last class we discussed about…

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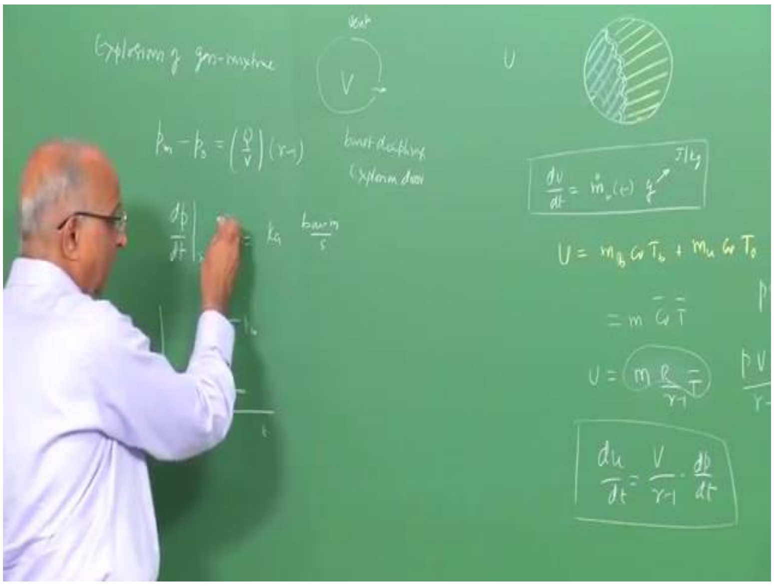

Explosions of gaseous mixtures, explosive gas mixtures in a confined volume tou know what did we tell? Well, I can calculate the maximum value of the gas pressure in the fixed volume of the gas, in which the mixture is there and this minus the initial pressure was equal to, was equal to something like energy density q by v into gamma minus 1. This was the value of the maximum pressure and we also got the expression for the maximum rate of pressure rise which we called as violence of the reaction into the volume of this particular fixed volume or the storage volume of the gas. In which the boundary does not move as equal to a K G value and this K G value was given in bar meter per second.

You know, generally we said that the k g value is between 55 to 75, for hydrocarbon mixtures is of the order of something like almost like 1000 or 900 for acetylene air and a little bit more for hydrogen air mixtures. You know the thing is that whenever we are talking of this particular gas mixture which are, which get into this explosion in a given volume. What happens is the pressure versus the time initially it starts with a initial pressure goes and reaches the maximum value. If we do not want the pressure to reach an upper limit like for instance the storage vessel is designed for a lower pressure.

What we do is, we provide some openings which we call as vents. That means, we give relief valves, which will open when the pressure reaches a particular value, beyond which the vessel is not safe enough to handle the pressure or else we provide, what we call as a burst diaphragm. That means, we give a section wherein if the pressure exceeds the diaphragm ruptures or you give something like an explosion door, such that the gas and if when the at this pressure, if the vent valve opens or if the burst diaphragm gives way or the explosion door opens up, the pressure cannot rise up any further and it falls.

Therefore, the design of these vent passages or the opening of the burst diaphragm and explosion doors are necessary. And let us just illustrate how it is done for one particular case. Let us for instance consider the case of how the dp by dt increases. Well, what happens the energy in the given volume increases that means the internal energy increases. And how does it increase? You have the explosion occurring in a given volume. Let us say, the explosion get initiated here at anytime, let us say the flame is over here.

Therefore, the mass of the gas burned at that instant of time that means the rate at which the gas is getting burned. Let us say, this is the thickness of the flame, this is the area of the flame, this is the area of the flame, this is the thickness of the flame. The rate of internal energy increase, that is d u by dt is equal to the rate at which the gas is getting burned at this instant of time.

Let us say m b at this instant of time. And of course, you know the per unit mass of the gas burnt, you have some exothermicity where q is in joules per kilo gram. This is kilo grams per second into joule per kilo gram, so my joules per second is the rate at which the internal energy increases. But if we are considering, let us say the spark has happened and you have the gas which is burning and progressing, may be at this instant of time when this particular mass of gets ignited and it is burning. You have gas corresponding, this corresponds to the burned gas and the gas ahead of it, that means ahead of the burnt volume corresponds to the unburned gas mixture.

Therefore, at this particular instant of time, What is the total energy? What is available? Let us put this down, u is equal to the energy contained here plus the energy contained here that means m u m b the total amount of mass which is burnt into cv. Let us say, the mean value of c v into temperature of the burned gas plus the m u that is the mass of the unburned gas into cv of the unburned gas into t initial over here. May be these particular gases are seeing the waves, they get compressed and they slightly increase in temperature.

I can also write this as equal to approximately as equal to the total mass into something like cv into and a mean value of temperature a mean value of specific heat is the value u over here. And now, I can, I can again simplify this. I can, I can write this as equal to, I have to anyway link up the du by dt or rather I can also write u is equal to the way we wrote earlier u is equal to m c v into T and what did we say cv is equal to R by gamma minus 1, let us substitute over here. Therefore, we will have m into R divided by gamma minus 1 into the mean value of temperature over here.

And therefore, you know this I can write mRT as equal to p v and v is a constant. Therefore, I write p v into mRT is pv, the perfect gas equation or the ideal gas equation, gamma minus 1 or rather I get the value of d u by dt with respect to time, the change in internal energy as equal to v divided by gamma minus 1 into, I get over here T p by dt.

And now, this is the expression for du by dt in terms of the pressure rise. This is the expression in terms of the burned gas volume. And therefore, if I can equate these two, I get dp by dt and this is how we got this particular expression. We said well, this is the characteristic length if length increases the time increases and we achieve this particular expression.

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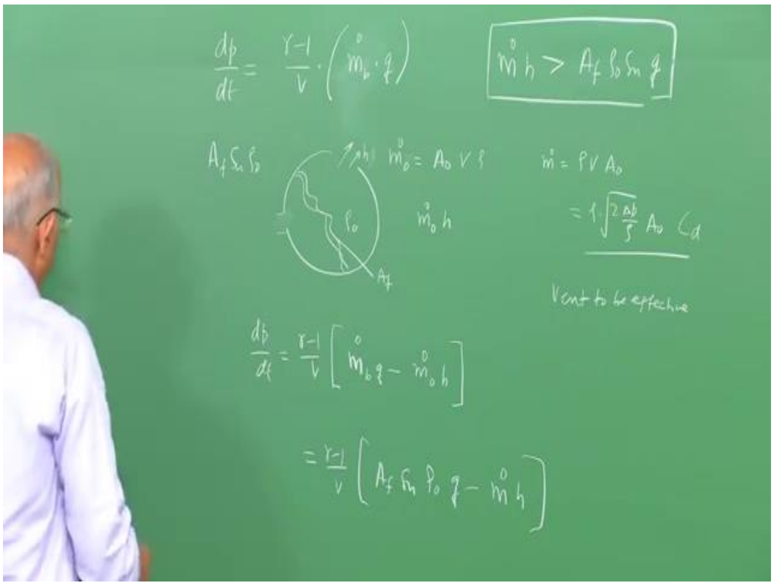

Let us do this because we are interested in sizing up the opening required for venting out the gases. And therefore, let us, let us put this down I can now write dp by dt is equal to from this expression gamma minus 1 divided by v into I get the value of du by dt, but the value of du by dt we saw is equal to m dot v into q.

And therefore, I can write I can substitute d u by dt as m the rate at which the burned gases are being generated into the exothermicity of the heat release that means the energy released in joules per unit mass of the gas. You know, if I were to put a vent opening what is going to happen? You know, this is the rate at which heat is getting generated, if I am going to have an opening, let us say I again draw this I have let us say, the flame over here, the flame surface area is A f, the unburned gas density is rho 0. I could give this vent either in the unburned gas region, I could give a opening in the burned gas region or it could be in the mixture of these two. I could vent out either the unburned gas or the burned gas whatever it is.

Let us, take the particular case, when I am venting out, let us say the unburned gas as it were or may be a mixture of gases. Therefore, what is going to happen the rate at which the gases are getting vented out, through the opening let us say m dot o is equal to the area of this particular opening into the mass flow rate through the opening and that is going to give me something like a velocity into is into the density of the gases which is going out. That is the mass flow rate through the opening and what is the energy which is leaving? If it is at the initial conditions, well the enthalpy at which it is leaving is h naught, if it is leaving at this place the enthalpy corresponds to the burned gases, let us in general say that the enthalpy at which is leaving is equal to something like h over here. Therefore, the burned gases are leaving with an enthalpy equal to m dot o into h over here.

Therefore, the dp by dt considering into account the venting of gases becomes equal to gamma minus 1 divided by v into I have, here it is just with the gases alone m dot v into q minus the rate at which the gases are leaving through the opening into something like the enthalpy over here. Now, I can also write the expression for m dot v in terms of the area of the flame and what is it? Area of the flame I have A of the flame into the velocity of the flame Su could be laminar could be turbulent as Su could be there into rho 0 is the value of this. I can also write this as gamma minus 1 into v into the area of the flame, that is the surface area into s u into rho 0 into q minus the value which is leaving the m dot into h.

For the vent to be effective, I should start getting reduction in the value of dp by dt. For example, I go back to this figure initially the pressure keeps increasing. The vent or the explosion door or the burst diaphragm opens here, the pressure begins to decrease. That means, from the increasing value I get the decreasing. Why should it happen? Because this particular term now becomes negative and therefore, for vent to be effective I must have the value of m dot that is the opening into the enthalpy must be greater than the rate at which the burning proceeds that is A f into rho 0 into s u into q. And this is the criteria which we use for designing the vent passage.

How is m dot related to the vent opening? Well m dot is equal to the density of the gases which are going through the vent into the velocity of the vent into the area of the opening. And what is the velocity? If we assume that the gases are leaving at very low velocities, I can as well substitute it as a rho into 2 delta p by rho, is the velocity of the gases going through a 0. Well, the gases are not all leaving perpendicular to the vent. And therefore, I have a C D coefficient. And this is the value of m dot over here and this into the enthalpy of the gases here must be greater than this for the vent to be effective.

Therefore, we can always design a vent space when we are not able to have the close vessel, to be able to take the high value of pressure and this is how a vent operates. Now, we know we must also remember, let us go back to one example. Let us take the example of the Bhopal gas tragedy, in which we said well methyl isocyanate leaked and what was happened? You had something like a storage vessel. The storage vessel had methyl isocyanate as a liquid. Somehow through the trap here and through the vent some water came in, some chemical reaction got started pressure started to build up the vent opened and when the vent opened because of the gases which have been generated because of the reaction between water and the liquid methyl isocyanate.

In addition, there were some impurities we said some chloroform would have been there, some iron filings were there. Anyway there was frothing of the liquid because of the gases being generated. It is the froth and the gases, methyl isocyanate which escaped and whenever through a vent you know you have a two phased medium which goes out namely a liquid and a gas. The liquid when it goes out, when it meets the atmosphere, it further vaporizes therefore, the vent sort of allows much more mass to go if it enters the vent through a two phase medium. Of course, this criterion does not come here. We are talking of gas phase explosions, only gases are escaping only the hot gases are escaping or the cold unburned gases are escaping.

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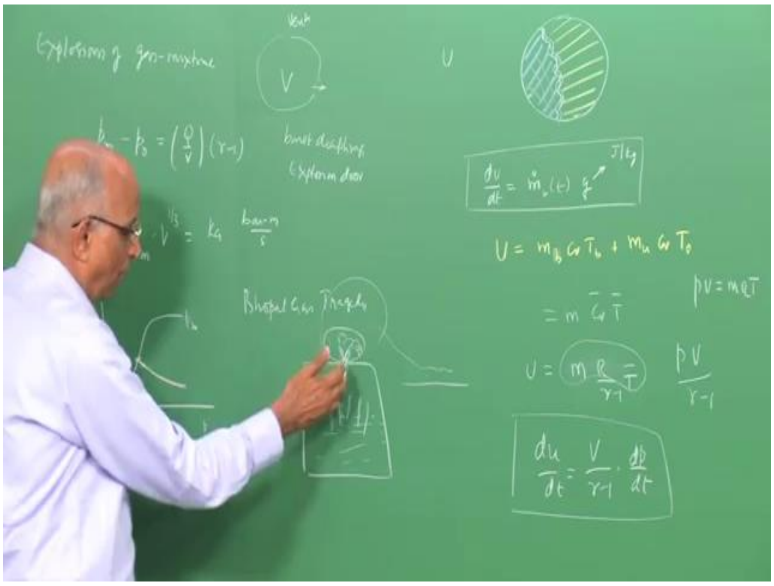

But we will keep this in mind because when we analyze the case of the Bhopal gas tragedy with vent. We find, yes the opening was small. If gases had alone leaked it would not have resulted in such huge cloud of methyl isocyanate passing through or being dragged along the ground and killing people. But in that case, maybe we would had a less amount of methyl isocyanate. May be we have to take that in account while designing a vent. Well this is all about when we say explosions, in the case of a given volume, in a given volume. And let us now extend, what little we learned about explosions in a closed volume to the case of dust explosions.

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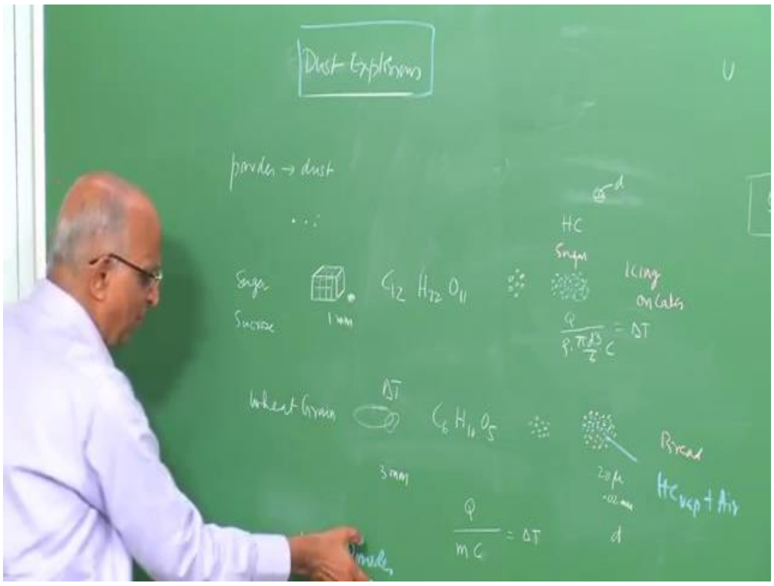

I think, we have to first define what we mean by dust? You know any powder, a fine powder we say is something like a dust. We say a dust, dust particle by mean when we say a dust particle, we mean it is fine particle, may be a few microns in size. Let us take one or two examples. Let me take you through the example of, let us say a wheat dust or flower which is being formed may be a sugar dust is being formed. And let us, let us put the figures down.

Let us say, I have a crystal of sugar, the sugar crystal is something like this may be of finite size may be a millimeter or so. This is the crystal of sugar. Well, the crystal of sugar is what we call as sucrose and the chemical formula is, let us say C 12 H 22 O 11 is the sugar. Similarly, I take a wheat grain and you know the wheat grain looks something like this maybe. It is something like this. I have a wheat grain, the chemical formula for wheat is very near to C 6 H 10 O 5.

Now, What I do? I take this sugar crystal may be around 1 m m by 1 m m by 1 m m or this wheat grain which is around let us say 2 m m long may be half m m or 3 m m long by 1 m m. And then, I sort of maybe I crush it, I splinter it into further and further particles that means I sort of pulverize the sugar particle and then I make it into the same volume of a single crystal. May be I make it into so many particles here. I further pulverize it and make it into still finer particles and this is the number of particles which I get over here small, small particles. So, also I crushed these wheat grains.

Let us assume that the wheat grain is very dry, I am able to pound it and make it into small pieces of wheat grain over here. I further make it and make it into very fine powder of wheat, which I call is wheat flower or aata which we call it. This is my finer wheat.

Therefore, what is it you know originally sugar or sucrose has this Carbon, Hydrogen and little bit of Oxygen. Wheat also has Carbon and Hydrogen I pounded it, I made it into a dust particle. I say this is the sugar and this sugar powder is used for making icing or used for icing on cakes. You have this is wheat flower which is used for making bread let us say. Is there any problem with this? You know, here the characteristic dimensions if I assume it to be equivalent sphere well the diameter I say is equal to 2 and a half or 3 m m. I have here around 1 m m, I make this into something like let us say 20 micron size that is equal to 0.02 m m and here I make it around the same value.

Now, What is it? Now, the diameter or the dimensions of this powder is quite small. The dimensions of this is quite large and let us say I transfer some heat in a given volume over here. I transfer some heat Q and what is the temperature rise of this body or the sugar crystal? It is going to be m mass of this sugar crystal into the specific heat of sugar crystal is the thermal capacity of this sugar crystal. This is going to be the increase in temperature. So, also that is delta T.

If I transfer some heat in this particular region over here what is going to happen. Assuming lump system I transfer heat Q, the Q divided by mass of this, divided by specific heat of this is the increase in temperature delta T. Now, after pounding it and generating a dust over here, I transfer some heat in the same region over here and here let us say I take one particular thing which is subjected to Q. I have Q divided by m, What is m? Density volume let us say each of this small powdered particles are spheres of diameter let us say small d. Then the volume is equal to pi d cube by 6 into the capacity. Here, the diameter or the equivalent dimension is very large. Therefore, the increase in temperature is small.

But since, the diameter of a spec or a dust over here is very small, the increase in temperature is very large. So, also the increase in temperature of a dust particle here is very large. Therefore, if the increase in temperature is such that the material of flower beings to paralyze and it begins to, it begins to paralyze and it begins to release the hydrocarbon gases. What is going to happen?

I am going to get the hydrocarbon gases which are released around the specs of the dust what I have around the dust. I show in blue the regions wherein the hydrocarbon gases are available. Hydrocarbon gases are available here. And anyway air is available it is in the medium of air therefore, the hydrocarbon gases mixed with air and what I have, I have a mixture of the hydrocarbon vapor which is the paralyzed gases plus the air which is available. And this becomes an explosive gas mixture and if I have a sustained heat source over here, well this hydrocarbon and mixture can explode and I have what we call as a dust explosion.

You know such type of things our organic food, which we eat may be sugar, may be wheat, maybe we talk in terms of other. We have cornflower we have maybe the milk powder. You know, when we consider these fine particles of the milk powder dispersed in air, well it could give rise to dust explosions because if I find that there is some energy which is available here, it is sort of volatilizes, the volatile vapor mixes with air and that is what gives rise to a dust explosion.

You know, this dust explosions keep occurring regularly. It is something which we have to avoid and we must take some steps to avoid. In fact, if we go back and see let us take one or two instances of dust explosions and see whether they cause damage or not we will take a few case histories. Let us just take, we will start our discussions with this.

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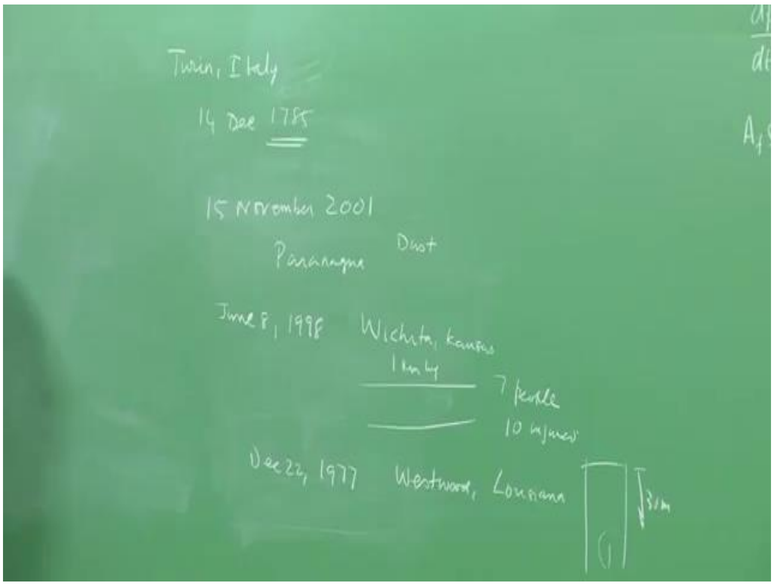

The first recorded case of a dust explosion was at Turin. You know, we have talked about this, Turin in Italy. This was on 14 December 1785. It so happened that, a baker you know it is the winter month in Turin and a baker sends his assistant boy to fetch cornflower from a store and it was late evening, it was dark. And therefore, the boy carries a candle in one hand may be a shovel in the other to take the cornflower. And being a boy he is playful he tosses the cornflower a little bit, he has candle on one hand.

The cornflower which is essentially the corn dust because it is of fine powder catches fire because from the candle and it just explodes. This is the first recorded case of a dust explosion and ever since you know there have been innumerable cases wherein in grain elevators while handling food stuffs we have been having this dust explosion.

Fortunately, in a country like India, we do not have much of the dust explosions because we handle food stuffs in open like for instance when we trade food we do it in open Mandis as it were wherein you do not have confinement and you do not allow an adequate concentration of the dust to get collected, but let us see some other examples.

Let us take one or two more examples. On 15 November 2001, in Brazil at a place called Paranagua, it is a port. You know, this was handling food stuffs. There was an elevator conveying food stuffs which was importing food grain and the entire port of Paranagua was destroyed in an explosion involving the food dust. So also, if I, if I take an example of something like on June 8 1998 at Wichita in the Kansas in US. What happened was, you know there was this elevator something like a 1 kilometer long storage facility got blasted because while handling food grain the dust exploded and something like 1 kilometer long storage facility was destroyed and something like a 7 people were killed in this particular explosion and something like 10 were injured.

Why we are talking of this? You know, if we take something similar on December 22 1977, you know a blast from a dust explosion at a place called West Wood in Louisiana, in Louisiana, it tore off something in something like 30 kilometers. I am sorry 30 meters of head space something like you have grain here something it tore off something like 30 meters of head space and killed something like 36 people and injured an equal number. Something you know these are quite drastic.

A similar thing 15 days before that on December 15 1977 at Galveston in Texas. Again, a major dust explosion occurred which again killed something like a 18 people and injured 30 people.

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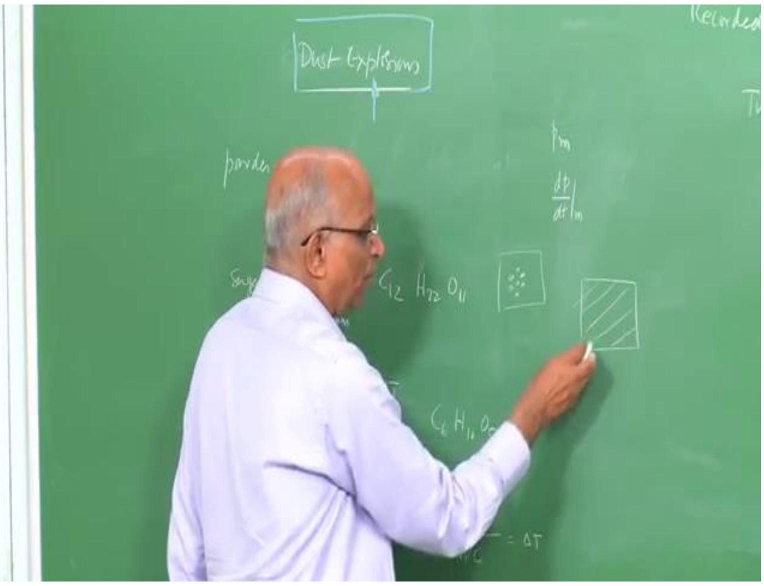

Therefore, you do have these dust explosions because of the volatilization of the fuel vapor and fuel vapor mixes with air and in a confined space you create the value of maximum pressure and you have the violence dp by dt maximum.

See, to be able to determine these things, you know it is a little more difficult for dust explosions the reason being, you know whenever I have a gas mixture I have a uniform gas mixture in a given volume. Whereas, in this it is not that uniform therefore, the dust explosions in addition to being controlled by the, by the volatile which are being formed by the dust, we also have the case in which may be the turbulence is going to affect your the value of pm that is the maximum pressure and the violence dp by dt.

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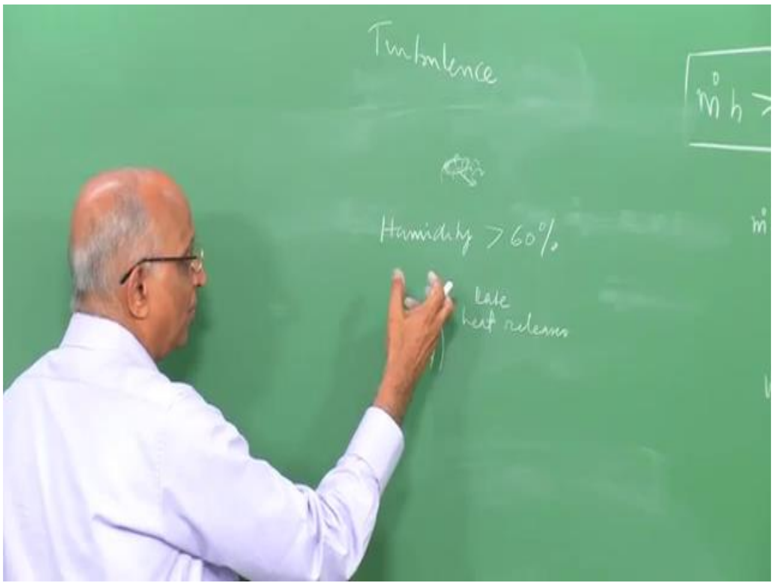

Not all, why does, turbulence effect because you have this fluctuation within the gas. May be the gases get concentrated in some region and you have density gradients of the dust in the given medium.

Therefore, turbulence affects it. You have humidity affects it, if the place has humidity greater than something like 60 percent of relative humidity, you know then you may not have a dust explosion because the water vapor may be absorbs the, does not allow the dust to paralyze that easily. And therefore, for humidity greater than 60 percent you may not have a dust explosion.

Whenever we are releasing energy and if the energy release is sort of spontaneous, the shock waves formed what they do is they take the dust and throw the dust away from the region of the ignition source. And therefore, these dust explosions are also very much sensitive to the heat that, is the rate at which the heat is getting generated or the rate at which energy is getting released in the medium. And therefore, the dust explosion is a little more complicated compared to what we studied in the case of explosion containing gas mixture.

Having said that, let us try to put our heads into trying to understand the physics of the dust explosion. Let us get back into what are the terms which we must determine. Are there something like let us say flammability limits can we define some equivalent of it or say what is the concentration of dust which gets into explosion. Therefore, we again look at it, you know What is it we are talking of?

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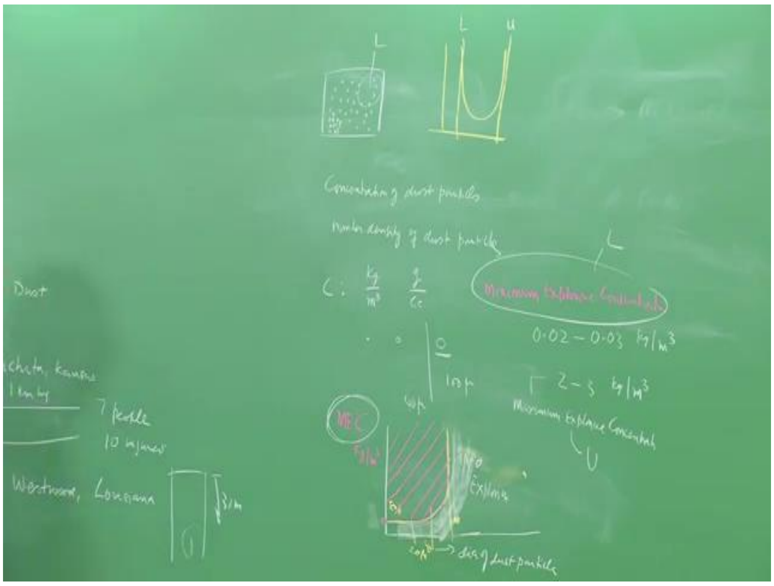

We are talking of the specs of dust mixed with air and from that dust you form the volatile mixture, which mixes with the air and forms an explosion. Therefore, we are looking at this collection of the dust particles over here. Now, when we look at this, the immediate reaction is may be in a given volume we must look at something like concentration of dust particle. What is concentration? You know, we must have a number of these dust particles or we say well the number density of dust must exceed some threshold value. Why should it exceed? I have a certain volume of air which is available to me, if I have a number of these dust particles number of these dust particles then only I can have a gas of adequate concentration such that the gas is flammable.

Therefore, if I say number density of dust particles, well I count a number of this dust particles put them together I am looking at something like kilo gram per meter cube of the dust particles. That is the mass of dust divided by the volume in which it is distributed or something like grams per c c.

This is the mass of dust divided by the volume over here grams per c c. Therefore, we talk in terms of concentration of a dust, a minimum volume we recognize is required, but we also recognize that the dust particle must be of small dimension. If it is very small well, it produces volatiles easily. If it is slightly larger, well it is much more difficult to produce if it is still larger well it is almost impossible to produce. And what we find is may be particles which are greater than around 100 micron or so are such that in case of a dust explosion they do not readily form a vapor. You know we require a minimum size of the order of something like 40 micron or so.

Therefore, we say if I were to now take a plot of let us say the diameter of the dust particle mean diameter. See, it is very difficult to get same the distribution of the diameter throughout. We just take out the mean diameter of the dust participle or say well in this case I have a mono size of dust that is a single size of dust which is distributed and I am looking at concentration. See, what happens let us now try to plot this figure.

I am just trying to take a look at what concentrations will lead to dust explosion. What will not lead to a dust explosion. Well, what is it we say when the diameter of the dust particle exceeds a threshold value, let us say 100 micron or so. Well, it is just not going to form that is no explosion because I cannot form a vapor. Well, if the diameter is less than 100 micron, let us say if it is of the order of may be 1 to let us say 20 micron. Well it readily forms a vapor and therefore, may be for these small diameters up to let us say 20 micron or so well this concentration, the minimum concentration, this concentration is able to form an explosion.

Therefore, I say well I can form an explosion over here as long as the concentration exceeds this. Well I can form a gas whose limits of flammability are such that it is flammable, it is within the flammable limits let us again plot it. You have the u shaped curve this is the lean concentration, this is the rich concentration. Therefore, it is a flammable gas and as a diameter keeps increasing well may be the energy the concentration because if the diameter is large, it does not produce sufficient vapor and therefore, I have a curve like this.

In other words, my curve is going to look like, something like this. That means for maybe we are talking of something like 40 microns over here, may be 100 micron over here. That means beyond this limit, it is no explosion is possible that means this is the region of no explosion and the region of explosions corresponds to the line over here. You know what is this? Can we draw some further conclusions from this?

See, we say that well this is the c value that is the concentration value we say it is kilo grams per meter cube. And therefore, we find that the minimum concentration what is required must be able to produce something must be able to give a flammable gas and we say, we call this as minimum concentration, minimum explosive concentration. And what is this minimum explosion concentration? If the particle size is small may be a smaller number density of particles is able to do that. If there particle size is little larger well I need more of them because I must move this.

And therefore, if I can plot this c minimum that is minimum explosive concentration then I get the minimum explosive concentration goes along this particular curve. And therefore, may be for very small particles it is constant may be for a range of concentration, for a range of particle size of dust between 20 micron to something like 100 micron. Well, the minimum explosive concentration increases till around 100 micron.

Well, I have the value tending to infinity and beyond this I cannot get any explosion that is the region corresponds to you know explosion over here. This is the explosive region, this is the non-explosive region and this is how we gauge it together. Therefore, you know what we need to do is, we need to find out what is the value of minimum explosive concentration. And in general if you do experiments we find that the minimum explosive concentration are typically around 0.02 to something like 0.03 kilo grams per meter cube for the lower flammability limit. And you know since we talk flammability limits as the upper flammability limit I can also get a number of dust particles which will give me a flammability limits corresponding to this was l. You will remember this was u, corresponding to u it could be of the order of 2 to 3 kilogram per meter cube.

These are the minimum explosive concentration and this upper limit will correspond to maximum explosive concentration. The minimum explosive concentration limit corresponds to the lean limit of flammability, the maximum explosive concentration corresponds to u, but in practice the maximum explosive concentration does not have any significance with respect to dust mixtures because in dust mixtures you know it is not uniformly dispersed especially when the concentration of dust particles is high. It is sort of segregated or stratified with the result in some places you have lot of these dust particles and you do not really have much air.

In the other cases, you have the dust particles which are not that densely populated. Therefore, in these regions l is still, that is the lean flammability limit is still the governing factor and it is the lean governing factor which controls the dust explosion.

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Having said that, you know let us determine we are now we now say the dust explosion just like for gaseous explosion we say well the gaseous mixture must be between l and u that is within the limits of flammability. We said well for dust explosions minimum explosive concentration is required.

How do you define concentration? I think we have to spend some more time on it we said concentration is kilogram per meter cube. Therefore, let us take some examples of how we handle food stuffs before we go any further. Let us take the example of let us say an elevator or some hopper in which we are handling food stuff, you know how do we handle it, let us put it together.

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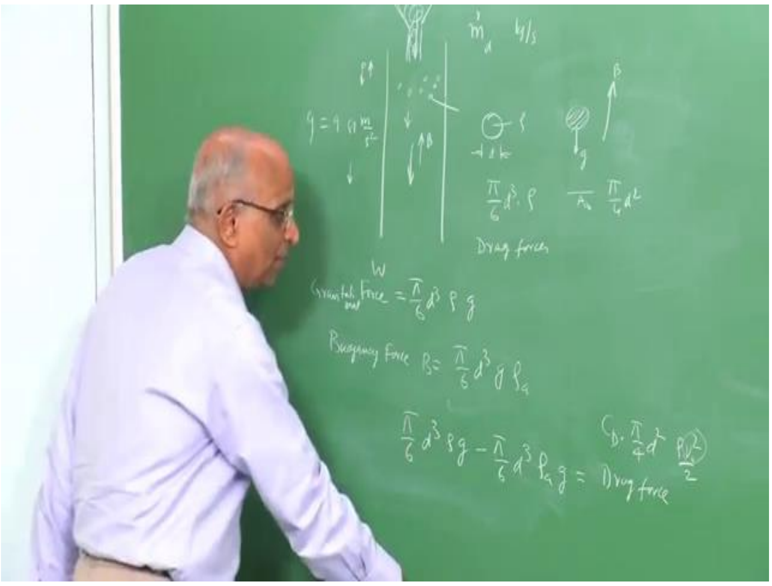

We have something like a chute or a pipe and what do we do when we handle food grains. Well we have something like a hopper, from the, in this hopper we put our may be wheat flower or corn flower whatever it is and we allow it to fall into the chute and this is how we handle this is something like a chute or an elevator through which the food grain travels.

Well, it need not be a flower may be I put wheat over here along with the wheat lot of dust is there. The dust also collects over here and it is these dust particles which create an explosion just like the flower which can also cause an explosion. Therefore, let us say I am dropping from this sort of hopper I am allowing the food stuffs to go at the rate of let us say m of the dust in so much kilo grams per second is the rate I am dropping it. Let us say each of these particles of dust which are getting dropped is of diameter, let us say I now show it expanded is of diameter d and it is falling down. What is the volume?

Let us assume that the powder or these fine particles which are coming down as dust particles is of small diameter d and let its density be rho. Therefore, the mass of each particle is equal to the volume of a sphere is equal to pi by 6 into d cube into the density is rho. This is the volume into density which is the mass of each particle. Now, let us in general whenever I have a hopper which is causing the flow of these dust particles through this chute.

What is happening? Well, the individual dust particles are being are traveling in free gravity and therefore, what is happening each of this particles is attracted by the gravitational field and the weight or the force with which it is attracted is equal to m g or rather the force with which it is falling down is equal to pi by 6 d cube into rho into the gravitational field g. With g is equal to 9.81 on the surface of the meter per second square.

Now, you know each of these particles is travelling let us say through air, the air is at one atmosphere pressure over here and what happens each of this particles is also displacing some air and since it is displacing some air, there is also some buoyancy force which acts up. What is buoyancy force? Buoyancy force depends on the volume of the fluid displaced and this volume of the fluid displaced into density of this particular medium gives the buoyancy force.

And therefore, let us say this is the gravitational force what we have, we also have the buoyancy force, let us call it as b. Gravitational force is the wait of the thing coming down buoyancy force is equal to the volume pi by 6 d cube into g into the density of air which it displaces. And therefore, what is happening now? You have the force on each particle with which it is coming up. It has a buoyancy force b and therefore what is going to happen.

You know, under equilibrium conditions you know these are all specs of dust which is coming down. It tends to travel at constant velocity namely the terminal velocity because initially you have the weight coming down, you have the buoyancy force coming down we find that the gravitational force is higher because the density is higher, the density of air being lower, the buoyancy force is lower. Therefore, it tends to have a net downward force and because of this net downward force it achieves a constant velocity in very short durations when because of the balance between this and this.

And what is happening? Let us put it down you have the gravitational force is equal to pi by 6 d cube rho g is the downward force minus pi by 6 d cube rho a into g is the buoyancy force and you get the net terminal velocity because of this and what is the terminal velocity going to do?

You know, in addition to this because of the velocity with which the particles are falling at constant velocity you have dragged forces and what happens is the downward force minus the upward force is equal to this drag force and this drag force comes becomes you are the particulates are coming down at a constant velocity. And this dragged force, now if you take a look at this well the cross section of a sphere is given over here.

Therefore, the area of the cross section over which the drag force acts is equal to pi by 4 into d square is this particulate diameter and what is the drag force drag coefficient into the area pi by 4 into d square into what is it into the dynamic effects namely rho v square divided by 2.

Therefore, this is the drag force and equal and now for equilibrium since it is to travel at the constant terminal velocity because of the balance between forces it goes at the constant velocity I have the weight of the particles minus the buoyancy force is equal to this. And this I can use to determine the velocity with which the flower will come down at constant velocity.

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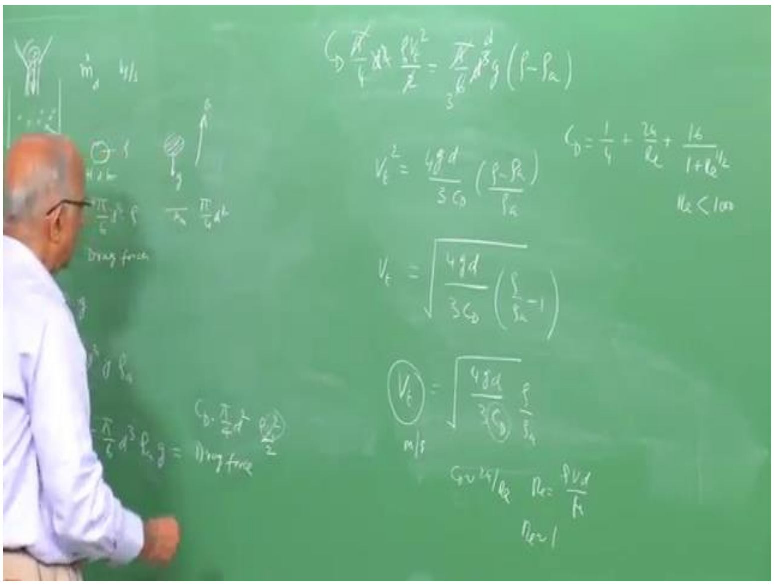

Well, let us solve this equation, we have C D into pi by 4 into d square which is the cross section of a circle over which the drag force are acting into rho v t square divided by 2. What is the rho over here? It is the air, that is the air density that is rho a into v t square divided by 2. I have on the left hand side pi by 6 into d cube into g into rho minus rho a. Let us go back again, pi by 6 d cube into g common into rho minus rho a. Therefore, if I were to now solve this I get pi and pi gets cancelled d square, d square gets cancelled with d over here. I have something like 2 getting cancelled giving me 3 over here.

Therefore, I get the value of v t square is equal to I get g into d g into d divided by 3 into 4 gd and C D comes here into rho minus rho a. And I get one more rho a over here or rather it gives me v t is equal to under root of 4 gd by 3 C D where C D is the drag coefficient into rho by rho a minus 1. In general, what happens is the density of air being a gas is very much smaller than the density of the material of the dust. And therefore, I can even neglect this and I can write this expression as v t is equal to I can write it as 4 gd by 3 C D into rho by rho a is equal to terminal velocity.

Therefore, I get the expression for v t, but what is this Cd? You know, we said that the terminal velocity is because the weight of the particle is offset by the drag force and buoyancy force and it travels at constant velocity. These velocities are extremely, extremely small that means the Reynolds's number is very small. And therefore, when Reynolds's number is very small that means we can say C D is of the order of 24 divided by R e where R e is defined as based on the diameter of the particles as rho v d by mu.

If we go to slightly higher values of Reynolds's number C D is equal to 1 by 4 plus 24 by R e plus I have 16 plus 1 over R e to the power half this essentially is for Reynolds's number less than around 1000. Whereas, when I say 24 by R e is for Reynolds's number of the order of 1 or so less than 1. Therefore, you know the value of C D you know g, you know d, I know the density of the dust particle, I know the ambient density I get the value of v t in meters per second. Once, I know the value of v t in meters per second I have to determine the concentration of dust particles in this particular chute over here and how do I do it?

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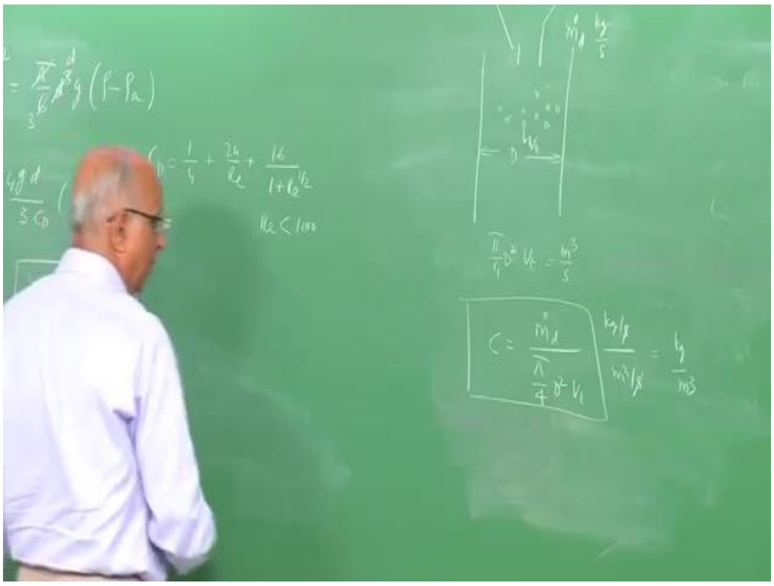

Well, I again put the numbers down, well I have the diameter let us say the diameter of this chute is capital D, in which the dust particles are coming down. Therefore, you know I find that these dust particles are coming down with the terminal velocity v t that means the volume of air being swept out in the frame of reference of the dust particles is equal to pi by 4 into d square into v t so much meter cube per second is the volume of air which is swept down. You know, how do I do this?

May be I sit on this dust particle and I am travelling, I now see the air coming towards me the value v t. Therefore, the air swept is equal to the cross sectional area which is equal to pi capital D square into v t so much meter cube by second through the hopper what is it I did? I allowed a dust particle to come through at a value m d kilograms per second.

This is the mass of dust particle, I am pushing into the form the hopper or from the hopper into the chute. And therefore, the concentration of dust particle is equal to m dot d divided by pi by 4 into d square into v t so much kilo grams per second divided by meter cube by second, second and second get cancelled have so much kilo gram by meter cube. Well this gives me the concentration of the dust particle in a gravity feed system and therefore, substituting the value v t from here I get the value of concentration as equal to let us write the value Concentration is equal to m dot d that is the feed gravity feed rate into pi by 4 into d square into I get the expression of under root 4 gd by 3 C D into rho by rho a.

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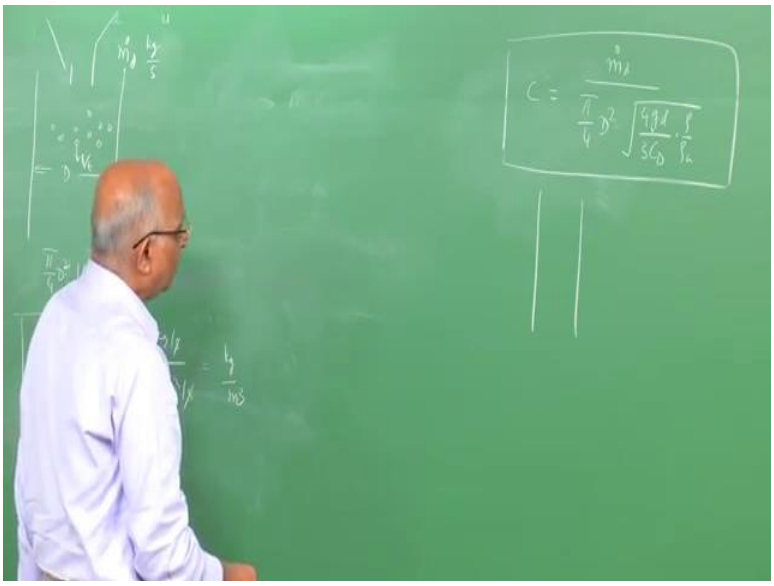

This is the value of concentration. Therefore, I know this concentration and let this concentration is greater than some threshold value well the chute can get into some dust explosion. Well, this is for the case of gravity feed, I can also consider some other cases you know when I do not have something like a hopper or a gravity which is allowing my dust to come down through a particular elevator or a particular chute. What is it I have?

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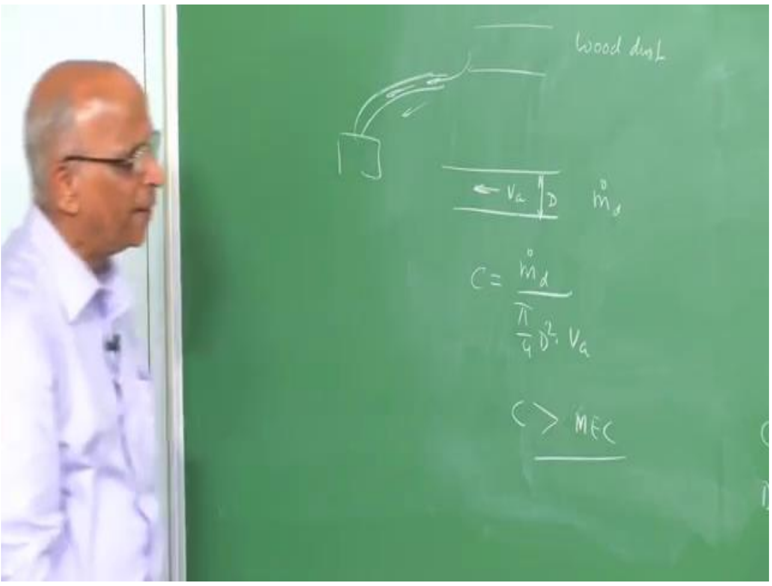

I can consider the following let us say I have a carpentry shop in which may be I have filings of wood let us say wood dust. And how do you remove wood dust? Well, I have a vacuum cleaner through the vacuum cleaner I have a hose and I generate low pressure in the vacuum cleaner and I sucked the dust out. Therefore, what does the vacuum cleaner do it allows the dust to be sucked in at some particular velocity.

Therefore in this case, well I have a pipe in which the air is moving in at a velocity v a and how do you get v a? I have a differential pressure over here I have differential pressure of a given density I have 2 delta p by rho which gives me velocity I know this value and if I know that the rate at which m dot d that is dust particle is coming over here I know the concentration is equal to m dot d using a similar way if my diameter of my pipeline which is conveying the dust particle is let us say capital D, I have pi by 4 into d square into v a over here. This gives me the concentration.

Therefore, for maybe this is the case of forced conveyance of dust that is the gravity feed for the dust, this is the forced mechanism of drawing dust. This is how we calculate the concentration and once we know the concentration we want to make sure that the concentration if it exceeds the minimum explosive concentration, well I am in trouble. And this is how we calculate the concentration for the dust in the different applications.

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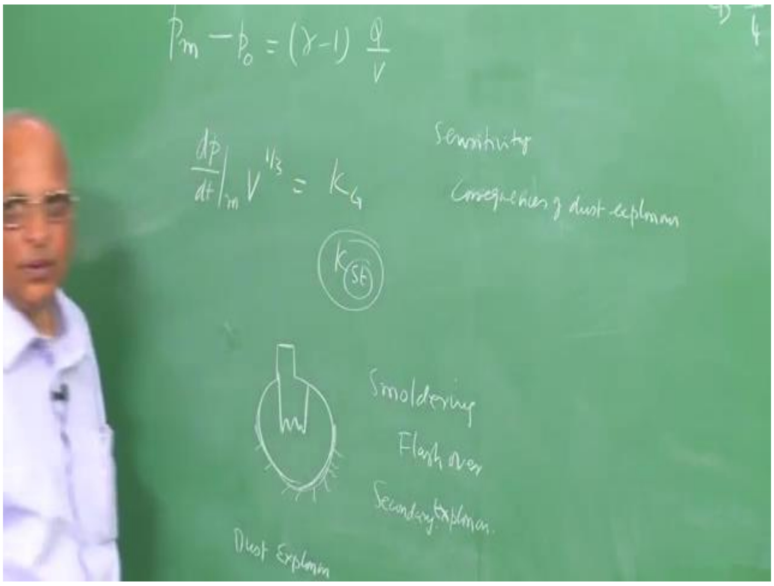

Having said that, it is necessary for us to do the similar thing what we did for gaseous explosions we can estimate the value of p m minus p initial is equal to gamma minus 1 into whatever we have Q by v. For this is the heat released from the dust particle which are generating heat over here which is the maximum value, we can also just like we wrote dp by dt maximum into v to the power 1 by 3 for the gases we called it as k g for the constant for gases. We now, call it as constant for dust and the value of k s t are again reasonably similar to the value for gases.

In some cases, they are also detonable and this is what may be we should take a look in the next class how do we categorize the dust explosions in terms of k s t instead of k g and the second thing is we must remember that whenever we have a dust mixture, like for instance we have a room in which there is dust and you have let us say a glass bulb over here have the filaments you know that dust keeps collecting on the glass over here and whenever the dust gets collected and then I have the heat source over here there is something like a pyrolysis of the dust which takes place dust, which is collected we call it as smoldering.

If there is some smoldering taking place after some level of smoldering well a part of it catches fire that means there is something like a flash over and during this flash over well the dust gets disrupted it further mixes with air and you could get an explosion. Therefore, whenever we talk of dust being collected at some places and initially we have smoldering, smoldering can get into something like an explosion which does not start with explosion it starts after sometime as a secondary explosion.

Therefore, in the case of dust we also have this problem of initial smoldering turning into a flash over and a secondary explosion. And therefore, I can be must be able to understand dust explosions a little more closely and for that what we do in the next class is, we will take a look at something like an equivalent of the k g value we will define the number again. We will take a look at classification of dust mixtures and see whether how to look at the sensitivity of the dust mixtures and how to look at the consequences or the severity of the consequences of the dust explosions.

Well, thank you.